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Minister of the Environment
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Edmonton, Alberta

and

The Hon. L. Marchand
Minister of State for the Environment
Fisheries and Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "Interim Report on Characterization and Utilization of Peat in the Athabasca Oil Sands Area."

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

Respectfully,

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INTERIM REPORT ON CHARACTERIZATION AND UTILIZATION OF PEAT IN THE ATHABASCA OIL SANDS AREA

DESCRIPTIVE SUMMARY

ABSTRACT

Two sites have been established for the study of stored peat. These are located at Evansburg, Alberta and on the Syncrude Canada Ltd. lease at Mildred Lake, Alberta. Fibric and mesic moss peat and fen peat have been investigated in terms of their physical, chemical and microbiological properties. Such material will eventually be stored at mining sites in the AOSERP study area, presumably for later use as an amendment to aid reclamation procedures.

The main purpose of this research was to quantify the changes in chemical, physical and microbiological properties that are likely to take place in the peat after a period of prolonged storage. A freeze-dry, air-dry, and thaw experiment was initiated to assess the rate of decomposition in stores peat. This indicated that drying affects most physical properties of peat. Drying affects the microbial activity in peat as measured by enzyme activity and CO_2 production. Generally freeze-drying appeared less detrimental than air drying.

The stored material at Evansburg was essentially composed of peat, whereas at Mildred Lake the material was a heterogeneous mixture of peat and inorganic material (sand, silt and clay). Both sites were instrumented with fiberglass temperature-moisture cells in order to record the annual variation in temperature and moisture in the stored material. Cellulotytic activity was measured by imbedding filter paper in the stored material at both Evansburg and Mildred Lake. Initial results indicate greater cellulose decomposition in the mixed peat material at Mildred Lake than at Evansburg. A higher rate of CO_2 evolution from the Mildred Lake samples indicated greater microbiological activity at this site. This increased

activity may be attributed to the presence of the inorganic constituents in the pile and to the application of commercial fertilizer.

In the investigation of the Mildred Lake stored material, positive correlations have been established between carbon content, and microbiological activity, enzyme activity, and cation exchange capacity. Those samples containing the greatest amount of peat were highest in microbiological and enzyme activity thus indicating a possible greater rate of decomposition. Unlike the stored material, undisturbed peat near Mildred Lake showed little activity. A similar investigation into the activity in the peat storage pile at Evansburg will be undertaken in 1978.

BACKGROUND AND PERSPECTIVE

This research project has been designed to supply information on peat in the AOSERP study area. Peat is the only organic material naturally available for rebuilding soil fertility after mining. The project is intended to identify the baseline state of peat at a limited number of in situ locations and industry storage piles in terms of classification and physical and chemical properties. It will also identify the nature and extent of interactions between the environment and stored peat. This information will permit the prediction of changes in peat characteristics during handling and storage. If peat quality is found to deteriorate during storage, the research will investigate alternate methods of storage and handling.

The information provided by this project will likely be of great importance to reclamation plans and material handling procedures.

ASSESSMENT

The report "Interim Report on Characterization and Utilization of Peat in the Alberta Oil Sands Area" which was prepared by K. Kong, J.D. Lindsay, and W.B. McGill (Research Council of Alberta, Soils Division) has been reviewed and accepted by the

Alberta Oil Sands Environmental Research Program.

The report is comprehensive and informative and includes discussion of the general characteristics of the peats investigated; the effect of drying, freezing/thawing, and fertilizer additions; and general conclusions. Readers are asked to note that as the report is an interim report on an ongoing research project, any conclusions and/or recommendations put forward are preliminary in nature.

The content of this report does not necessarily reflect the views of Alberta Environment, Fisheries and Environment Canada, or the Alberta Oil Sands Environmental Research Program. The mention of trade names for commercial products does not constitute an endorsement or recommendation for use.

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INTERIM REPORT ON CHARACTERIZATION AND UTILIZATION OF PEAT IN THE ATHABASCA OIL SANDS AREA

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for

ALBERTA OIL SANDS
ENVIRONMENTAL RESEARCH PROGRAM

Project VE 5.2

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ABSTRACT

Two sites have been established for the study of stored peat. These are located at Evansburg, Alberta and on the Syncrude Canada Ltd. lease at Mildred Lake, Alberta. Fibric and mesic moss peat and fen peat have been investigated in terms of their physical, chemical, and microbiological properties. Such material will eventually be stored at mining sites in the AOSERP study area, presumably for later use as an amendment to aid reclamation procedures.

The main purpose of this research was to quantify the changes in chemical, physical, and microbiological properties that are likely to take place in the peat after a period of prolonged storage. A freeze-dry, air-dry, and thaw experiment was initiated to assess the rate of decomposition in stored peat. This indicated that drying affects most physical properties of peat. Drying affects the microbial activity in peat as measured by enzyme activity and CO_2 production. Generally freeze-drying appeared less detrimental than air drying.

The stored material at Evansburg was essentially composed of peat, whereas at Mildred Lake the material was a heterogeneous mixture of peat and inorganic material (sand, silt, and clay). Both sites were instrumented with fiberglass temperature-moisture cells in order to record the annual variation in temperature and moisture in the stored material. Cellulotytic activity was measured by imbedding filter paper in the stored material at both Evansburg and Mildred Lake. A higher rate of CO_2 evolution from the Mildred Lake samples indicated greater microbiological activity at this site. This increased activity may be attributed to the presence of the inorganic constituents in the pile and to the application of commercial fertilizer.

In the investigation of the Mildred Lake stored material, positive correlations have been established between carbon content, and microbiological activity, enzyme activity, and cation

exchange capacity. Those samples containing the greatest amount of peat were highest in microbiological and enzyme activity thus indicating a possible greater rate of decomposition. Unlike the stored material, undisturbed peat near Mildred Lake showed little activity. A similar investigation into the activity in the peat storage pile at Evansburg will be undertaken in 1978.

ACKNOWLEDGEMENTS

This research project, VE 5.2, was funded by the Alberta Oil Sands Environmental Research Program, a joint Alberta-Canada research program, established to fund, direct, and co-ordinate research into the effects of oil sands development on the renewable resources of the Athabasca oil sands.

The able technical assistance of Miss R. Parnell and Mr. B. Armon is acknowledged.

1. INTRODUCTION

The purpose of the research is 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, is being carried out to monitor and quantify the changes that may occur during storage.

This report consists of three parts. Part I 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 of the report.

Part II 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.

Part III of the report 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 peats, 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 fibre content in peat, and Farnham and Finney (1965) used the fibre content as a criterion for classifying 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 hemicellulose 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.

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 1969; Wieringa, K.T. 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 willows growing in lime-deficient peat soil did not show any deficiency in 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).

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 of the latter is not favourable for the development of these organisms and that the cellulose of the sphagnum plant was highly resistant to decomposition.

Little reference to the study of organic matter decomposition by estimation of enzyme activity has been found; however, considerable literature (Bedford 1929; Waksman and Starky 1924; Dommergues 1969; Stotzky 1960) exists in respect to the mineralization of organic carbon by measuring the CO_2 evolution in soil.

It should be noted that no references have been found in respect to the effect of storage (piling) on peat properties and decomposition rates.

3. STUDY AREA

Research activities are carried out at three locations. The laboratory is located in Temporary Lab A at the University of Alberta. This is a comparatively new facility for the project, having been moved to this location in September 1977. It was formerly headquartered in the Printing Services Building at the University of Alberta.

Two field research sites have been established. In June, 1976, a peat storage pile was constructed near Evansburg, Alberta on the lease of Banff Mining and Quarrying Co. Ltd. In August of that year a second site was established on the Syncrude Canada Ltd. Lease #17 at Mildred Lake, Alberta in the Alberta Oil Sands area. Monitoring, sampling and field activities have been carried out at these sites since their establishment.

Originally it was planned to also investigate the storage area on the lease of Great Canadian Oil Sands Ltd., near Mildred Lake, however the apparent similarity between this site and that at the Syncrude site suggested that it was not necessary to carry on research in both locations. The Syncrude site was therefore selected for study.

PART I

4. GENERAL CHARACTERISTICS OF PEAT

4.1 CLASSIFICATION OF PEAT

Peats are classified in the Organic order of the Canadian Soil Classification System (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 percent or more organic carbon (30 percent 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 AOSERP study 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 3,000 percent.

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 ovendry 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, 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 peat and a fen sample from the Evansburg area and fibric and mesic moss and a fen sample from the Mildred Lake areas.

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 include the following: moisture content, specific gravity, bulk density, pore volume, air capacity, water 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 10.1.

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 fibre 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 the 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 that the undecomposed fibric peat. Such properties

Table 1. Physical properties of peat from Mildred Lake and Evansburg areas.

Type of Peat	Moisture Content %	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	96.9	40.0	56.9	95	80	3	31.3
Mesic	554	1.50	0.072	95.3	33.0	62.3	85	50	5	20.3
Fen	934	1.61	0.106	93.4	23.0	70.4	35	10	11	14.2
Evansburg Area										
Fibric	710	1.54	0.071	95.4	33.7	61.7	90	50	5	20.8
Mesic	1015	1.50	0.084	94.4	32.4	62.0	75	60	10	16.9
Fen	608	1.49	0.097	93.5	35.1	58.4	65	28	22	14.4

may well influence the rate of decomposition in the stored peat.

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 the tube was then recorded.

The results of the experiment are shown in Table 2. At Mildred Lake, in a fibric peat, the hydraulic conductivity was fairly uniform from the surface to the middle tier at 90 cm but low in the bottom tier at 125 cm. In the same area a dominantly mesic peat profile was characterized by hydraulic conductivity generally lower than the fibric peat site. The fen peat at Mildred Lake had lower hydraulic conductivity throughout the profile than either the mesic or fibric peat profiles in that area. In all cases, the hydraulic conductivity was lower in the bottom portion of the profiles indicating that some humification or decomposition has occurred at depth.

At Evansburg, the hydraulic conductivity in a fibric peat was determined. 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 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

Table 2. Hydraulic conductivity in peat.

Peat	Layer	Depth cm.	Hydraulic Conductivity cm/sec
		Mildred Lake	
Fibric	Surface tier	45 to 65	5.63×10^{-3}
	Middle tier	70 to 90	2.25×10^{-3}
	Bottom tier	105 to 125	8.87×10^{-4}
Mesic	Surface tier[a]	30 to 45	1.89×10^{-3}
	Middle tier[b]	45 to 75	2.85×10^{-4}
	Bottom tier[b]	75 to 120	1.60×10^{-4}
Fen	Surface tier	40 to 60	5.98×10^{-4}
	Middle tier	60 to 80	4.08×10^{-4}
	Bottom tier	80 to 100	4.82×10^{-5}
		Evansburg	
Fibric	Surface tier[a]	30 to 50	1.13×10^{-3}
	Middle tier[a]	50 to 75	5.32×10^{-4}
	Bottom tier	80 to 100	2.01×10^{-5}

[a] Mean value of 4 measurements.

[b] Mean value of 5 measurements.

stratified 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, total carbon, available phosphorus, and carbon/nitrogen ratio. The methods of analyses employed are described in Section 10.1.

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 showed a relatively low pH, generally in the 3.7 to 4.0 range 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 rich groundwater may have resulted in the relatively high pH values.

In terms of carbon, nitrogen and the carbon/nitrogen ratio, the fibric peat from the Mildred Lake area was very low in nitrogen content, and C/N ratio was high. The fen peat was highest in nitrogen content ($>2.0\%$), and the C/N ratio quite low. This appears to be a basic difference between the fen peat and moss peat.

The relatively low nitrogen content and pH in the fibric moss peat material results 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 have a low base saturation when compared to the fen peats. The fen peat samples are extremely calcium rich and this fact combined with the higher pH and nitrogen levels would suggest the material is more biologically active.

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

Classification	pH (H_2O)	Cation Exchange Capacity[a] m.e./100 g						Total C %	Total N %	C/N	P_2O_5 ppm
		Ca^{++}	Mg^{++}	K^+	Na^+	TEC[b]	Base Sat.%				
Mildred Lake Area											
Fibric peat	3.7	21.90	14.30	0.38	1.19	116	33	46.75	0.61	77	15
Mesic peat	5.9	81.30	12.80	0.06	0.32	166	57	39.18	1.47	27	6
Fen peat	6.6	94.22	10.94	0.13	0.38	110	96	46.49	2.80	17	4
Evansburg Area											
Fibric peat	4.0	13.32	2.76	0.20	0.33	115	14	44.86	1.25	36	3
Mesic peat	5.6	53.10	16.90	0.13	1.08	142	50	44.73	1.48	30	4
Fen peat	7.1	129.26	19.69	0.15	0.25	165	90	35.13	2.19	16	4

[a] Extracted with NH_4OAc, 1 N solution.

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

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 hemicellulose existing in sphagnum plants is highly resistant to the action of bacteria (Waksman and Purvis 1932). On the other hand, the anaerobic conditions are unfavorable 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 bacterial 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 is being estimated as a measure of peat decomposition. The enzyme, cellulase, hydrolizes cellulose material in organic matter to produce reducing sugar. Therefore, soil enzymes produced by microorganisms can be used to investigate the humifaction of organic material (peat). Table 5 shows the cellulase C_1 (which attacks highly ordered forms of cellulose) and B-glucosidase activities which are very low in moss peat (fibric and mesic layers), but high in fen peat. The low content of

Table 4. Distribution of microorganisms in peats.

Peat	Bacteria Number germs /g dry peat	Fungi Number germs /g dry peat
Mildred Lake		
Fibric	28×10^4	21×10^3
Mesic	20×10^5	28×10^3
Fen	16×10^6	27×10^4
Evansburg		
Fibric	59×10^5	37×10^4

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

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

cellulase C_1 may be attributed to two 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 the 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.

Mandell and Reese (1963) also suggest that physical factors may affect the cellulase action. Fungal cellulase in general is stable at 30°C from pH 3 to 8 and usually show 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.

Carboxymethycellulase 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 the chemical properties, such as pH, N, Ca, 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 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 1). 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 mixes may 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 2 and 3.

In both peats, additions of P increased respiration rates. 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 appeared to actually depress respiration rate in the fen peat. This may have resulted from high NH_3 levels from the $NH_3 + H \rightleftarrows NH_4 +$ 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. Similarly, addition of $CaCO_3$ to fen peat had a slight inhibitory effect on respiration rate.

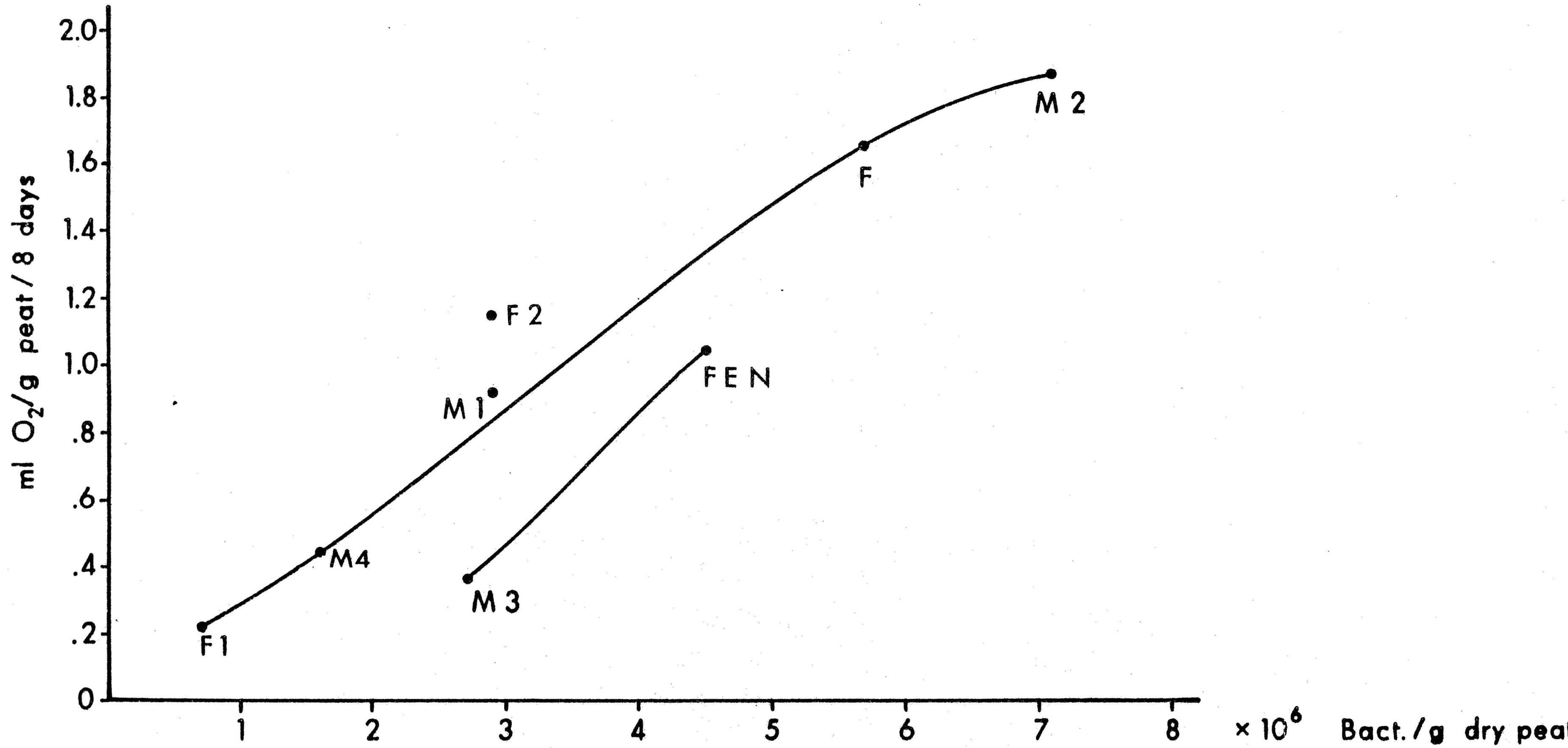

Figure 1. Relationship between number of bacteria as determined by plate counts and O_2 uptake by eight peat samples incubated at 25 ± 0.5°C. F_1 and F_2: two fibric peats from Evansburg area, M_2 and M_4: two mesic peats from Evansburg area, M_3: Fen peat from Evansburg area, F: fibric peat from Mildred Lake, M_1: mesic peat from Mildred Lake, Fen: fen peat from Mildred Lake.

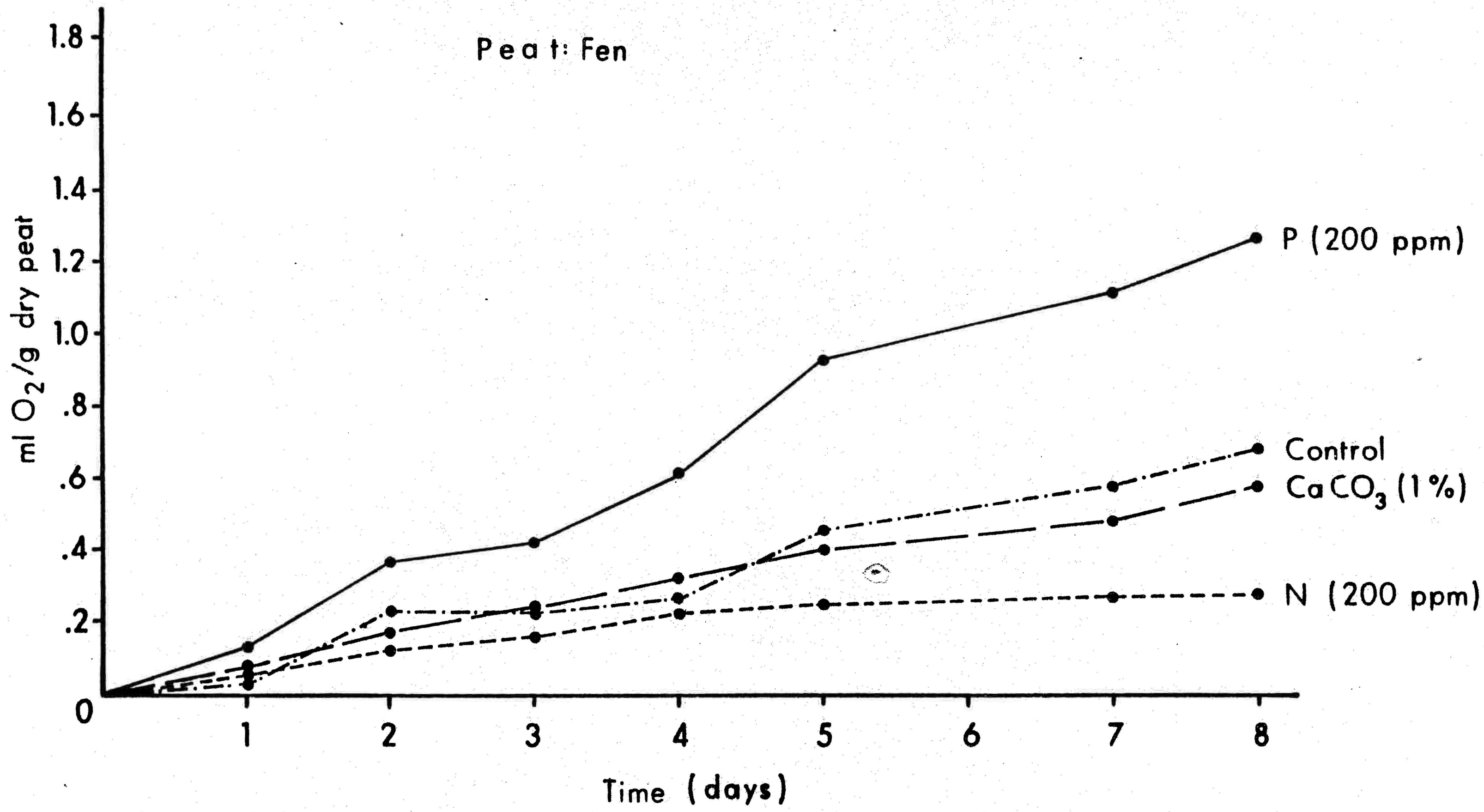

Figure 2. Effect of amendments on O_2 uptake by fen peat sample incubated at 25 ± 0.5°C. Concentrations of N, $CaCO_3$ and P are based on wet weight of the peat.

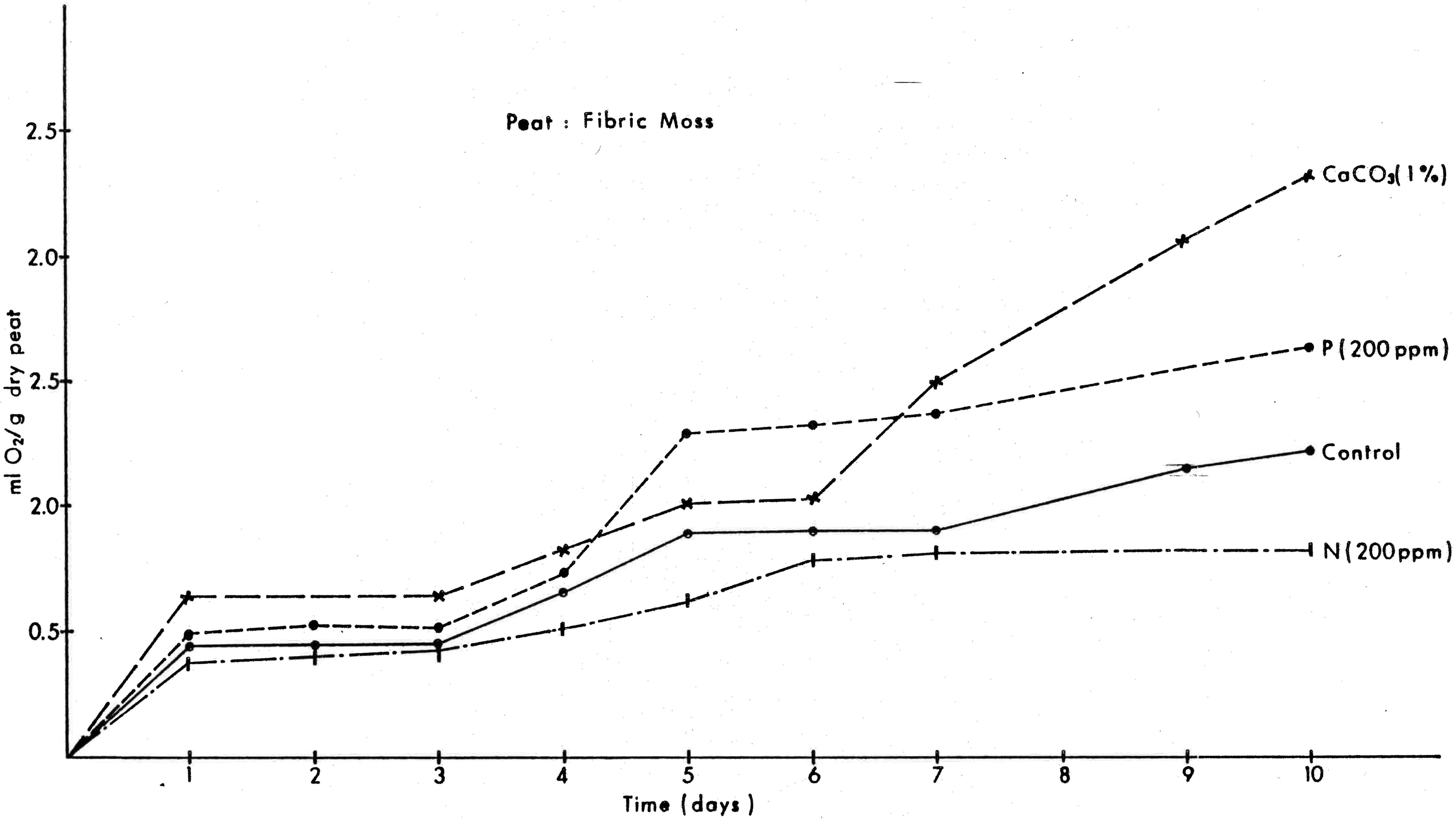

Figure 3. Effect of amendments on O_2 uptake by fibric peat sample incuabted at 25 ± 0.5°C. Concentrations of N, $CaCO_3$ and P are based on wet weight of the peat.

PART II

5. EFFECT OF DRYING, FREEZING/THAWING AND FERTILIZER ADDITIONS TO PEATS

5.1 METHODS AND MATERIALS

5.1.1 Freeze-thaw Experiment

Three peats from the Mildred Lake area were used: F (fibric), M (mesic), and FEN (fen). 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. Each treatment was incubated at 25 ± 0.5°C. On Days 7, 14 and 21 the peats were frozen at -10°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 percent $CaCO_3$.

On Day 49, 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 uCi/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 Days 1, 6, 9, 27,34 and 64. At the same times, samples were taken for estimation of fungal hyphal lengths by the Jones and Mollison technique. Numbers of cellulose degraders were estimated for Days 1, 27, 34 and 64. Enzyme activities were determined on Day 1, after the drying treatment.

Physical analyses of the peat were made after drying and at the end of the experiment. They included fiber content, bulk density and 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 10.1. 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 was 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 0.2g of POPOP (1,5-bis-[methyl-5-phenyloxozolyl] -benzene) and 8.0g of PPO (2,5-diphenyloxazole) dissolved in 2l of Toluene (scintillation grade) after which 1l Triton X-100 was added as an emulsifier. One ml samples of the NaOH solution containing $^{14}CO_2$ was added to 15 ml of this solution in 20 ml scintillation vials and counted for 1 min (>10,000 cpm).

5.1.3 Microbial Enumeration

5.1.3.1 Plate counts. Bacteria were counted 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 6 to 8 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 10.1.

5.1.3.2 Fungal hyphal lengths. Lengths of fungal hyphae were estimated by the Jones and Mollison technique (1948), with modifications based on Parkinson, Gray and Williams (1971).

5.1.3.3 Cellulose decomposers. Cellulose decomposers were estimated by a Most Probable Number 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.

5.1.3.4. Estimation of enzyme activity. The method of determination of cellulose C_1, carboxymethylcellulase Cx and B-glucosidase activities is described in Section 10.1.

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 by 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

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

Peat	Treatment	Bulk Density g/cc	Pore Volume %	Air Capacity %	Void Ratio	Fiber Content Unrubbed %	Fiber Content Rubbed %	Permeability $\times 10^4$ cm/sec
Fibric	Normal	0.052	96.5	38.7	27.6	95	85	4.38
	Freeze-dried	0.056	96.3	35.8	26.0	95	89	1.28
	Air-dried	0.061	95.9	34.4	23.4	95	80	2.10
Mesic	Normal	0.086	94.3	21.1	16.5	80	55	3.60
	Freeze-dried	0.079	94.7	27.7	17.9	75	50	1.09
	Air-dried	0.090	94.0	28.1	15.7	75	55	1.06
Fen	Normal	0.119	92.6	20.7	12.5	35	< 10	2.83
	Freeze-dried	0.107	93.3	25.2	13.9	35	< 10	0.82
	Air-dried	0.116	92.7	29.6	12.7	35	< 10	0.51

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. Drying would have to be considered very undesirable in terms of erosion control in all 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. 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. The use of fen peat and probably also highly humified moss peat may not be advisable for erosion control in areas where probabilities of dessication 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 peat would probably be the most desirable.

5.2.2 Effect of Drying on Microbial Distribution in Peat

Figure 4 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 5 and 6).

Numbers of cellulose decomposers also varied among the three peats. Fibric peat contained too few for reliable counts.

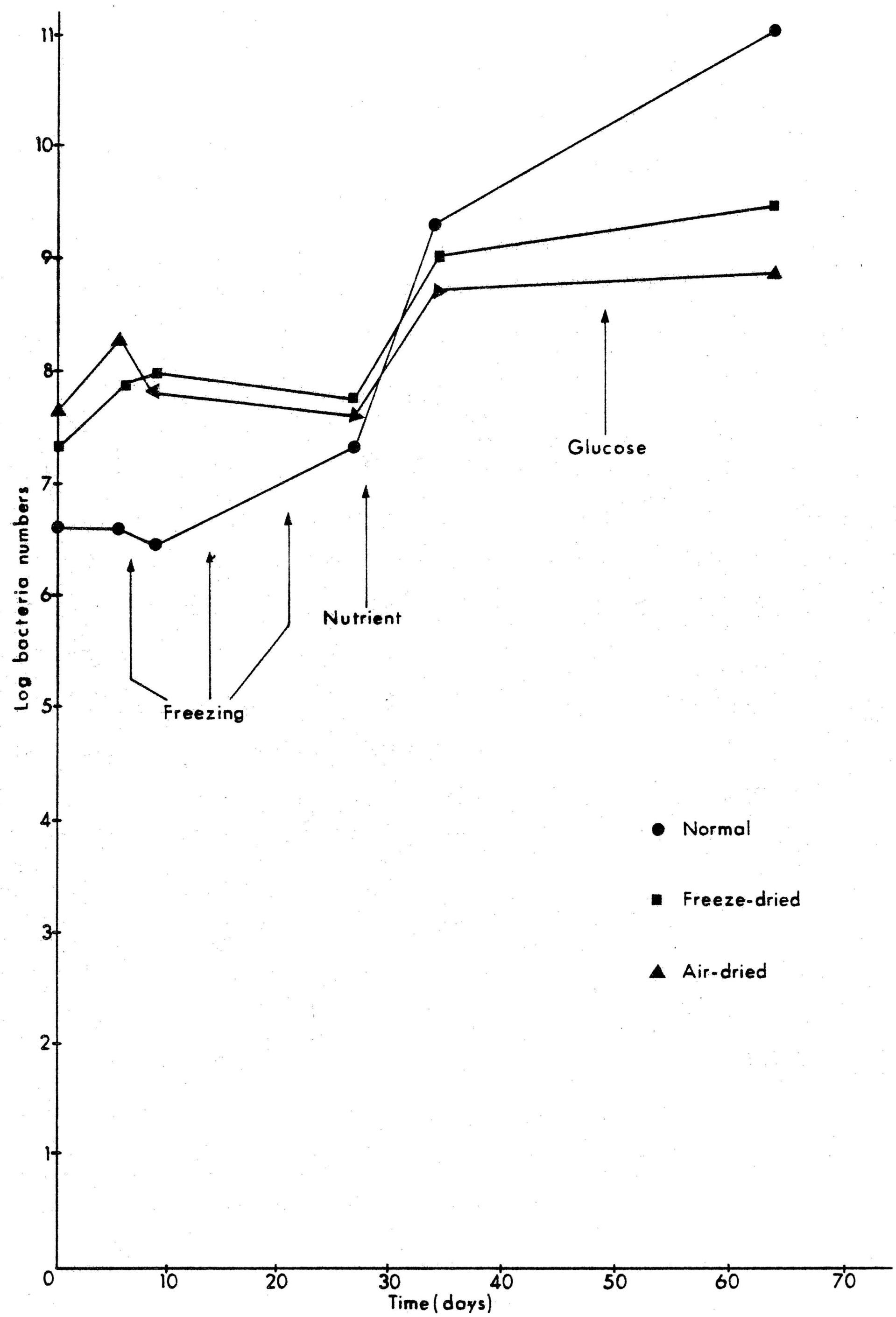

Figure 4. Change in number of organisms in mesic peat following physical and nutrient treatment.

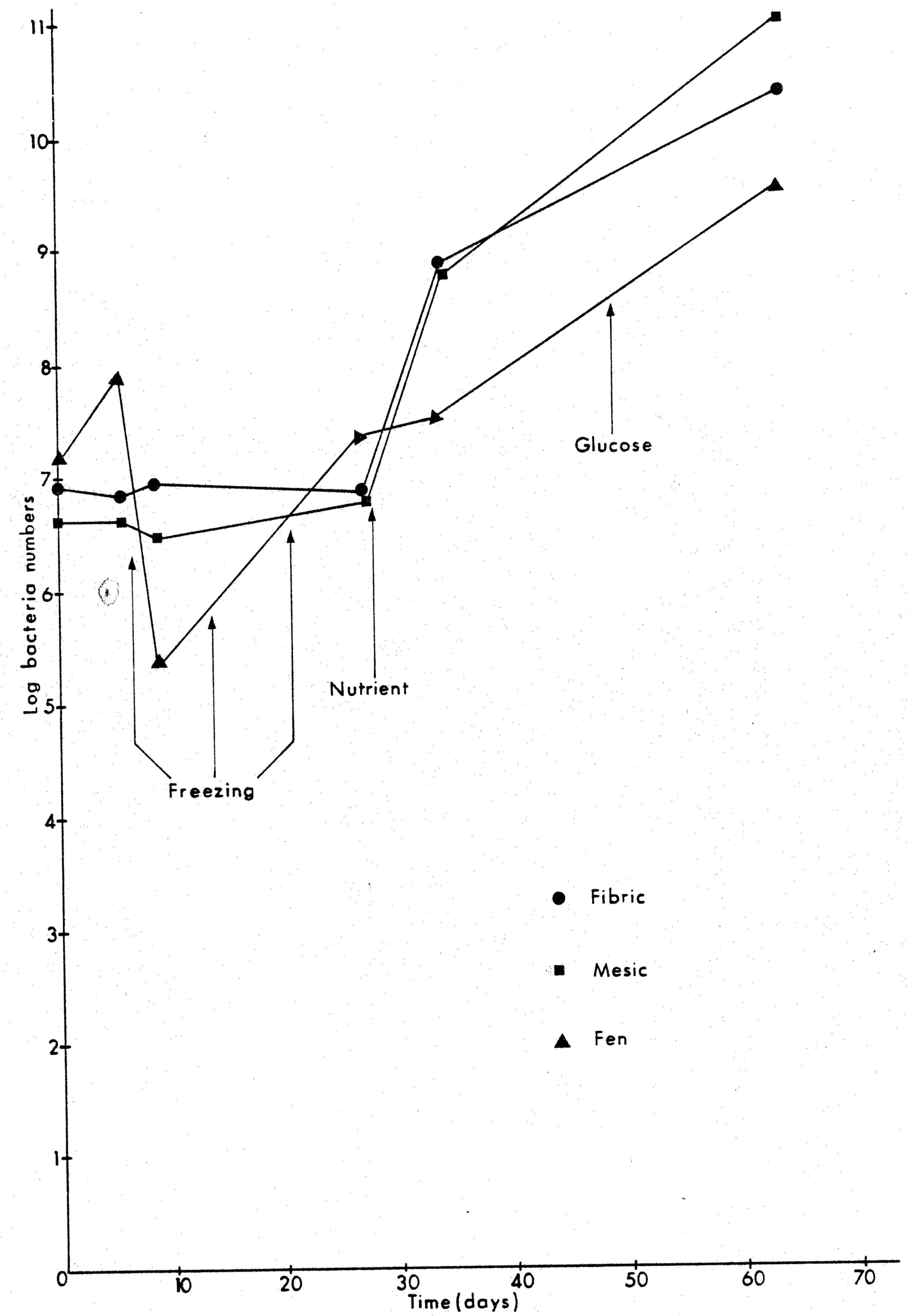

Figure 5. Change in number of organisms in fibric, mesic and fen peat following physical and nutrient treatments.

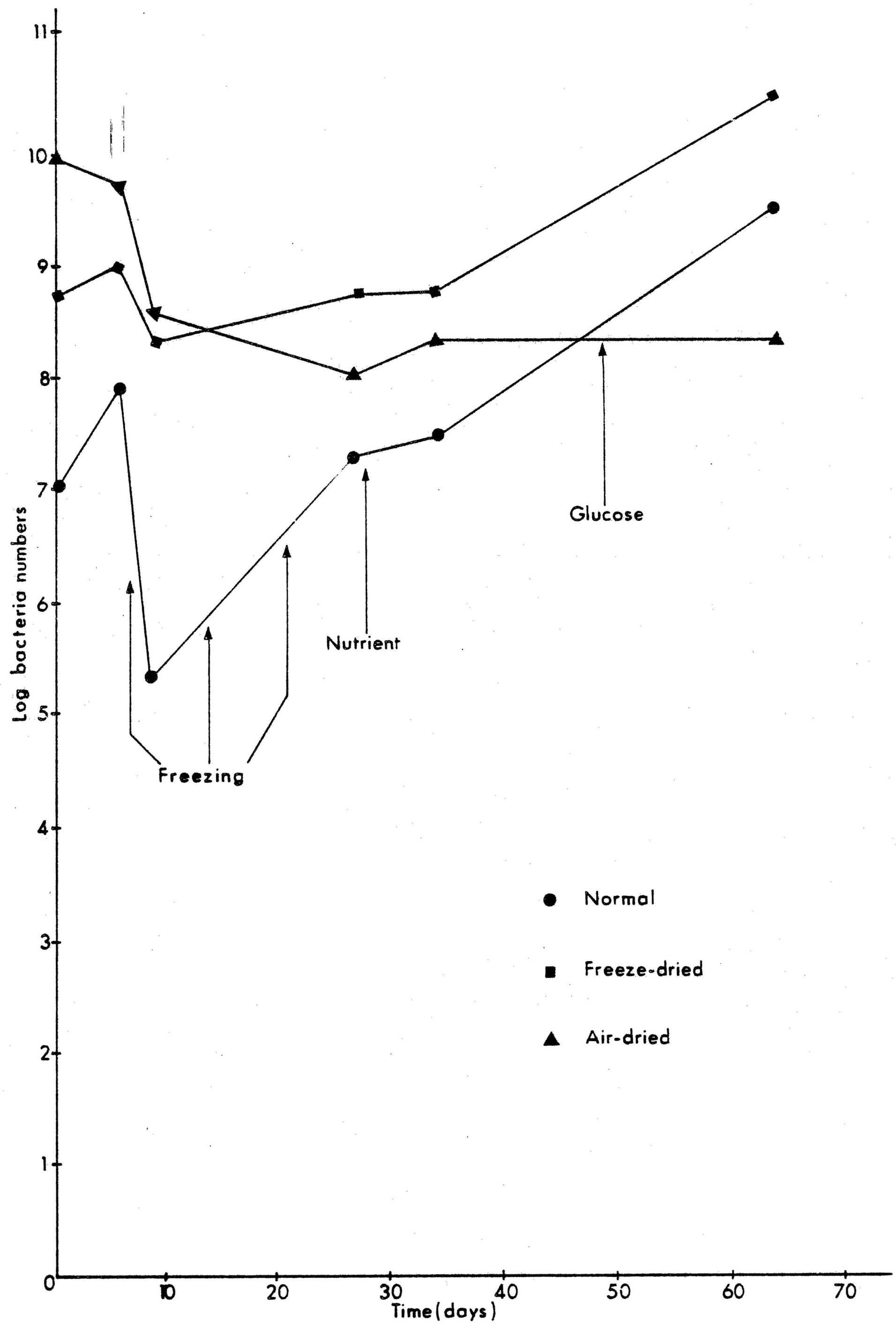

Figure 6. Change in number of organisms in a fen peat following physical and nutrient treatments.

Addition of nutrients caused a greater reaction in the mesic peat than the fibric, while addition of glucose caused a rise in the numbers of organisms in mesic peat and a sharp drop in the numbers in the fen peat.

Samples for fungal length are still being processed, but there appears to be a significant drop from the beginning to the end of the experiment (Table 7).

Table 7. Hyphal lengths by phase-contrast microscopy.

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

The major differences in bacterial numbers between 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 peat (3.7 - 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 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.

5.2.3 Effect of Microbial Activity on Physical Properties of Peat

Results reported in Figure 4 are generally in agreement with literature data. However, very few if any reports are available

Table 8. 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.

Peat	Treatment	Bulk Density[a]	Pore Volume[a]	Air Capacity[a]	Void Ratio	Fiber Content[a]		Hydraulic Conductivity[a]
						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 - not determined

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 8 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 peat drying initially increases bulk density, it may 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. 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 fiber content both rubbed and unrubbed was greater than the initial effect of drying. Drying tended to hasten the rate of loss of fiber, especially rubbed fiber. Dried peats (fibric and mesic) always had a lower fiber content after incubation than the corresponding normal peats.

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, all peat treatments had a higher permeability than the corresponding normal peat prior to incubation. In fact, 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. Further work to outline the causes of beneficial effects of the treatments imposed is needed.

5.2.4 Effect of Drying on Microbial Activity

Drying affected microbial activities to varying degrees as measured both by enzymatic activity and CO_2 production (Table 9, Figure 7). 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 7 days incubation following rewetting was greater in the rewetted air-dried moss peats than in the normal samples. The fen peat was unaffected by drying. The respiration rate of the fen peat sample was almost double that of the two moss peats.

Since the activity of cellulose degrading enzymes was reduced by drying and the soil respiration rate was generally

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

Peat	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 5 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 3 hours after adding substrate (Salicin).

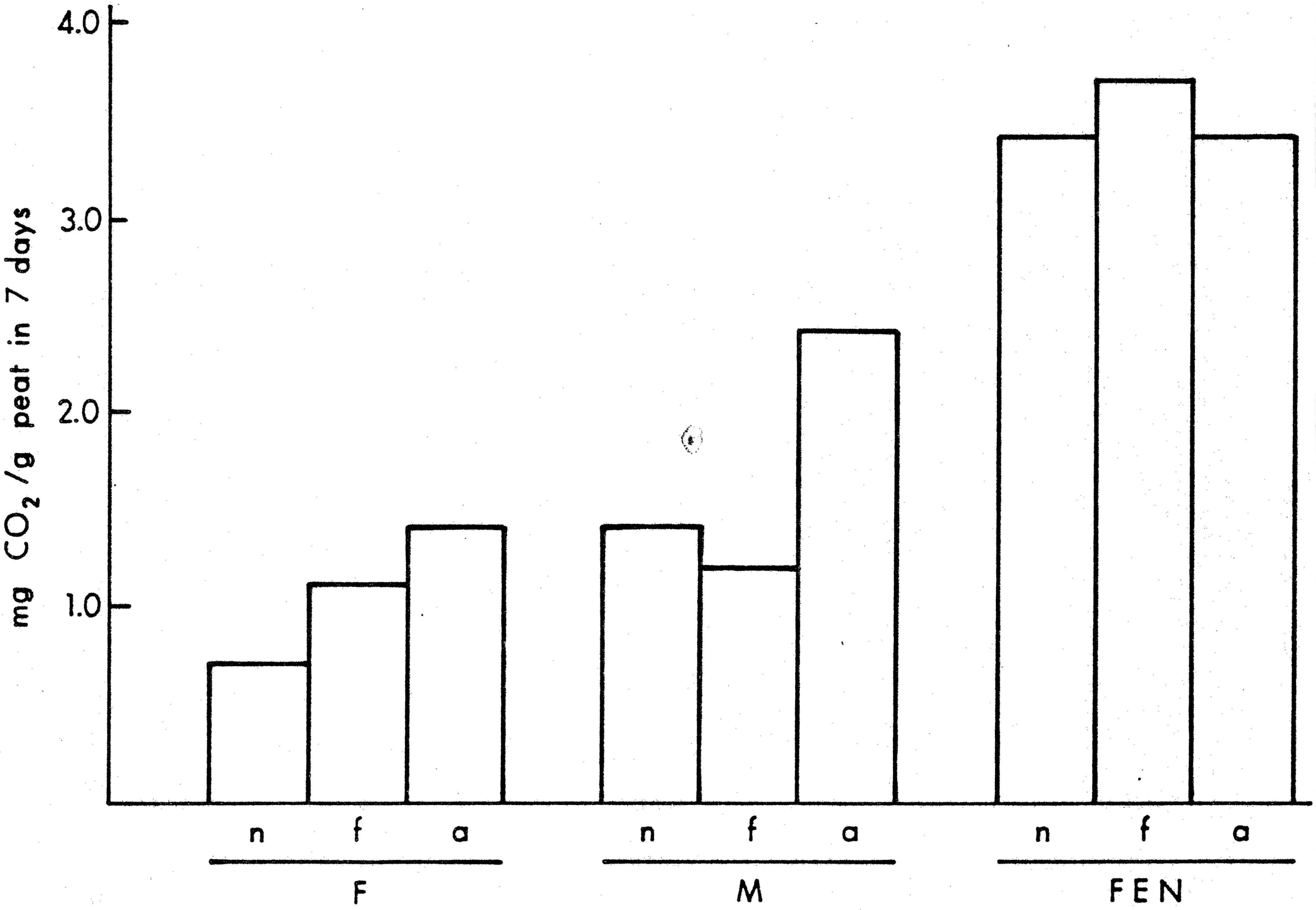

Figure 7. CO_2 production from peats F (fibric), M (mesic), and FEN remoistened after air-drying (a), freeze-drying (f), as compared to the control (n). Incubation temperature was 25 ± 0.5° C.

increased by this treatment a substantial amount of activity occurring in peat may be related to turnover of microbial tissue and not to cellulose degradation. Shields et al. (1974) showed that freezing and thawing and wetting and drying 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 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 7 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.

5.2.5 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 8). 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 per g dry peat whereas the respective values for the fen sample and fibric sample were 24.0 and 18.1 mg CO_2 per 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 CO_2 produced during this phase of the experiment totalled in 21 days approximately the same as in 7 days after rewetting.

Additions of nutrients and lime altered the relative rates of CO_2 production. Whereas the previous (physical) treatments

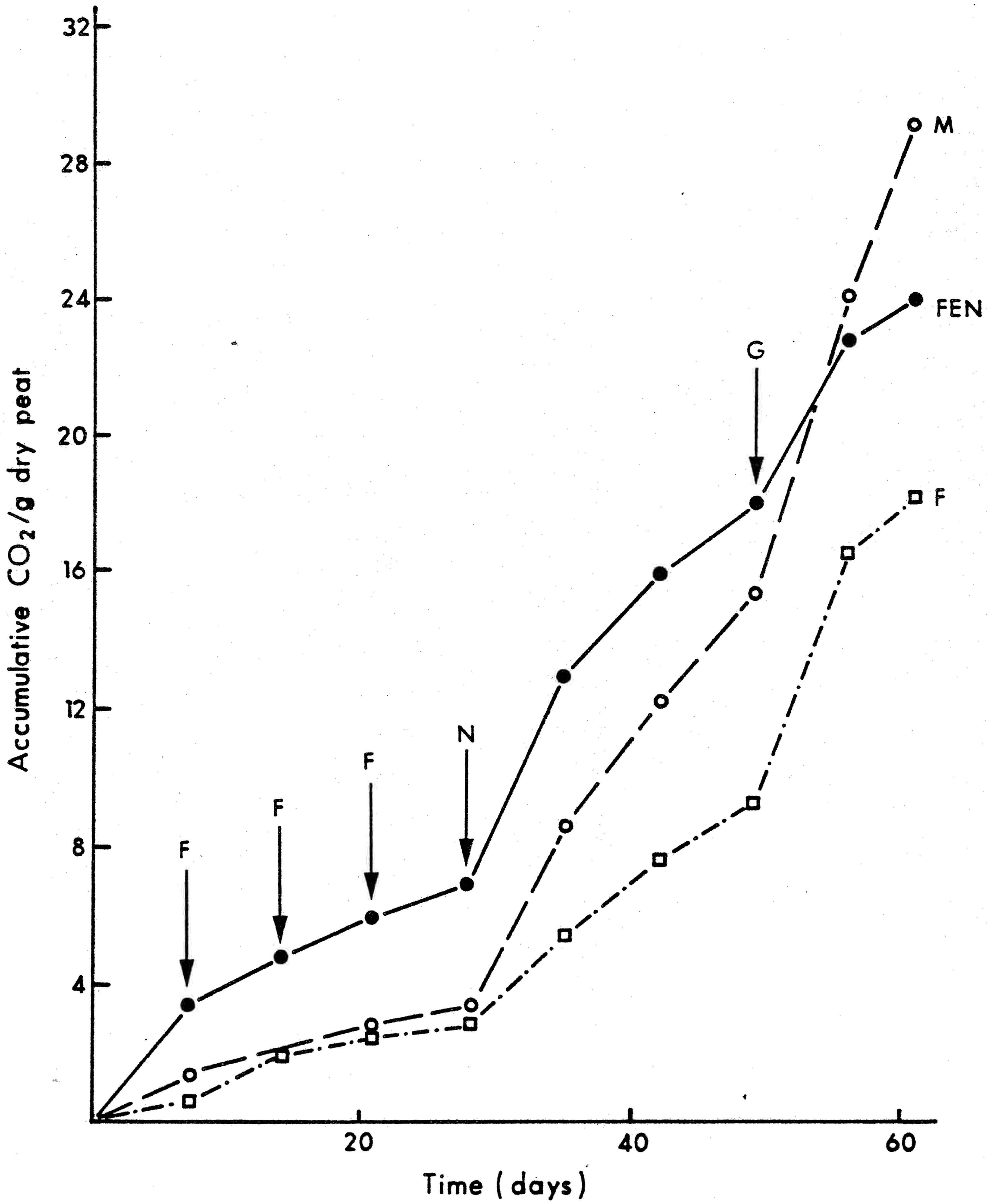

Figure 8. Accumulative CO_2 production from control portions of peat F (fibric), M (mesic) and FEN during 61 days incubation at 25 ± 0.5^0 C. Freezing events are designated F, addition of nutrients by N, and addition of glucose by G.

had 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 sample. Thus during 21 days following nutrient and lime amendments, 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 3 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 much of the activity in disturbed peat samples is a result of turnover of microbes within the peat. Peat properties which affect the activity of microbes are probably mainly chemical and not physical. The initial chemical properties of a disturbed peat, however, are undoubtedly a result of its past physical environment.

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 which kill microbes may in the long term 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 than the control over the 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.

5.2.6 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 peat lands. 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 9). 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. 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

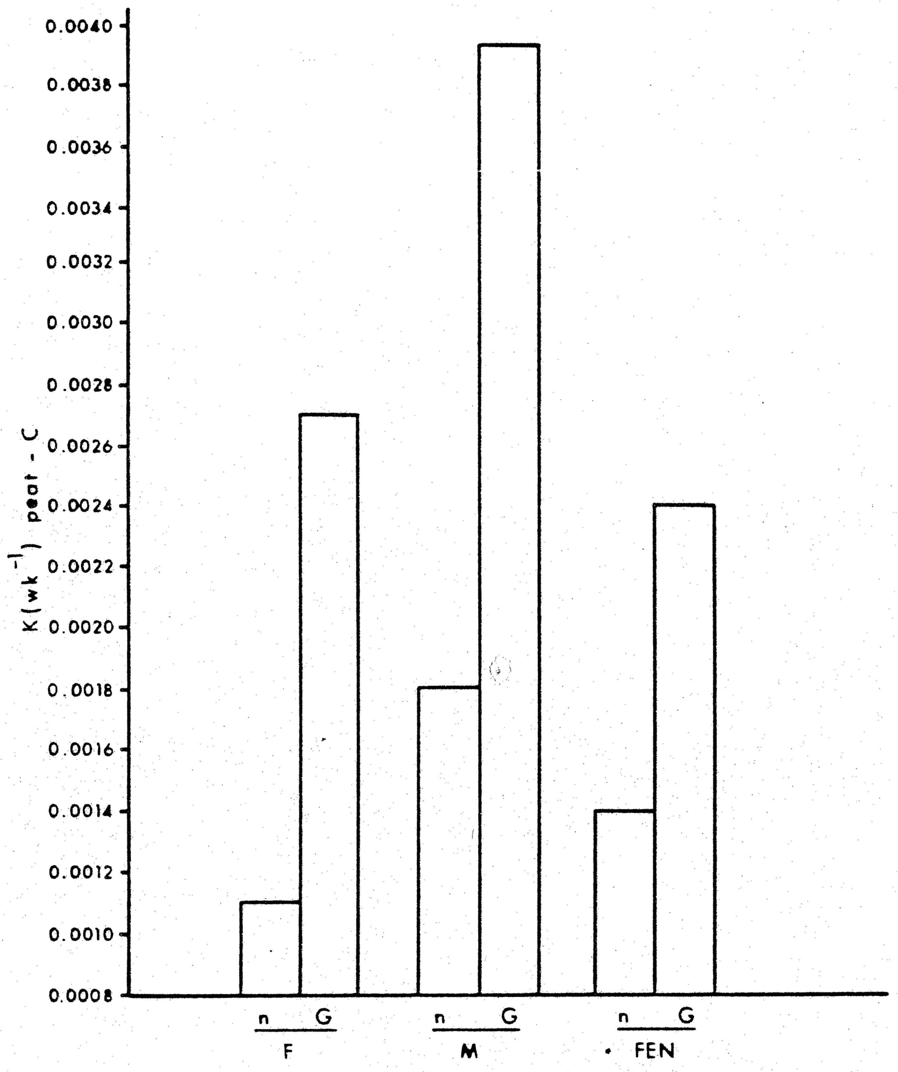

Figure 9. Effect of added glucose on the rate of carbon loss defined as

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

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.

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.

PART III

6. STORED PEAT MATERIALS

6.1 FIELD STUDY

6.1.1 Temperature and Moisture Regimes in Stored Peat Piles

6.1.1.1 Method. Soil temperature and moisture fiberglass electrical cells were imbedded in the peat 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 facing slope and the south facing slope. In addition, a set of cells was installed in an undisturbed tree covered location adjacent to the pile. The placement depths ranged from 20 centimeters to 200 centimeters, the intervals being 20 cm, 50 cm, 100 cm and 200 cm. A reading was also recorded by hand thermometer at 7 cm.

At the Mildred Lake site, the cells were located at 4 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 10 shows the temperature fluctuations that occurred on the north facing slope at Evansburg for the period October 1976 to November 1977. Figure 11 shows similar information for one of the locations at the Mildred Lake site for the same period of time.

The development of soil microorganisms depends on environmental conditions, such as temperature and moisture. Some microorganisms can survive under low temperature and high moisture content. Flanagan and Scarborough (1974) have pointed out that

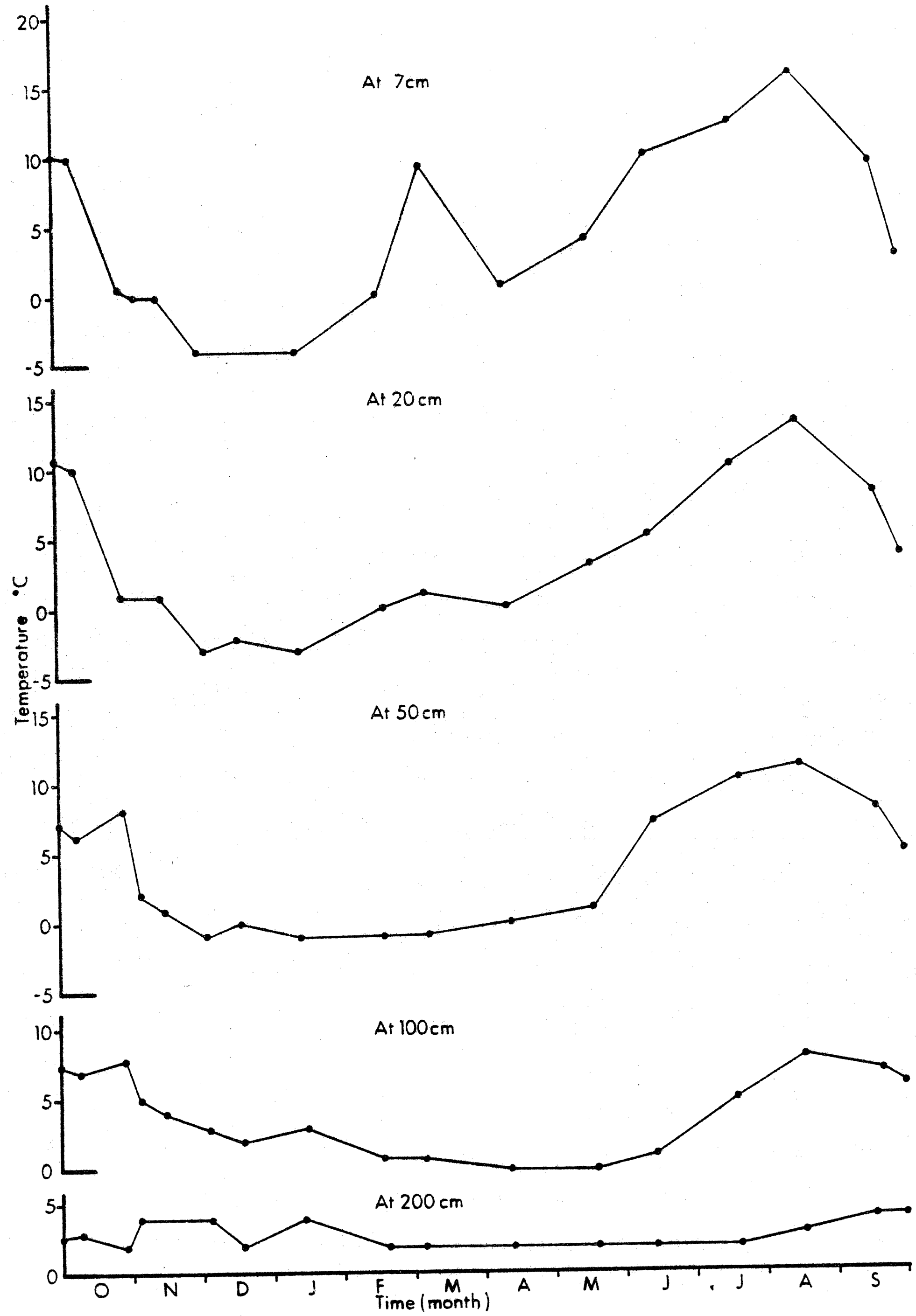

Figure 10. Temperature regime in Evansburg peat pile.

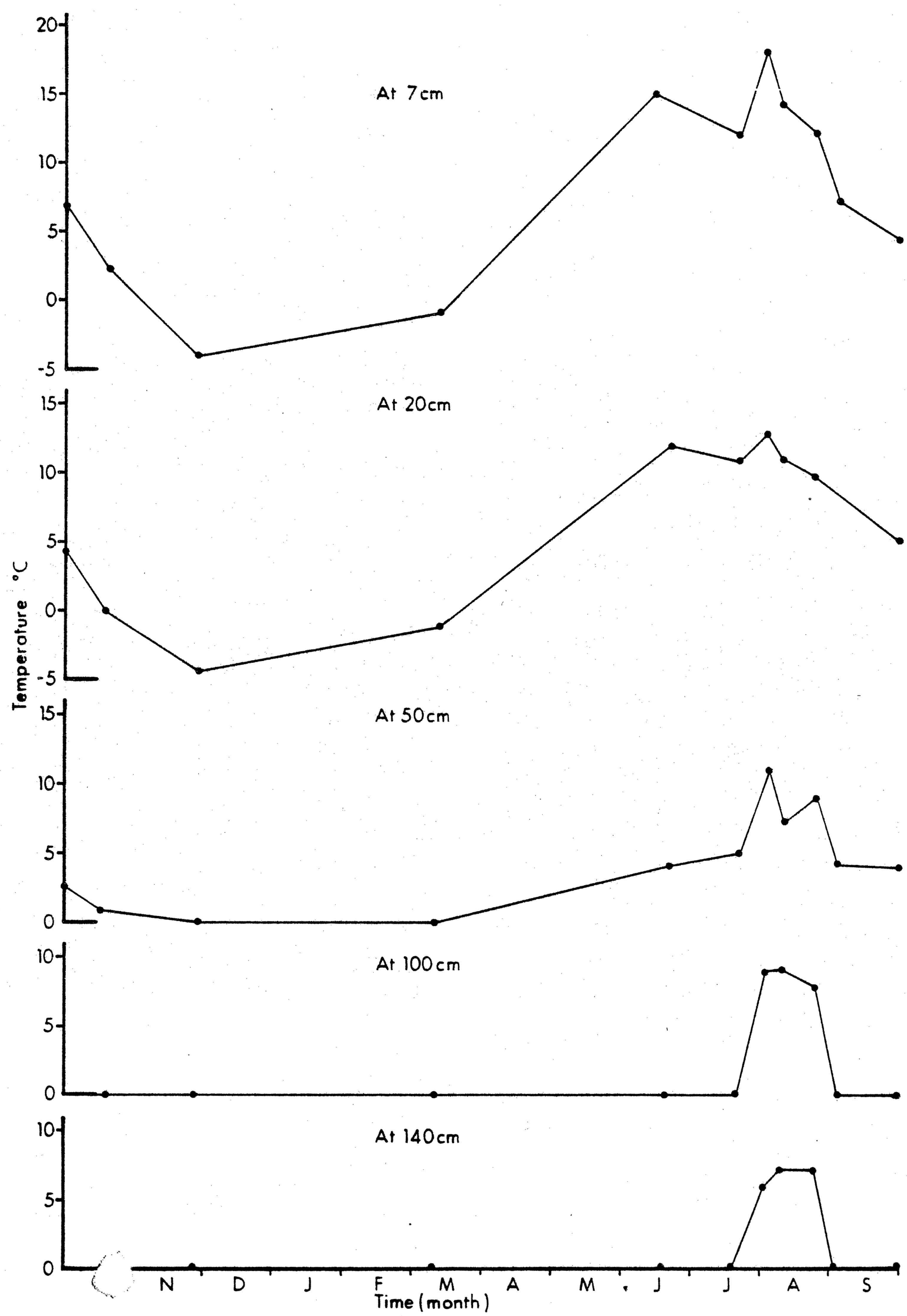

Table 11. Temperature regime in Mildred Lake stored peat material.

cellulolytic fungi can survive in a wide range of temperatures down to $-7^{o}C$; some have an optimum cellulase activity at 6 to $8^{o}C$. At these temperatures, however, most of the other enzyme systems do not function well, therefore the relatively low temperatures in some portions of the peat piles may make the cellulolytic organisms important decomposers.

An optimum temperature and moisture may favour the activity of microorganisms. Kononova (1961) mentioned 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 (1974) suggests the optimum moisture for development of microorganisms is in the range of 120 to 400% and an approximate optimum temperature range of 23^{o} to $28^{o}C$. Flanagan and Veum (1974) have also pointed out that moisture levels in excess of 300% depress microorganism respiration rates. However, the moisture regime which begins to attenuate 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 intensity of microbiological activity mentioned in this report is based on the scale suggested by Kononova (1961) and shown in Table 10.

Table 10. 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

The data for the Mildred Lake site indicates that optimum temperature for microbial activity occurred in the top 7 cm from about the middle of May to the end of August, some 101 days. By comparison at the 20 cm depth optimum conditions only occurred from June to August. At greater depths, 100 cm and 140 cm, the temperature was at or near $0^{\circ}C$ for a major part of the year rising to between $5^{\circ}C$ and $10^{\circ}C$ for only a short period from late July to early September. Such data would suggest that microbial activity would be relatively low for a major portion of the year at these depths in the storage piles.

It is generally assumed at this time that the higher temperatures at depth during the mid-July to mid-August period is a reflection of the high surface temperature rather than the activity of thermophilic organisms. Generally, thermophilic organisms are active only above a temperature of $37^{\circ}C$ such as may be found in manure piles.

At Evansburg, the near surface 7 cm layer temperature was above $10^{\circ}C$ for 93 days, from June to September; at the 20 cm depth the temperature was above $10^{\circ}C$ for only 49 days, and for only 31 days at 50 cm. At greater depth, 100 and 200 cm, the temperature was generally at 0° to $5^{\circ}C$ for a major portion of the year. At no time during the year did the temperature at 100 and 200 cm reach the near optimum temperature of $10^{\circ}C$ (Table 10).

The data indicate that the temperature in the surface layer (7 cm) is similar at the Evansburg and Mildred Lake sites. In general, the temperature is above $10^{\circ}C$ for about 100 days. At greater depth, 50, 100 and 200 cm, the temperature at Evansburg appears to be somewhat higher than at Mildred Lake. In fact, the data (Figure 11) indicate that the stored material at Mildred Lake is frozen for a major portion of the year, rising above $0^{\circ}C$ for only a short period from late July to early September. During the lengthy freeze period at Mildred Lake microbiological activity will be extremely low whereas at Evansburg such activity can be assumed to be higher for a longer period. It can also be suggested that during the period in which the material is frozen microbiological activity will also be restricted because of the lack of an available moisture supply.

The temperature regime in the undisturbed site at Evansburg is shown in Figure 12. At Evansburg near surface temperatures (7 cm) were highest in August but were at a level suitable for intensive biological activity for the period June to September. From November to February the surface layer was frozen. It is interesting to note that during the winter months the peat in the undisturbed site froze to a depth of about 50 cm but below this depth remained unfrozen. At greater depth, however, the temperatures remain relatively low and it can be assumed that at the 100 and 200 cm depths the biological activity is low throughout the year.

Data for the undisturbed Mildred Lake site is shown in Figure 13. The annual temperature trends are similar to those at Evansburg, particularly at depths of 100 to 200 cm. In the near surface layer (7 cm), the temperatures at the Mildred Lake site were somewhat higher than at Evansburg during the summer months and this may be related to air temperature. At 20 cm and 50 cm depths the temperatures were somewhat lower at Mildred Lake than at Evansburg.

In general, for the reporting period, it would appear that the temperature at the 7, 20 and 50 cm depths would be suitable for biological activity at Evansburg but perhaps limited to the surface 7 cm layer at Mildred Lake.

Moisture measurements in the stored peat were recorded at times when the temperature was above freezing. Therefore, the results reported herein are only for the period June to November. Data for the Evansburg site is shown in Figure 14 and for the Mildred Lake site in Figure 15. Using the criteria outlined by Kononova (1961) it would appear that optimum moisture content at the 50 cm depth in the Evansburg storage pile occurs in spring and again in the fall. During the summer period the moisture content is somewhat above optimum. At Mildred Lake the optimum

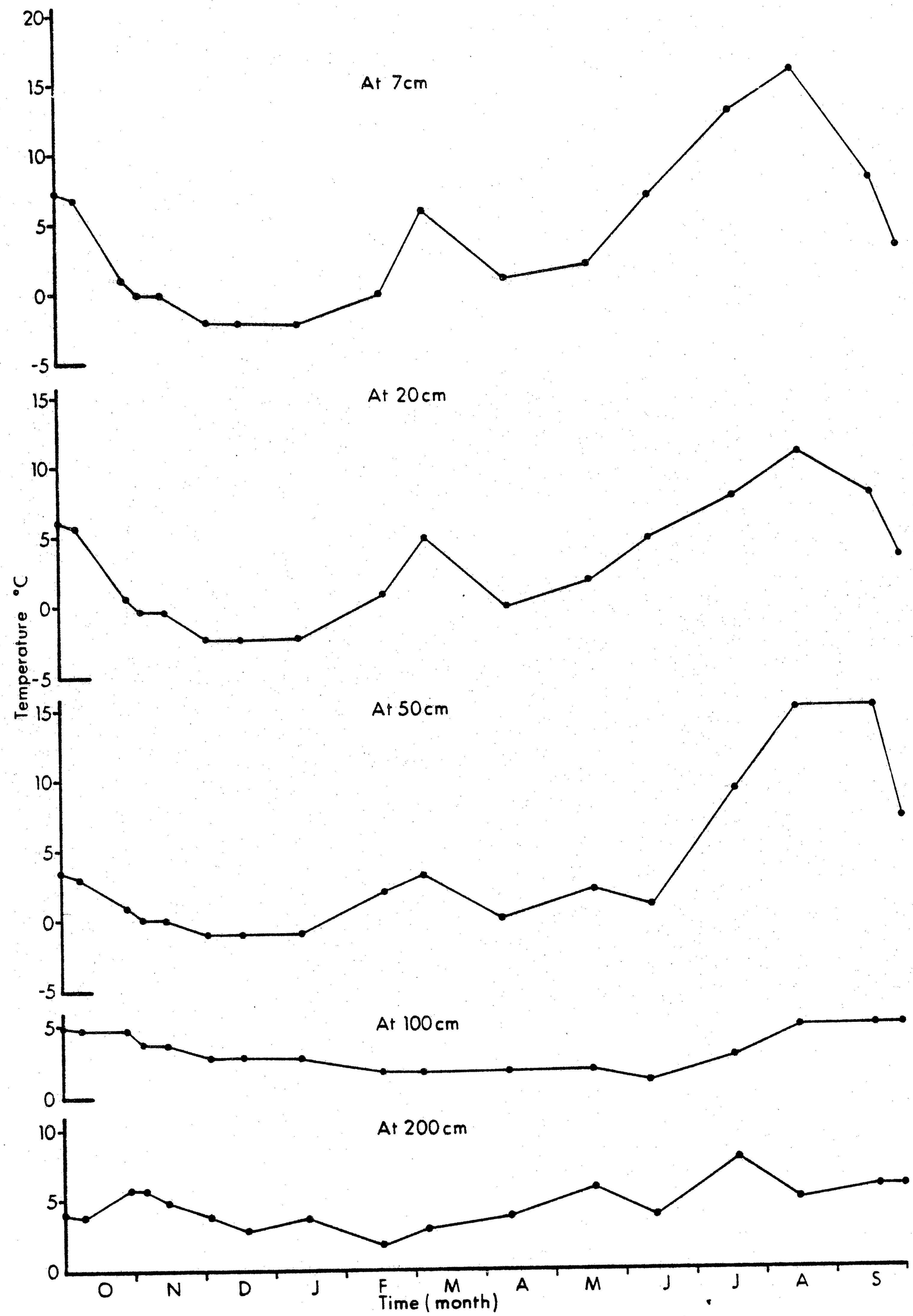

Figure 12. Temperature regime in Evansburg undisturbed peat piles.

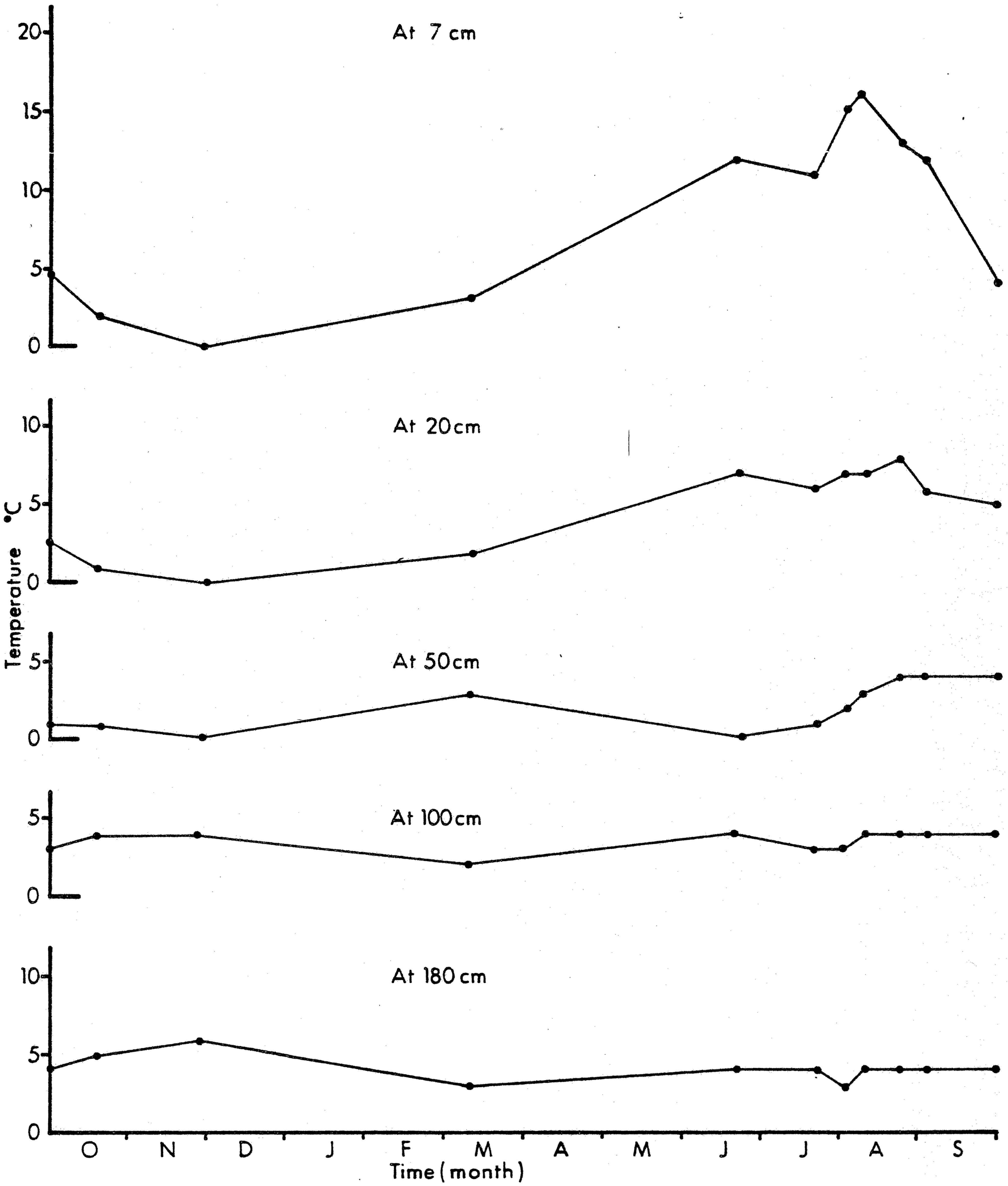

Figure 13. Temperature regime in Mildred Lake undisturbed peat site.

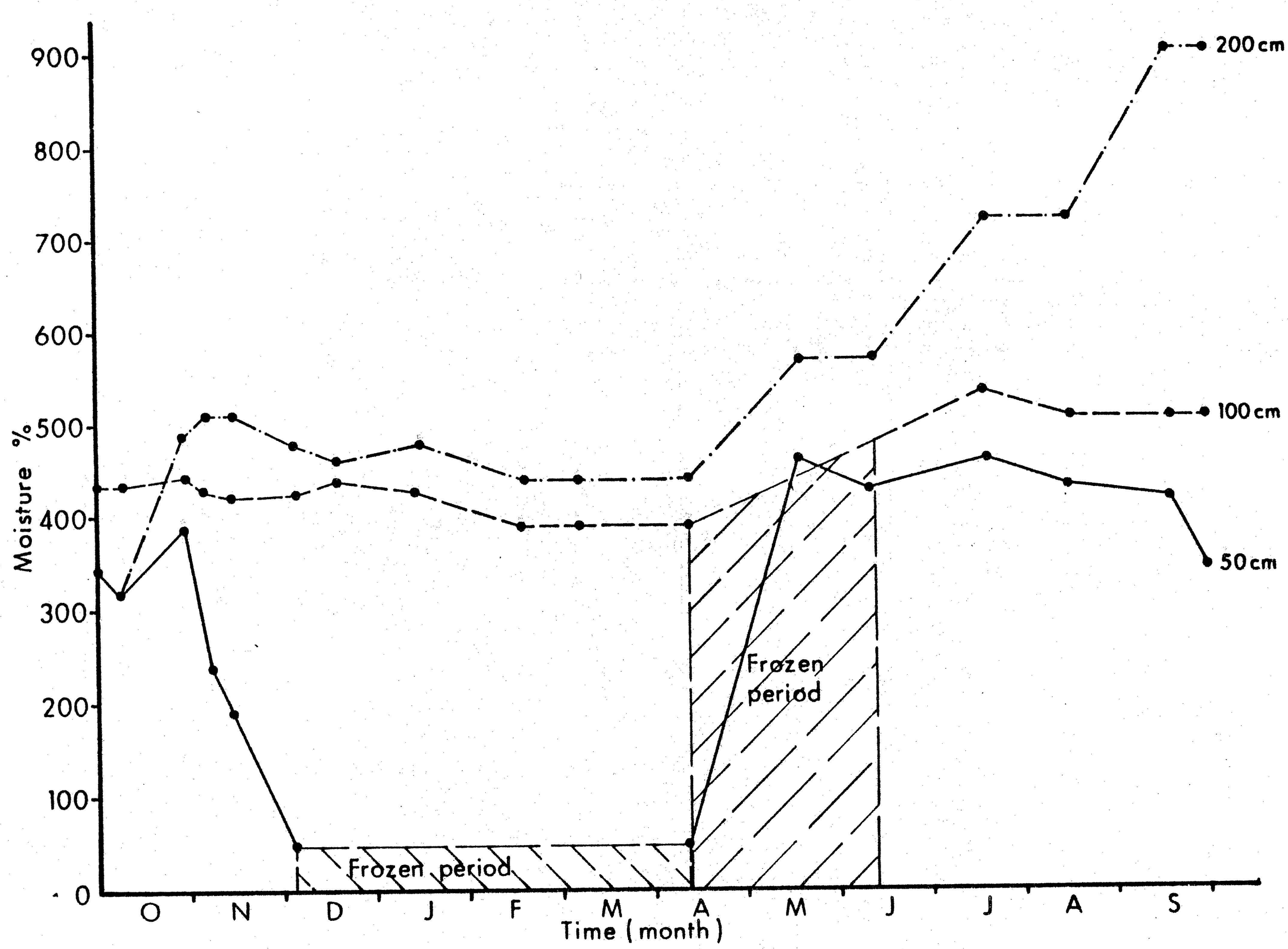

Figure 14. Moisture regime in Evansburg peat pile.

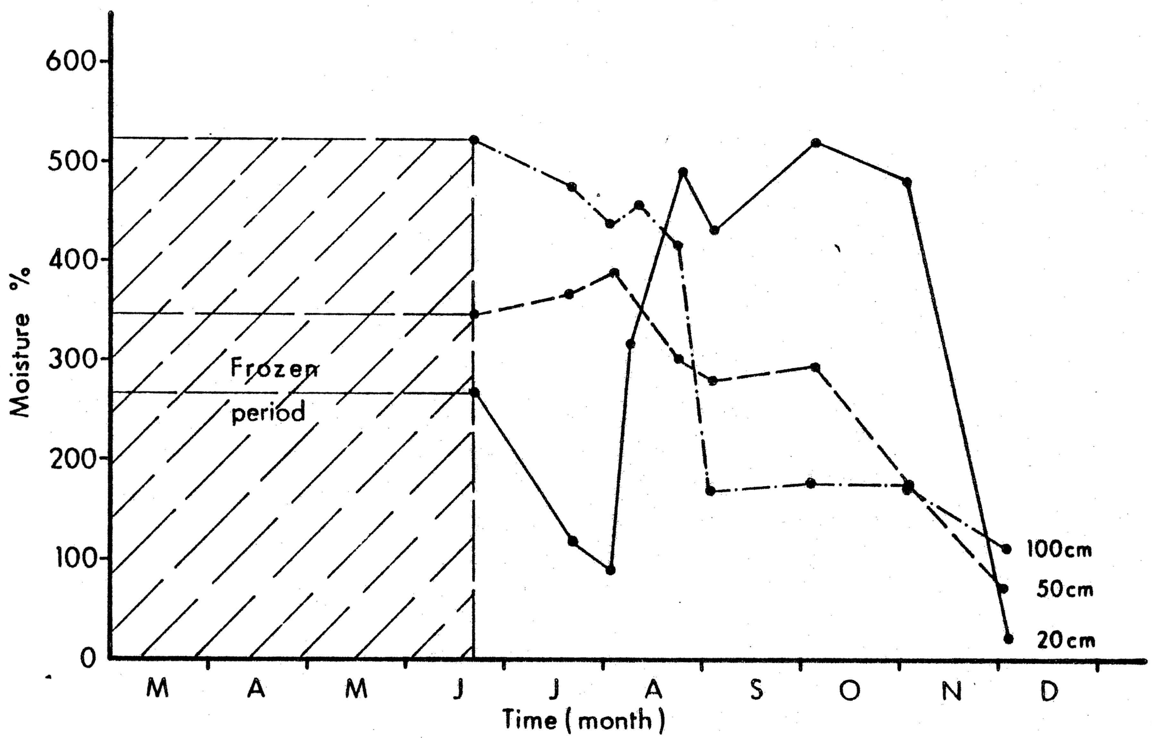

Figure 15. Moisture regime in Mildred Lake stored peat material.

moisture content appears to extend from mid June until late November. In comparing the moisutre content at the 100 cm depth it would appear that optimum conditions exist at Evansburg from February to April whereas at Mildred Lake the period of potential maximum activity is from August to November. However it should be noted that no attempt has been made to correlate optimum temperature and optimum moisture levels. To carry out such a correlation a fairly extensive sampling program is required in order to establish simultaneous temperature and moisture levels. Such an investigation is being considered for the next field season.

The obvious high moisture level at the 200 cm depth at Evansburg is attributed to surface water accumulation following the spring thaw. Such moisture appears to have moved up the storage pile by capillary action to the 200 cm depth. 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 matter content of the material at Mildred Lake ranges from 3% to 64% whereas at Evansburg the more homogeneous material has an organic matter content close to 75% throughout the pile.

The amount of mineral material no doubt drastically affects the microbiological activity. Flanagan and Veum (1974) reported the respiration rate of microorganisms in a bog with 66.6% organic matter 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 13.1%. 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.

6.1.2 Cellulolytic Activity in Stored Peat Material

6.1.2.1 Method. The purpose of this experiment was to determine the cellulolytic activity in the stored peat at the Evansburg and Mildred Lake sites. As well the experiment was carried out in an undisturbed site at Mildred Lake.

Filter paper was buried at each of the sites and left for one year. At the end of this period the degree of decomposition was measured by determining the loss in weight.

At Mildred Lake the filter paper was buried at a depth of 20 cm at the undisturbed site and at 20 cm and 50 cm in the stored material. At Evansburg, the filter paper was buried at 20 cm in an eight year peat pile and at a similar depth in a one year old pile on both south and north facing aspects.

6.1.2.2 Results. In the Mildred Lake stored material the decomposition, as measured by weight loss, 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 and the application of fertilizer which would stimulate microbiological activity. By comparison, there was little evidence of filter paper decomposition in the undisturbed site at Mildred Lake. A few brown spots developed on the filter paper, probably as a result of fungi activity but the weight loss did not exceed 4%. The microbiological activity at this site is not intensive probably because of low mineral nutrient content and anaerobic conditions resulting from a high water table.

Waksman (1928) has studied microorganisms in sphagnum peat and suggests that the nitrogen given off by the decayed material is low and insufficient to stimulate microbiological activity. Further, he suggests a competition exists between the sphagnum plant and the cellulolytic microorganisms for nutrients. However, some anaerobic organisms may survive in deeper sphagnum layers where calcium carbonate is higher and may encourage development of cellulose decomposers.

In the present experiment at Mildred Lake the greatest cellulose decomposition appears to be taking place near the surface, as a result of aeration and the application of nitrogeneous fertilizers.

Results of the work at the Evansburg site are presently being compiled and will be reported at a later time.

6.1.3 Soil Respiration Study of Stored and Undisturbed Peat

6.1.3.1 Material and method. Soil respiration rate was determined by estimating the CO_2 evolution under field conditions. The method used is essentially the same as described in Section 10.1. However, instead of using a constant temperature incubator the samples were simply examined in the field where 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 layer. The respiration rate, at this site, however, may well be affected by a number of factors and the results should at this time be considered as preliminary. It is possible that in the root zone (surface layer) much of the added nutrient (fertilizer) was used by the plants of the cover crop resulting in an insufficient supply for microbial activity. The competition for nutrients may well have been less in the subsurface layer where the roots were not concentrated, resulting in a greater available supply for the microorganisms. More extensive investigations into the in situ CO_2 evolution at this storage site is planned for 1978.

In an area of undisturbed peat at Mildred Lake the respiration rates varied with the type of peat. Fibric peat was relatively high in microbial activity in the surface layer as compared to the subsurface layer whereas in mesic peat the rates were lower for the surface than the subsurface layers. It should be noted that the fibric peat was examined in a relatively open area and less competition for nutrients with the plants may well have contributed to the increased microbial activity. At the site at which the mesic peat was examined less solar energy reached the ground surface because of a relatively dense tree cover.

Respiration data for the stored peat at Mildred Lake and Evansburg is shown in Tables 11 and 12.

The data indicate greater microbial activity in the heterogeneous material at Mildred Lake than in the pure peat stored at Evansburg. At Mildred Lake, the evolved CO_2 amounted to 1.043 to 2.399 mg. CO_2 per gram of carbon per day, as compared to 0.323 to 0.527 mg at Evansburg.

The apparent low activity in the peat pile at Evansburg may be attributed to a drying effect in which free water drained from the pile and further desiccation occurred as a result of wind action. This irreversible action results in shrinkage of the peat material. On the other hand, the material at the Mildred Lake site contains a relatively high amount of inorganic material and this fact coupled with the fertilizer application probably contributed to an enhanced respiration rate at this site.

6.2 LABORATORY STUDY

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). This overburden material was piled to a height of about three meters.

Following construction of the storage pile, the area was seeded to several forage species and fertilized extensively. The species used and fertilization program is shown in Section 10.2.

An experiment was therefore designed to compare the potential cellulolytic activities in different samples of the stored organo-mineral material from the Mildred Lake storage area.

Table 11. Respiration rate in Mildred Lake stored material 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	1.043 ±0.13	2.056 ±0.36	2.038 ±0.33	2.399 ±0.39	2.470 ±0.24	1.310 ±0.10	0.884 ±0.11	1.216 ±0.18

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

Table 12. Soil respiration rate in Evansburg peat pile and undisturbed peat site.

Respiration rate based on	Undisturbed Peat Site		Peat Pile	
	surface	subsurface	Site No. 1	Site No. 2
CO_2 mg/g C/day	0.593 ± 0.15	1.724 ± 0.16	0.527 ± 0.04	0.323 ± 0.03

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

6.2.1 Method and Materials

A total of forty samples were taken randomly at the surface (10 cm) and subsurface (40 cm) across the storage areas. These samples were then passed through a 5mm sieve in fresh condition. Half of each sample was air dried, then ground to pass a 2mm sieve for chemical analysis (Section 10.1) and particle size determination (Section 10.1). Tests of enzume activity and CO_2 evolution were conducted on a fresh sample, adjusted to an optimum moisture content which equalled 1.5 times the equivalent moisture (moisture remaining after being centrifuged at 2,400 r.p.m. for 2 minutes).

The method for determination of cellulolytic activities is described in Section 10.1.

Fertilizer treatments were added to all samples based on the same amount. Soil samples were incubated at 25°C ± 0.5°C for 46 days. Cellulose powder (CL41 Whatman) 1% was added to each sample on Day 9; phosphorus (200 ppm of P) as K_2HPO_4 was added on Day 16. Nitrogen (200 ppm of N) as $(NH_4)_2SO_4$ was added on Day 28.

Carbon dioxide evolution was measured with the method described in Section 10.1. CO_2 evolved was determined every two days. Enzyme activities were determined at the beginning and the end of the experiment.

6.2.2 Results

6.2.2.1 Characterization of stored material. The samples obtained from the Mildred Lake storage area were extremely variable in terms of organic matter and mineral content. Based on the analyses of 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 is shown in Table 13.

Table 13. Classification of stored material at Mildred Lake.

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%

Based on the above criteria, 7 samples were placed in Group I, 13 in GroupII, 6 in Group III, and 14 in Group IV. The particle size and organic matter content (means and standard errors) are shown in Table 14.

Table 15 shows the Group I (peat predominant) material was highest in exchangeable Ca^{++}, Mg^{++} and total CEC, but the base saturation was less than in the other groups. In comparing the nitrogen and carbon content, the peat-dominated material was highest, but the pH values were somewhat lower. The range of Ca^{++}, Mg^{++} and nitrogen content in Group IV (peat-sand mixture) material was slightly less than the Group I, but the carbon which was covering the fine sand particles was only 15.5%. The pH value was also lower in the peat-predominant group.

Table 14. Organo-mineral component of four designated categories of stored material.

Stored Materials	Organic Matter %	Mineral Material %		
		Sand	Silt	Clay
Group I	54.7 ± 3.2	12.3 ± 3.9	24.3 ± 3.7	8.9 ± 3.5
Group II	7.9 ± 1.2	65.7 ± 3.4	17.7 ± 2.7	8.8 ± 1.3
Group III	7.7 ± 1.7	19.5 ± 8.5	31.2 ± 3.1	41.7 ± 8.4
Group IV	26.7 ± 1.8	35.5 ± 5.9	24.9 ± 3.4	12.9 ± 1.7

Results are means ± standard error of the means for 7 samples in Group 1, 13 samples in Group II, 6 samples in Group III and 14 samples in Group IV.

Group III (sand-clay mixture) and Group II (sand predominant) materials were very low in carbon content, not exceeding 4.5%. The pH values however, were somehow higher than the first two groups. The main criteria used in the designation of stored material was based on the organic matter content and particle size distribution. Accordingly, the stored material is extremely heterogeneous. However, the organic matter (mainly peat) in stored material plays an important role in modifying the physical and chemical properties of soil, and indirectly affects their biological properties. Soil respiration and enzymatic activity are two such properties affected by organic matter content.

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 the material (Figure 16). The standard error of the estimate is 19.5 me/100 g soil. Clay content would be expected to effect the CEC. This is not apparently the case with these materials. The multiple regression of CEC on clay and %C was calculated as CEC (me/100 g) = 10.05 + 3.55 (%C) + 0.277 (% clay). The standard error of the estimate

Table 15. Chemical properties of stored material for the four categories.

	pH in H_2O	NH_4Ac Ext. Cations (me/100g)				CEC	Base Sat. %	C %	N %	C/N	P_2O_5 ppm	Bitumen %	Ash %
		Na	K	Ca	Mg								
Group I (peat)	6.2±0.3	2.4±0.9	0.4±0.1	95±17.0	22±2.7	121±12	98±4.6	31.8±1.8	3.1±0.4	11.8±2.1	13±2.1	1.6±0.3	30±2.7
Group II (sand)	6.7±0.2	0.4±0.1	0.1±0.02	28±5.2	4.4±0.5	23±4.6	156±22.0	4.5±0.7	0.5±0.1	12.5±1.6	9.3±1.0	0.7±0.2	89±1.5
Group III (sand-clay)	7.1±0.1	3.0±0.9	0.8±0.2	27±2.9	12±2.3	39±4.0	114±6.0	4.5±1.0	0.4±0.1	11.3±1.0	29.3±8.4	0.3±0.05	87±1.1
Group IV (peat-sand)	6.4±0.2	0.9±0.4	0.1±0.02	76±10.0	12±1.3	76±6.2	117±9.0	15.5±1.0	1.7±0.2	10.4±1.1	7.7±0.5	0.8±0.1	67±2.1

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.

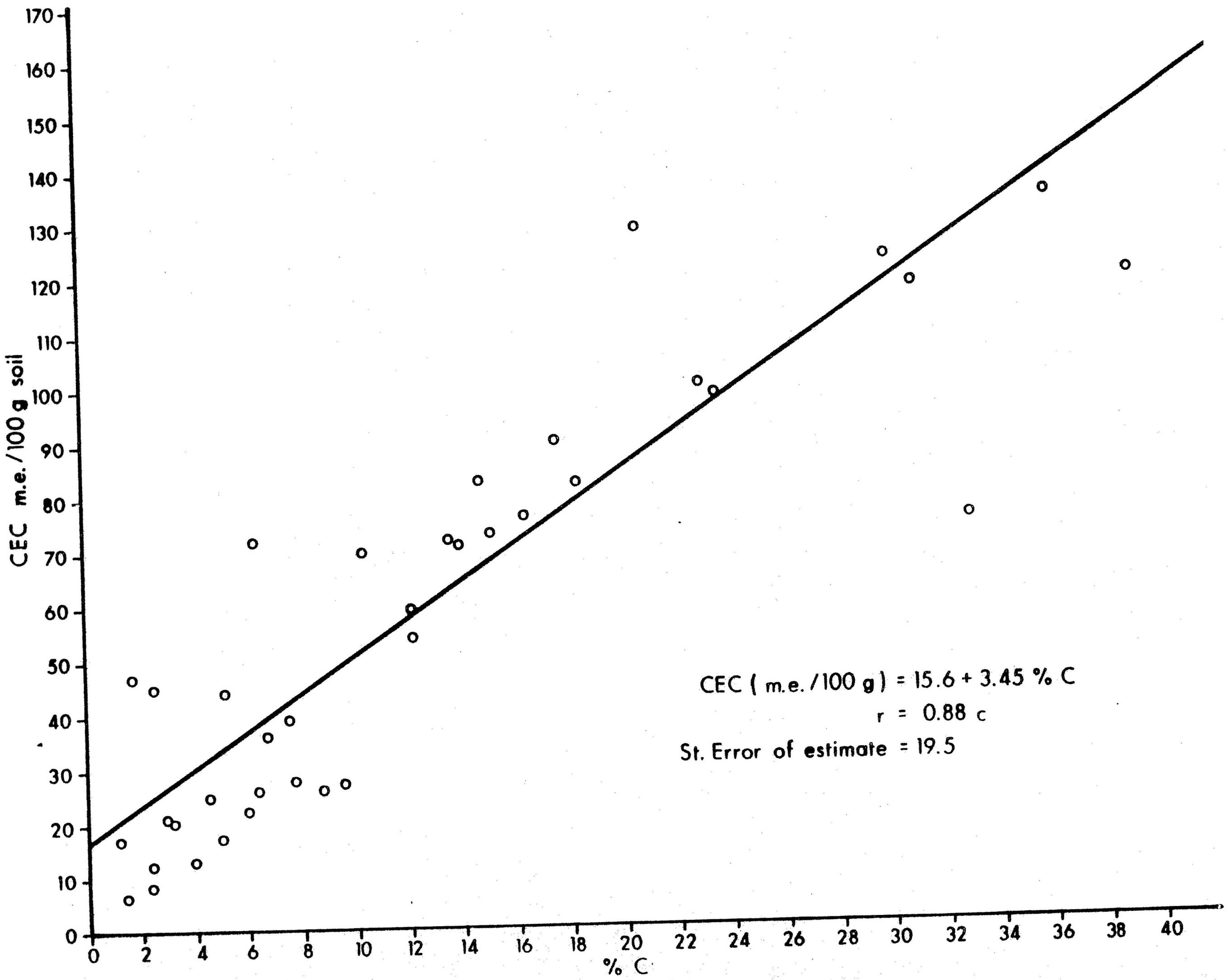

Figure 16. Relationship between cation exchange capacity (C.E.C.) and the total carbon content in stored peat material.

is 19.2 me/100 g which is only very slightly lower than that obtained by using %C alone. The clay content ranged from 2 to 47%. The correlation of CEC with % clay was not significant at 0.13.

6.2.2.2 Enzyme activity in surface and subsurface material before and after fertilizer treatment. In general, enzyme activities were low before treating with fertilizer but increased after treatment. There was no significant difference in the enzyme activity of the surface and subsurface layers (Table 16). Activity in the material was generally found to be highest in B-glucosidase, and lowest in Cx activity. This was opposite to that of pure peat in which the B-glucosidase was low and Cx activity high. 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 quantitatively and qualitatively as well, because the predominant fungal flora may be replaced by bacteria involving a change in enzymatically different organisms.

Table 16 also shows a highly significant difference between the untreated and fertilized material. Fertilization stimulated enzyme activity significantly. Kuster and Gardiner also mentioned that the supply of readily available nutrients, particularly nitrogen in peat, may result in stimulated microbial activity and increased enzymatic activity. This confirms Hofmann's (1962) observation that the addition of nitrogen and phosphorus induce increased enzyme activity.

In comparing the rate of increase in enzyme activity by fertilization, it is interesting to note that the Cx activity was most affected by fertilizer N; the rate of increment was ten times more for the subsurface soil and fifteen times more for the surface soil.

Table 16. A comparison of enzyme activity in surface and subsurface stored material.

Enzymatic Activity	Surface				Subsurface			
	Original		Treated		Original		Treated	
C_1	0.843	a	2.595	b	0.783	a	1.442	ab
C_x	0.436	a	6.744	b	0.491	a	4.965	b
B-glucosidase	1.025	a	3.822	b	1.228	a	3.530	b

Means in the same row followed by the same letter are not significantly different at the 95% level. C_1 and Cx activities are expressed as mg reducing sugar per g of carbon per 5 days (C_1) and 24 hours (Cx), B-glucosidase activity is expressed as mg saligenin per g of carbon per 3 hours.

In comparing the enzymatic activity in the four groups of stored materials, the groups (I and IV), highest in organic matter content, had the higher activity. F values were calculated using the mean of groups compared with the other stored material. The results are summarized in Table 17.

B-glucosidase activity had the highest F value (37.9 for the control and 13.0 for the treated sample) which was significant at the 99.5% level. This was probably due to the low variation within each group of the stored material. On the other hand, C_1 activity had a low F value (3.3 for the control and 3.4 for the treated sample), indicating a wide variation within each group of material.

In comparing the three cellulolytic activities in the different groups of stored material only a slight significance in C_1 activity was found between the Group III and Group IV materials; Cx activity was significant between Groups I and II, highly significant between Groups II and IV and Groups III and IV. It is interesting to note that the Cx and B-glucosidase activities

Table 17. A comparison of enzyme activity in four designated categories of stored peat material.

Stored Peat Material	Pre-treatment C_1	Pre-treatment Cx	Pre-treatment B	Post-treatment C_1	Post-treatment Cx	Post-treatment B
Group I	0.138 ab	0.112 a	0.323 a	0.443 a	0.893 a	0.600 a
Group II	0.058 ab	0.017 b	0.056 b	0.100 b	0.316 b	0.221 b
Group III	0.030 a	0.027 a	0.053 b	0.103 ab	0.225 b	0.177 b
Group IV	0.095 b	0.057 ac	0.140 c	0.165 a	0.493 c	0.273 bc
F ratio	3.3[a]	5.7[b]	37.9[b]	3.4[a]	9.7[b]	13.0[b]

Results are means of 7, 13, 6 and 14 samples for Groups I, II, III and IV respectively.

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

[a] $p < 0.05$

[b] $p < 0.001$

C_1 and Cx activities are expressed as mg of reducing sugar per g of dry soil per 5 days (C_1) and 24 hours (Cx); B-glucosidase activity is expressed as mg of saligenin per g of dry soil per 3 hours.

were highest in those soils containing a significant amount of organic matter.

Table 17 shows that in the fertilizer treated material the Cx and B-glucosidase enzyme activities were significant or highly significant between the Group I and the other three groups. C_1 activity, however, was only slightly significant between Groups I and II, and Groups III and IV. No significant difference in activity was found between the mineral soil groups, II and III.

After fertilization and incubation (64 days at 25°C), enzymatic activity generally increased. The Cx activity increased eightfold in the highly organic Group I and Group IV materials, and up to 15 times in the sandy Group II material. The results indicate that enzyme activity is closely related to the organic matter content of the material.

6.2.2.3 Relationship between cellulolytic enzyme activity and organic carbon content in stored peat materials.

The influence of organic carbon on enzyme activity was calculated based on the correlation factor which was presented in Table 18.

The cellulase C_1 activity in surface and subsurface materials was highly significantly correlated (r = 0.71) with the organic carbon of stored peat materials in the control sample (Figure 17).

Cx activity was only slightly significantly correlated (r = 0.58) with the organic carbon in surface but non-significantly correlated in subsurface materials (r = 0.36) (Figure 18).

B-glucosidase activity in the surface and subsurface material was highly significantly correlated (r = 0.73 and 0.89) with the organic carbon (Figure 19).

Table 18. Correlation of cellulase (C_1), carboxymethylcellulase (Cx) and B-glucosidase activities with the factor of total carbon content in stored peat material.

Enzyme Activity	Horizon	d.f.	Correlation Coefficients r	Standard Error
C_1 control	surface	17	0.71^{c}	0.49
	subsurface	19	0.71^{c}	0.81
treated	surface	16	0.65^{b}	0.64
	subsurface	18	0.85^{c}	0.64
Cx control	surface	16	0.51^{a}	0.22
	subsurface	19	0.36^{NS}	0.86
treated	surface	17	0.04^{NS}	1.49
	subsurface	19	0.77^{c}	0.48
B-glucosidase control	surface	16	0.73^{c}	0.58
	subsurface	19	0.89^{c}	0.42
treated	surface	17	0.60^{b}	0.45
	subsurface	19	0.79^{c}	0.40

Results were obtained with samples from surface 10 cm and subsurface 40 cm of stored peat material.

NS = p 0.05

^{a} $p < 0.05$

^{b} $p < 0.01$

^{c} $p < 0.001$

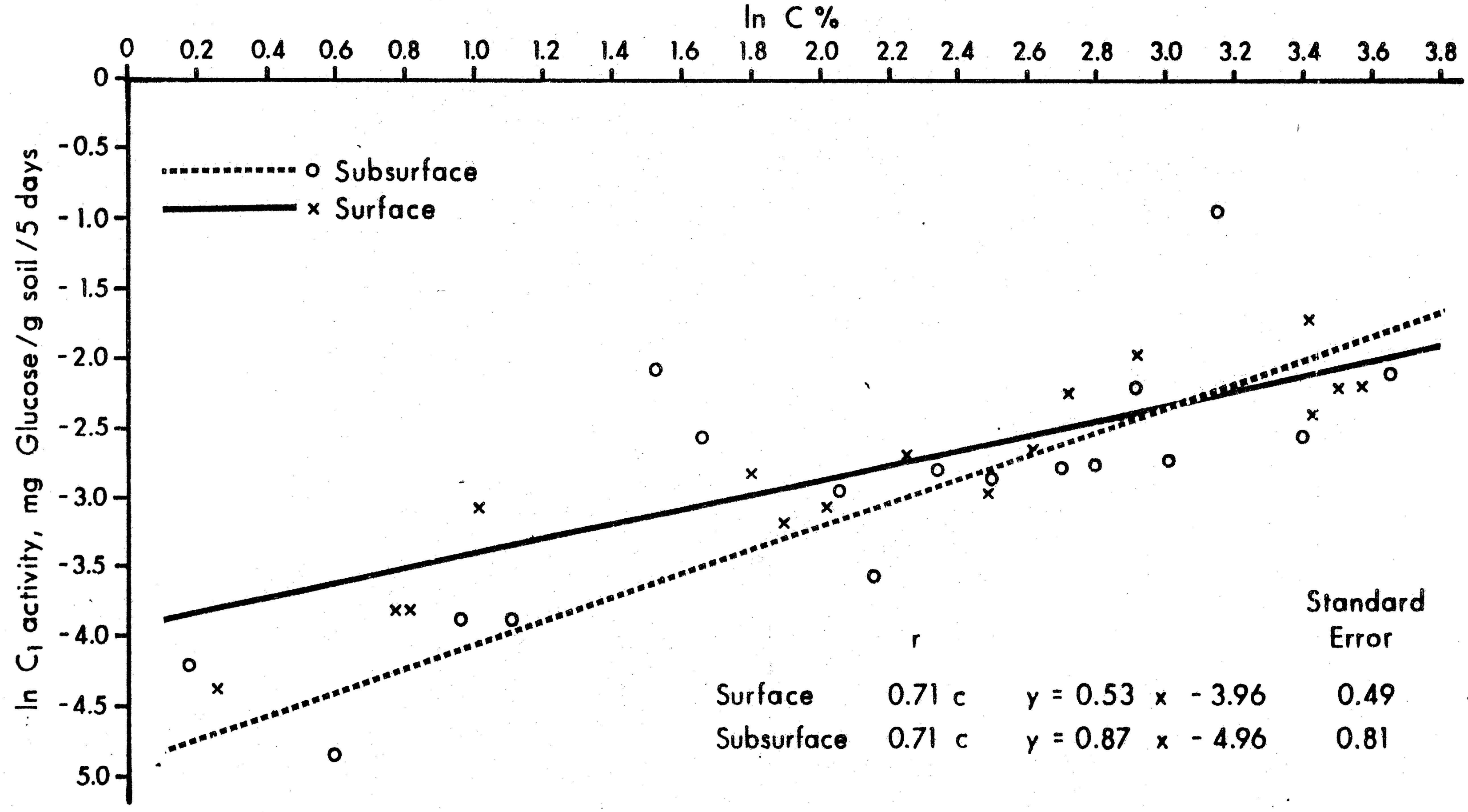

Figure 17. Relationship between cellulase activity (C_1) and carbon content in control stored peat material.

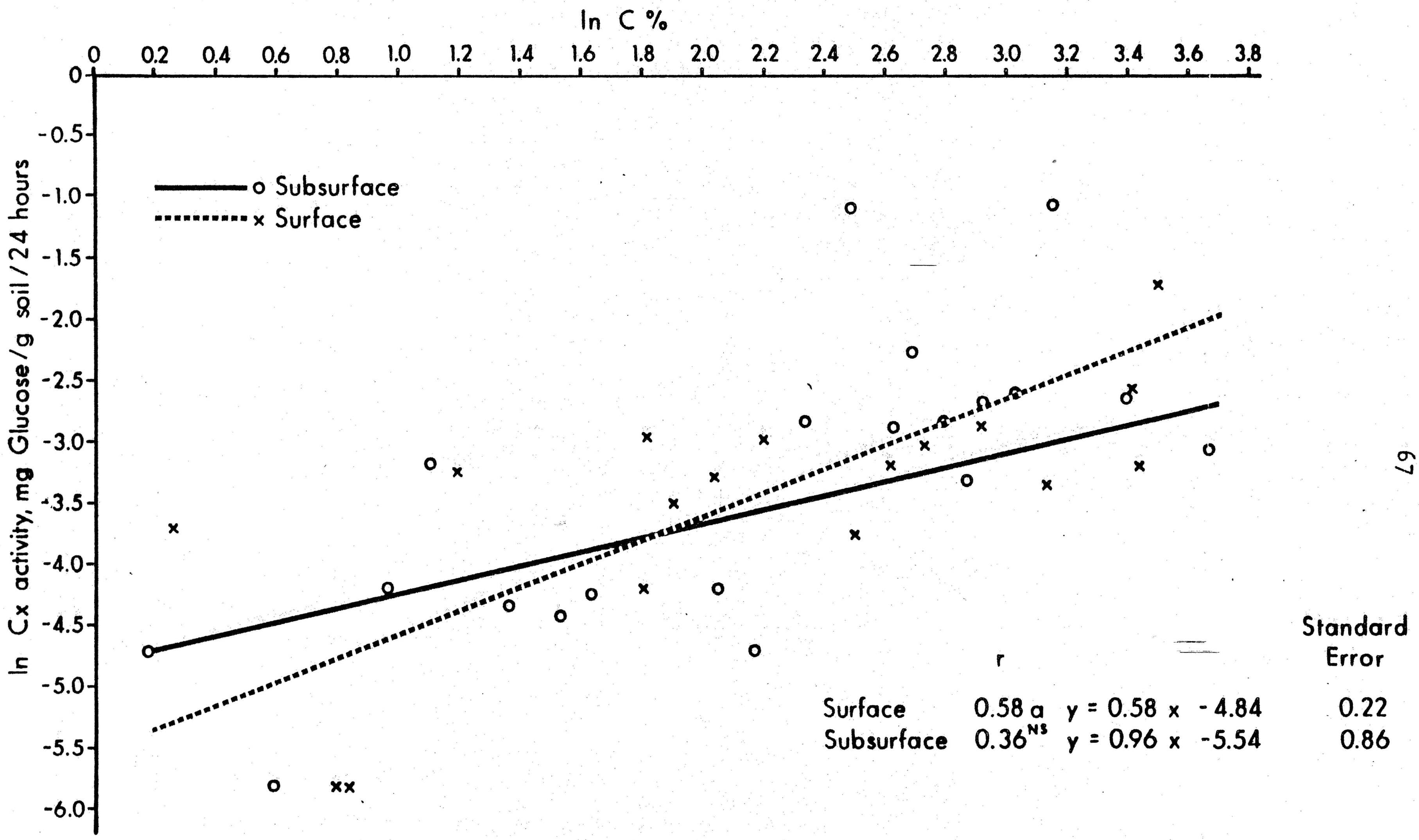

Figure 18. Relationship between carboxymethyl-cellulase activity (Cx) and carbon content in control stored peat material.

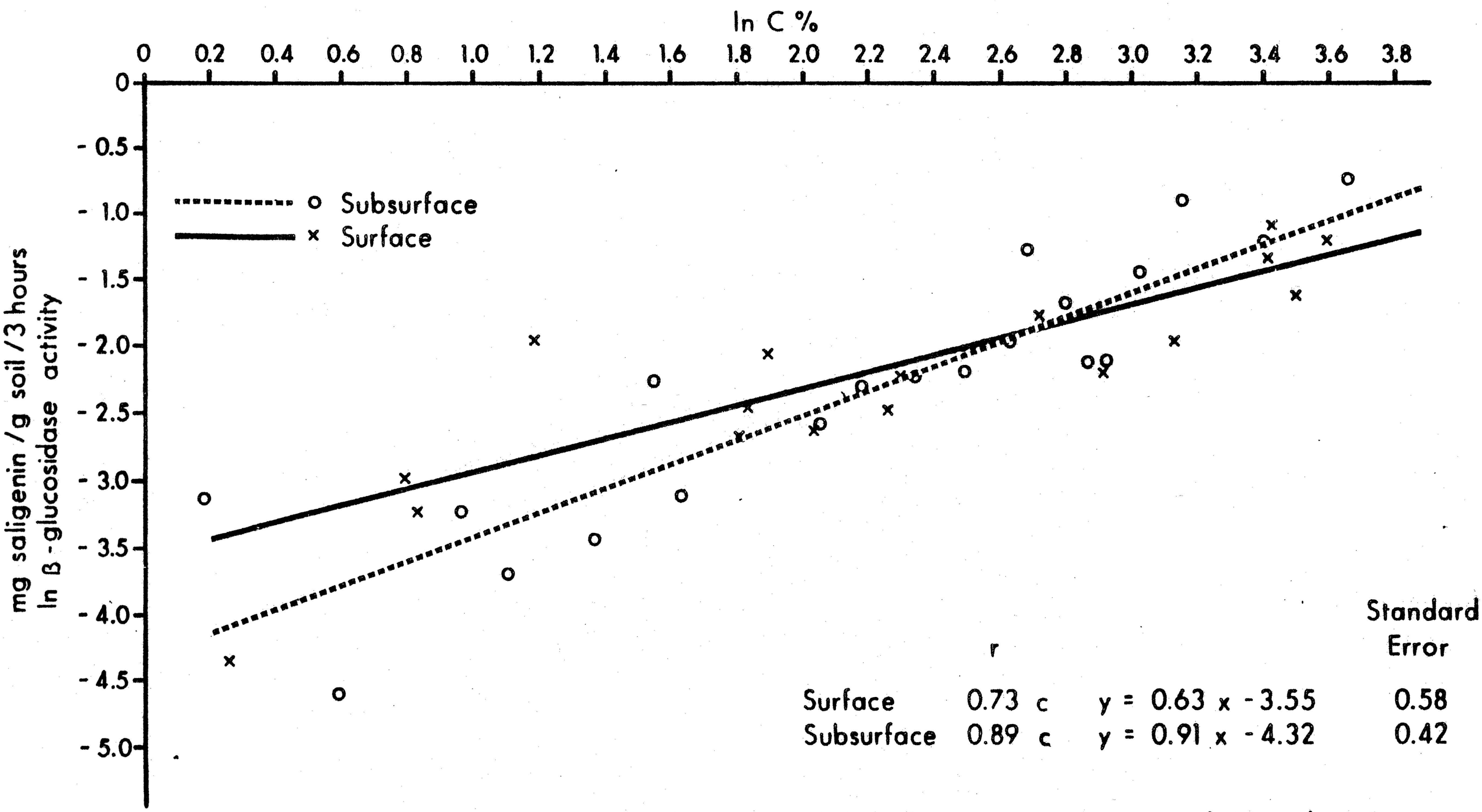

Figure 19. Relationship between B-glucosidase activity and carbon content in control stored peat material.

6.2.2.4 Effect of fertilizer treatment on the mineralization of carbon in stored material: The rate of mineralization of carbon was estimated by the amount of CO_2 produced during 46 days incubation at 25°C. CO_2 evolution was calculated on the amount of CO_2 in mg per gram of carbon content in the soil. Figure 20 shows the addition of cellulose powder (1%) and the potassium phosphate (100 ppm) had no affect on CO_2 production in all samples, but after adding ammonium sulphate (100 ppm of N), respiration rate increased at varying rates depending upon the type of stored material: peat predominant > peat-sand mixture > sand predominant > clay-sand mixture (Figure 20).

In general, the respiration rate was higher in the highly organic material than in mineral material. It would appear that the presence of fertilizer N was the main factor stimulating microbial activity.

In studying the relationship between the respiration rate and the total carbon content in stored material, the carbon content is important in controlling soil respiration rate (Figure 21) and the correlation coefficient in CO_2 production and carbon content was highly significant ($r = 0.74$) with 36 degrees of freedom in the untreated material; similar results were also obtained in the fertilizer treated material, showing a highly significant correlation coefficient with the CO_2 production based on the dry weight of soil.

It is possible that the organisms are dominant where the carbon content is highest. Such organisms may use the carbon as an energy source for synthesizing the microbial cell. This effect will be most obvious where fertilizer N is applied (Table 19).

6.2.2.5 Relationships between enzyme activity and soil respiration rate in stored peat material: Enzyme activity has a positive relationship with soil respiration rate (Table 20). On an organic carbon basis, the correlation

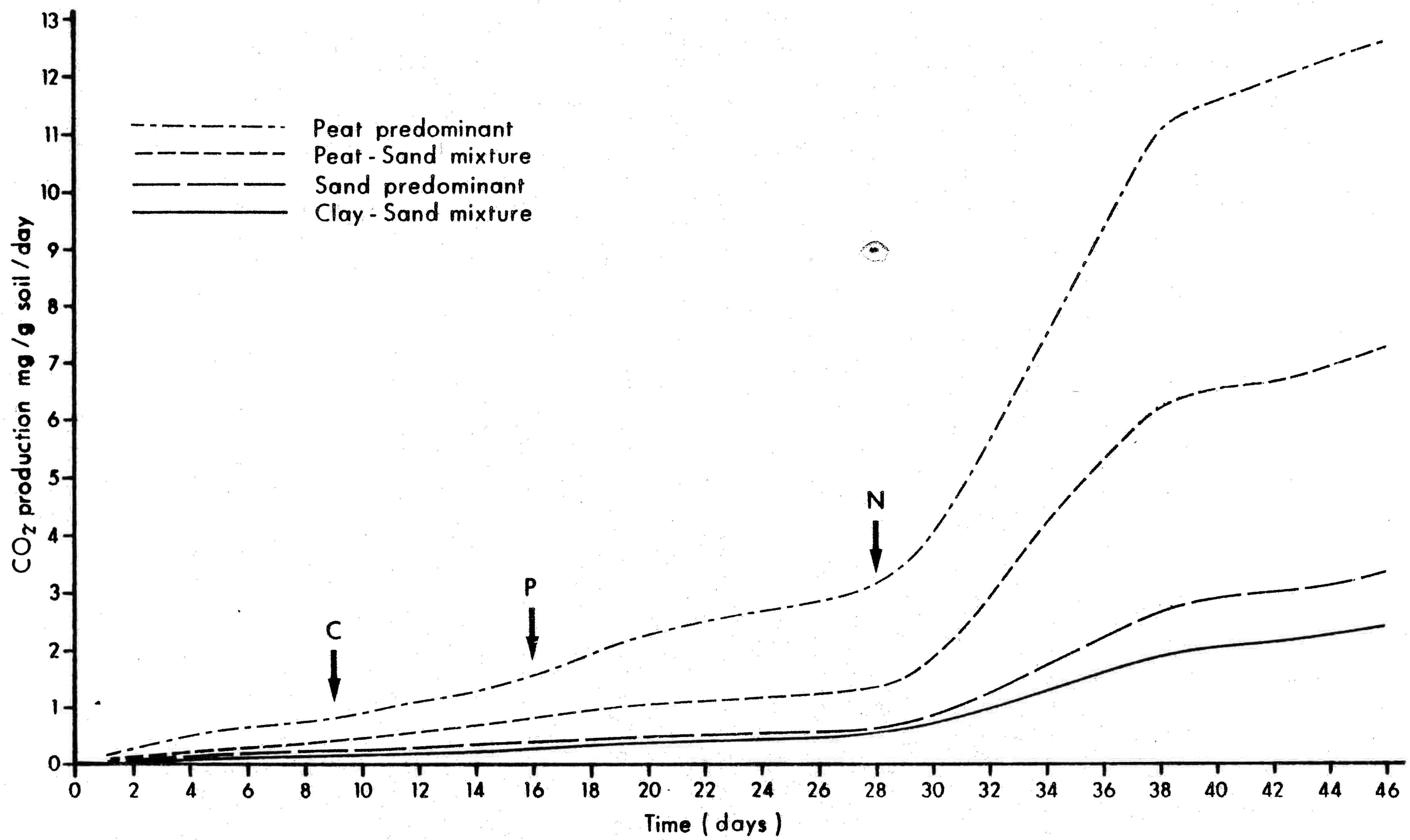

Figure 20. Effect of fertilizer (C: cellulose, P: K_2HPO_4, n: $(NH_4)_2SO_4$) on CO_2 evolution in four designated stored peat materials.

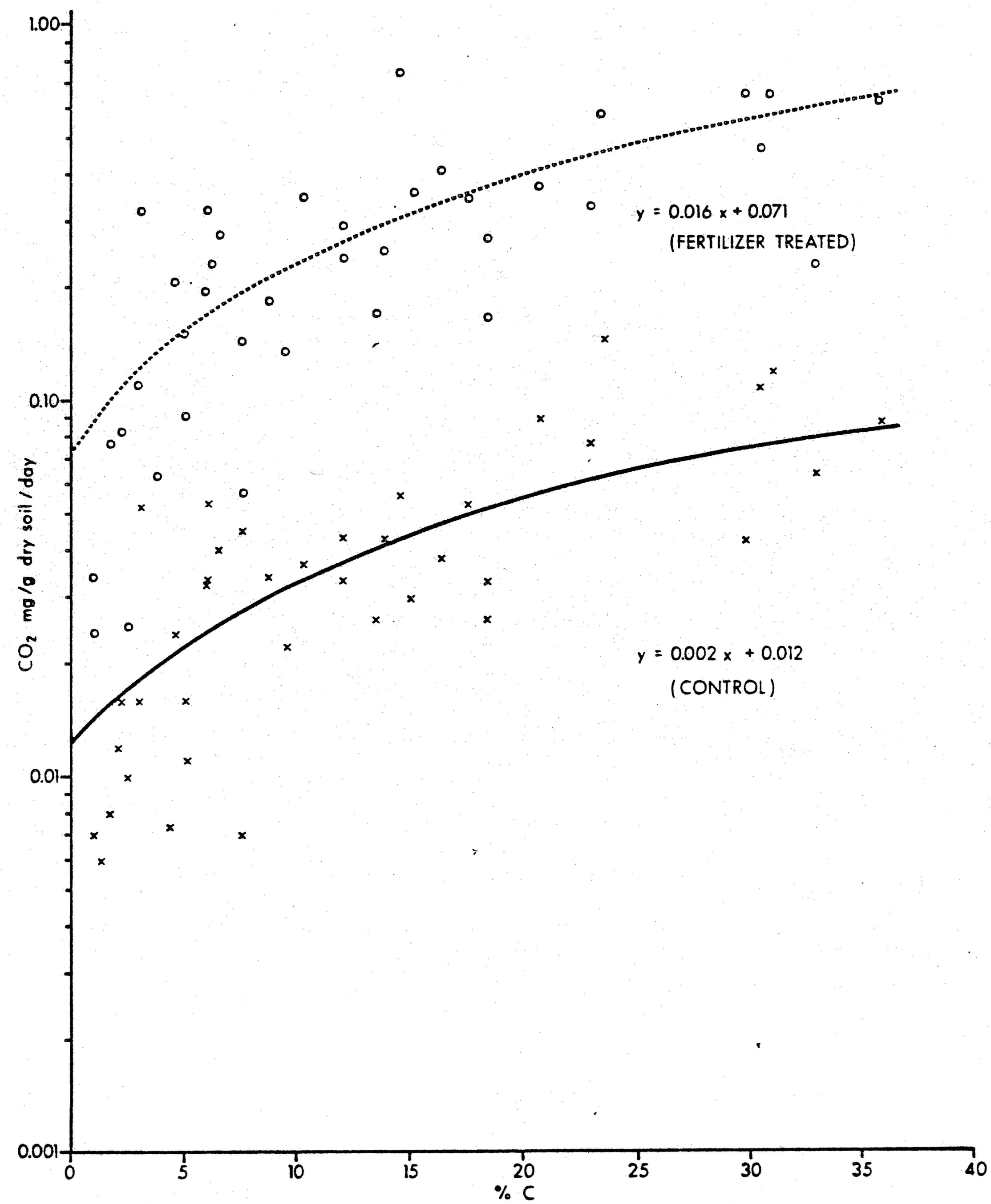

Figure 21. Correlation of soil respiration rated (based on dry weight) with organic carbon in stored peat material.

Table 19. Analysis of variance - the effect of fertilizer on CO_2 production of four stored peat materials.

Fertilizer Added	CO_2 Produced (mg/g of C/day)							
	Group I		Group II		Group III		Group IV	
		$S\bar{x}$		$S\bar{x}$		$S\bar{x}$		$S\bar{x}$
Control	0.297 (a)	0.06	0.597 (b)	0.09	0.376 (a)	0.08	0.286 (a)	0.03
+Cellulose	0.353		0.545		0.466		0.361	
$+K_2HPO_4$	0.397		0.455		0.440		0.292	
$+(NH_4)_2SO_4$	1.814	0.23	3.422	0.64	2.665	0.71	2.174	0.28

Mean in same row underlain by same letter not significantly different at 95% level.

Mean in same column joined by the same line not significantly different.

Table 20. Correlation of soil respiration rate with enzyme activity and carbon content in stored material.

Treatment	Variable: Independent	Variable: Dependent	r	Standard Error
Control	%C	CO_2/g C/day	0.74[c]	± 0.021
	C_1	"	0.44[b]	± 0.23
	Cx	"	0.35[a]	± 0.096
	B	"	0.22[NS]	± 0.065
	%C	CO_2/g soil/day	0.75[c]	± 0.001
Fertilizer treated	%C	CO_2/g C/day	0.79[c]	± 0.13
	C_1	"	0.08[NS]	± 0.106
	Cx	"	0.65[c]	± 1.26
	B	"	0.66[c]	± 1.24
	%C	CO_2/g soil/day	0.79	± .002

NS = non-significant

C_1 = Cellulase activity expressed as mg of glucose/g C/5 days.

Cx = Carboxymethylcellulase activity expressed as mg of glucose /g C/24 hours.

B = B-glucosidase activity expressed as mg saligenin/g C/3 hours.

[a] $P < 0.05$

[b] $P < 0.01$

[c] $P < 0.001$

coefficient between carbon content and CO_2 production was 0.74 in the control samples and 0.79 in fertilizer treated samples, both presenting a highly positive significant correlation at the 0.1% level. It is interesting to note that the enzyme activity shows a significant correlation with CO_2 production in these materials. In the control treatment, (non-fertilized), the positive correlation coefficient between C_1 and Cx activities with CO_2 production was 0.44 and 0.35 with 38 degrees of freedom. On the other hand, B-glucosidase activity was not significantly correlated with the CO_2 production (Table 20).

In fertilizer treated material, Cx and B-glucosidase activities were found to be highly significantly correlated with the CO_2 production. The only non-significant correlation was between C_1 and soil respiration rate. This would suggest that the increment of C_1 activity was not necessarily dependent on the addition of fertilizer. It would appear that the cellulose decomposer reacts on the stored materials with added fertilizer but at the same time depends on organic carbon to provide an energy source. Enzymatic activity also appears to have a slight influence independent of the carbon content to which it is also related (Figures 22, 23, 24). The standard error of CO_2/g C was reduced from 1.57 to 1.24 by using B-glucosidase activity in the fertilized treatment rather than relating it to %C. Similarly when expressed on a soil weight basis the standard error was reduced from 0.02 to 0.001 in the control treatment; the estimation of CO_2/g of C and CO_2/g of soil was not changed by using enzyme activity.

Also it can be suggested that the peat improves the physical properties of the stored material by increasing air capacity and maintaining the moisture holding capacity. Most of the organic decomposers are aerobic, requiring oxygen to oxidize organic matter, and an optimum moisture content to hydrolyse the complex organic compounds. The results also indicate that the original relatively inactive peat material, after being incorporated with the stored material, becomes a biologically active inducer and plays a role in the preservation of the stored material.

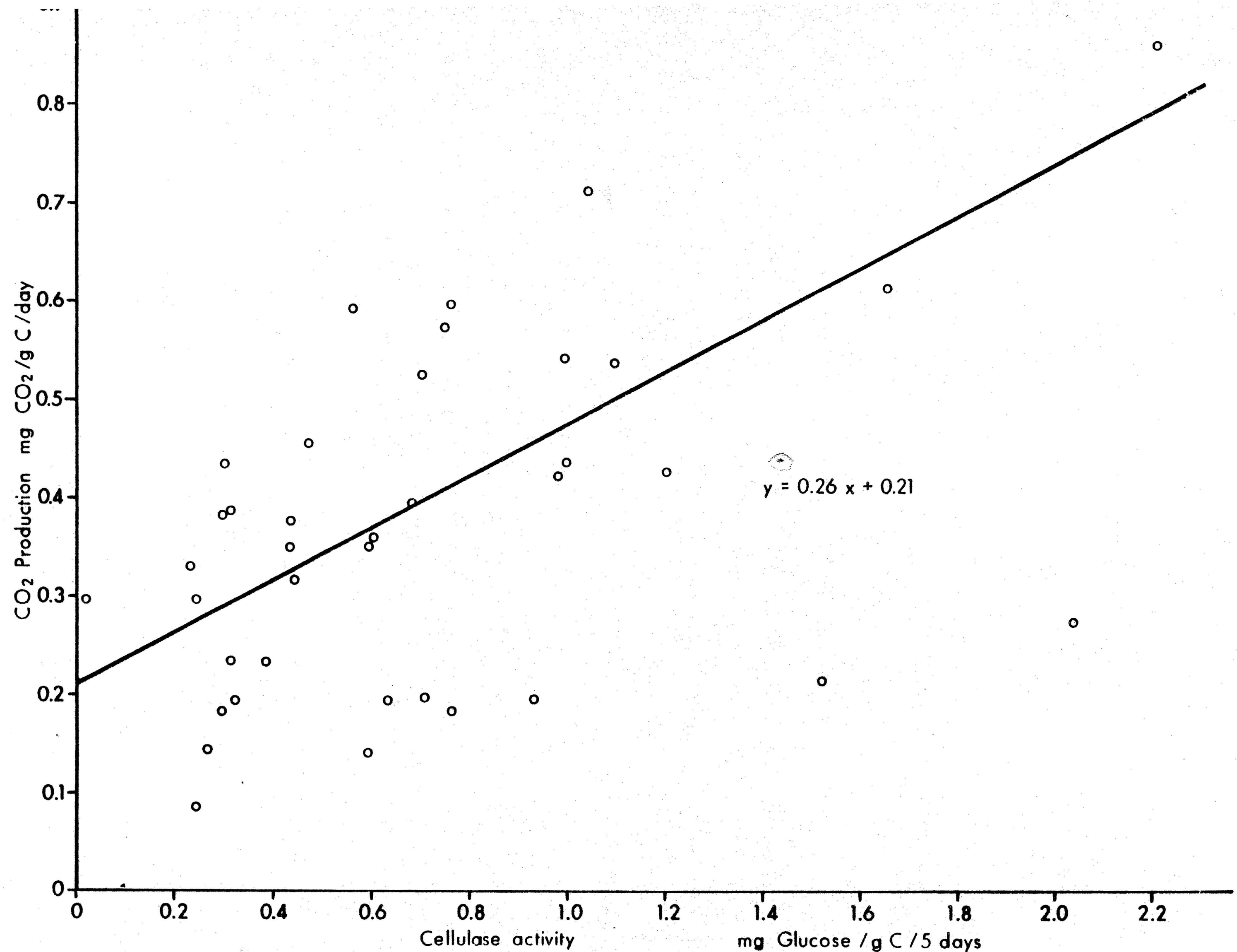

Figure 22. Relationship between respiration rate and cellulase (C_1) activity in control stored peat material.

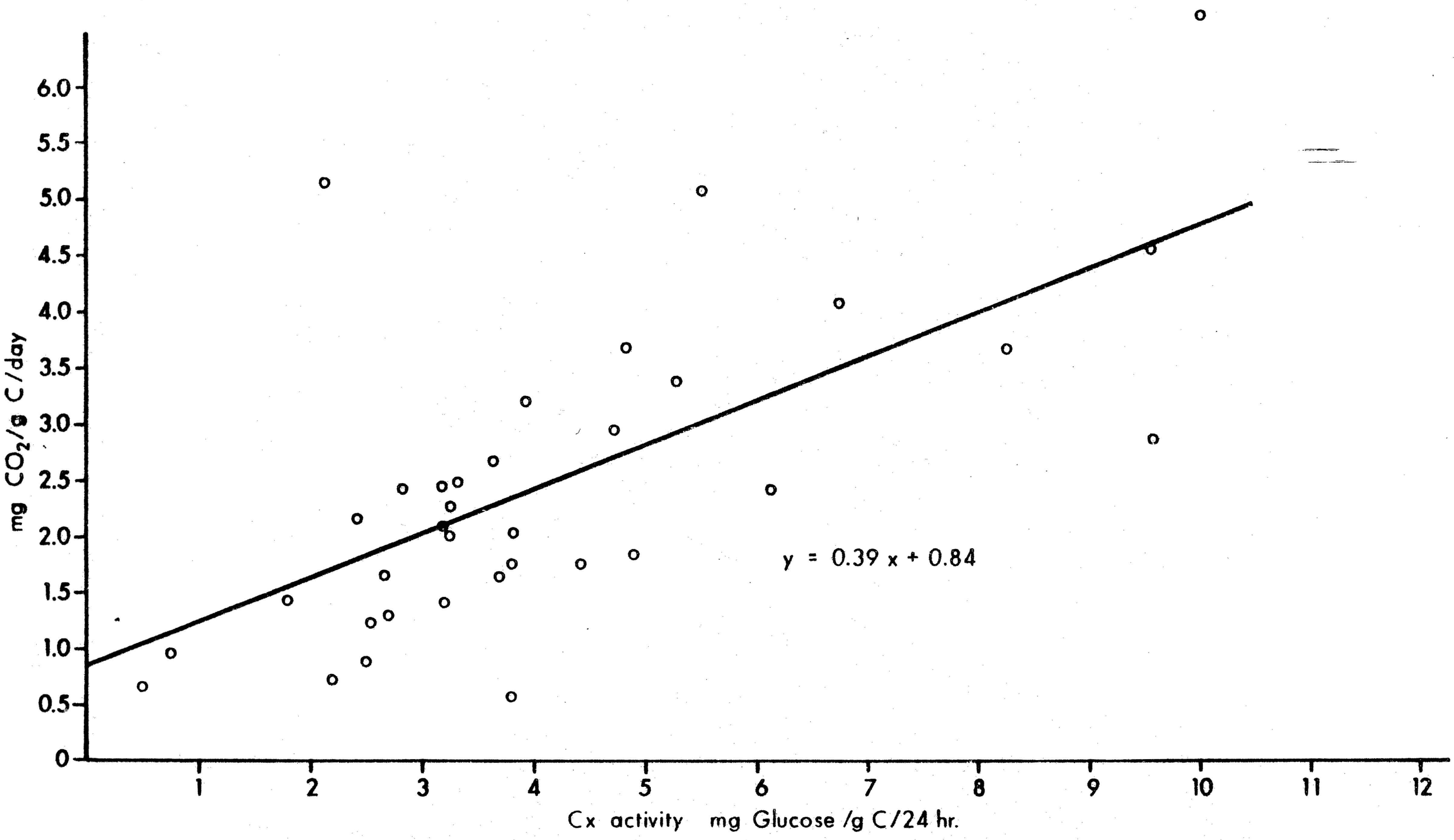

Figure 23. Relationship between respiration rate and carboxymethyl-cellulase activity (Cx) in treated stored peat material.

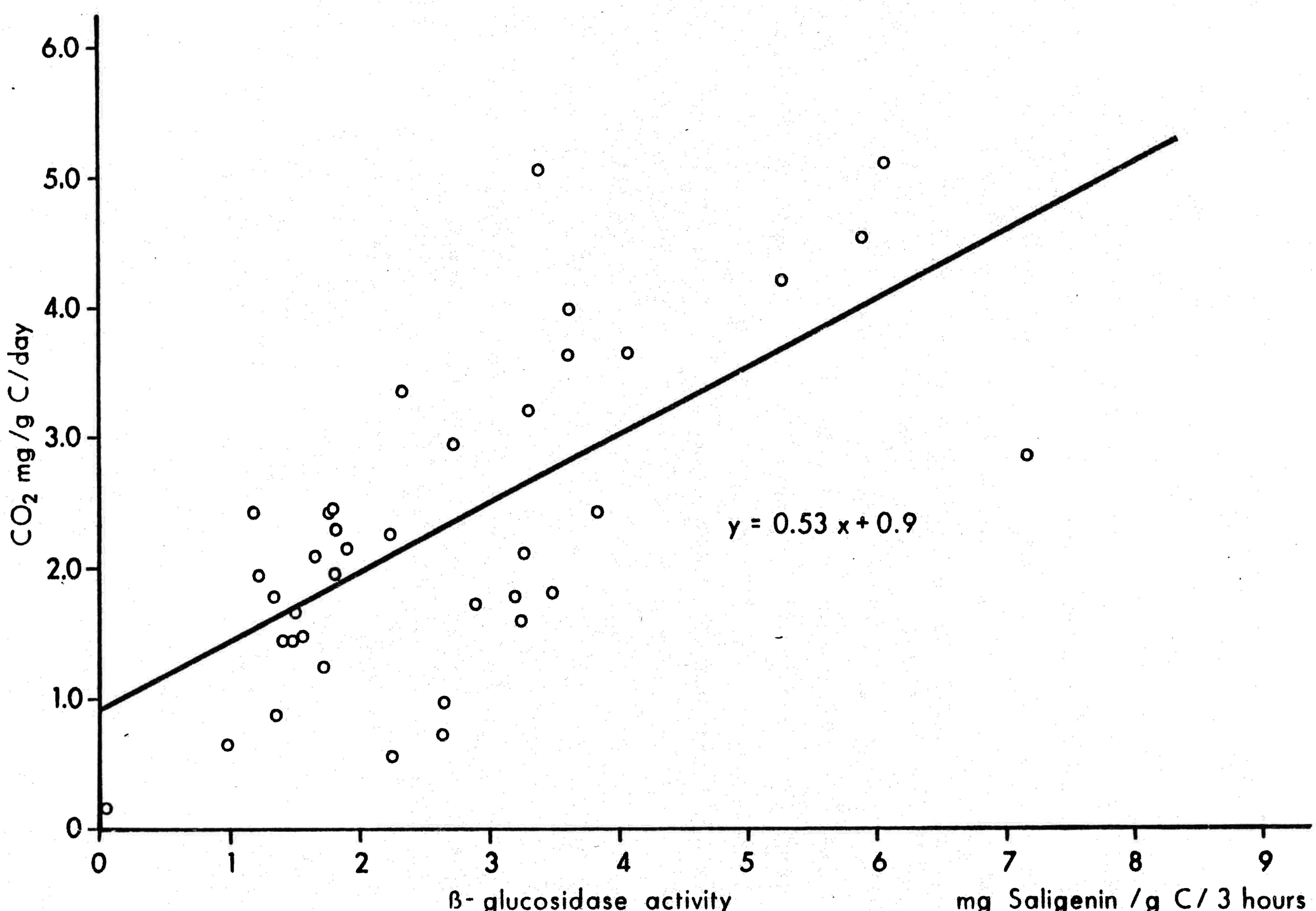

Figure 24. Relationship between respiration rate and B-glucosidase activity in treated stored peat material.

7. GENERAL CONCLUSIONS

7.1 PART I

Generally the characteristics of the peats - fibric and mesic moss and fen from the Mildred Lake and Evansburg areas showed a range of physical and chemical properties. The fibric is the least decomposed in terms of fiber content and ash content. The fen peat has the lowest fiber content and highest ash content. In terms of bulk density the fibric peat is lowest indicating little decomposition as compared to the mesic moss and fen peat.

The fibric peat samples are the most 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 accounts for the higher pH values in the fen peat. In terms of base saturation, the fibric moss is relatively base unsaturated as compared to the fen peat. The mesic peat is intermediate between the two.

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

In examining the various peats, the microbiological populations are highest in the fen peat and lowest in the fibric moss. The relatively low pH values and low nitrogen content probably limits the microbiological activity in the fibric peat.

The enzyme activity and O_2 uptake correlates with the microbiological population. It is lowest in the fibric and mesic moss peats and highest in the fen peat.

7.2 PART II

Drying affects most of the physical properties of peat. Bulk density was increased in fibric and mesic moss peat but it had a negligible effect on the 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 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 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.

7.3 PART III

Based on the Kononova (1961) temperature criteria for microbial activity, optimum conditions occurred for the longest period near the surface and decreased with depth. At Evansburg, optimum conditions extended over a 93 day period at the 7 cm depth, 49 days at 20 cm and 31 days at 50 cm. At depths of 100 and 200 cm the temperature did not reach an optimum level at any time of the year.

In terms of optimum moisture content using the Kononova criteria, maximum microbial activity occurred at the 50 cm depth at Evansburg in the spring and fall but at Mildred Lake, where a cover crop was sown, the optimum conditions continued from mid June to late November.

In general it would appear that in the storage piles at Evansburg and Mildred Lake optimum conditions for microbial activity occur during the summer months near the surface of the piles and decreases with depth.

The cellulolytic activity, as measured by the decomposition of imbedded filter paper in the storage pile at Mildred Lake, is greatest near the surface and decreases with depth. By comparison, there was little evidence of decomposition of filter paper in any portion of an undisturbed peat area near the storage area. The cellulolytic activity in the storage pile can probably be attributed to the incorporation of inorganic material, fertilization and optimum temperature and moisture conditions at the storage site.

Based on laboratory analysis of organic matter content and proportion of inorganic material some 40 samples from the Mildred Lake storage area were classified into four groups: Group I - peat predominant; Group II - sand predominant; Group III - sand/clay mixture; and Group IV - peat/sand mixture. The results of these analyses indicated the extremely heterogeneous nature of the stored material.

The chemical, microbial and enzyme activity data for the four groups suggests that each group has properties of practical significance. The Group I category has a relatively high cation exchange capacity and exchangeable calcium and magnesium, and nitrogen and carbon contents as compared to the other groups, particularly Groups II and III. These latter two groups are predominantly mineral material. Such properties indicate that as a reclamation amendment the Group I soils will be superior in terms of plant nutrient retention against leaching, moisture holding capacity and air capacity. The enzyme activity is highest in Group I (Table 17) suggesting that the biological activity is relatively high. Such material will likely result in improved mineralization, not only of nitrogen but also of other available mineral constituents.

The enzyme activity in surface (0 to 10 cm) and the subsurface samples (40 to 50 cm) was not significantly different. However following fertilizer treatment, enzyme activity increased in all samples.

In studying the relationship between enzyme activity and carbon content the results indicate a highly significant correlation between both C_1 and B-glucosidase and total carbon content. Also in comparing enzymatic activity and CO_2 evolution in laboratory samples the C_1 and Cx activities positively correlated with CO_2 production but the B-glucosidase activity was not significantly correlated.

Carbon is an important element in controlling soil respiration rate. An investigation of the 40 samples from the Mildred Lake storage area gave a highly significant correlation ($r = 0.74$) between CO_2 production and carbon content. This correlation occurred in both untreated and fertilized samples.

The addition of cellulose powder and potassium phosphate did not stimulate or increase CO_2 production. However, the addition of ammonium sulfate increased the respiration rate in all four groups of samples. This affect was particularly noticeable in those samples having the highest organic matter content - Group I and Group IV.

It would appear that microorganisms in stored material require not only mineral nutrients but also organic carbon as an energy source to synthesize the microbial cell. Most of the carbon in the stored material is derived from peat.

In general, undisturbed peat is relatively inactive in terms of microbial activity. By comparison the stored material is relatively active probably as a result of the incorporation of some mineral material, and in the case of the Mildred Lake material as a result of the addition of nitrogen fertilizers.

8. FUTURE PLANS

1. Continue monitoring of temperature and moisture regimes at Evansburg.
2. Continue peat decomposition studies - enzyme activities, microbial enumeration and CO_2 evolution (respiration rate).
3. Initiate a study to determine the fate of peat when mixed with tailing sands. This study would be concerned with the reaction of peat and tailing sands and other inorganic material (till, fluvial sands, Clearwater Formation). The purpose would not be to assess the value of peat as an amendment but rather to determine the effect of inorganic materials on peat after incorporation or during storage. Such material will likely affect decomposition rates, physical and chemical properties of the peat.
4. Initiate a study to determine the amount of lignin decomposition relative to cellulose content in peat. This study should provide data in regard to decomposition rates and changes in physical properties of peat. The material used would consist of "pure" peat samples and the heterogeneous mixture of peat and inorganic material presently being stockpiled at oil sands plants.
5. Consideration will be given to the occurrence and persistence of toxins produced during the storage period. Such toxins to include fatty acids, phenolic acid, methane, and waxes. At Evansburg, a comparison of toxic levels can be made between two peat piles; the two year old peat pile used for this study and an eight year old pile located on the property.
6. The Mildred Lake research site was lost to the project in December 1977 due to construction

activities. Therefore, an alternate site is required for the study. It is suggested that a new site be established adjacent to the Alberta Oil Sands Environmental Research Program Mildred Lake Research Facility. A research design for the experimental area is presently under consideration and will be presented to AOSERP management well in advance of the field season.

9. REFERENCES CITED

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10. APPENDICES

10.1 METHODS OF ANALYSES

10.1.1 Physical Properties

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

b. Bulk Density - Moist peat was placed in a two litre container and submerged for 24 hours. The container was then removed and allowed to drain through the bottom for two hours. The bulk density is reported as the oven dry weight of peat per unit wet 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 difference between the wet weight of peat and the dry weight. It was calculated from the equation of Puustjarvi, (1968).

Water capacity = wt. of wet peat - wt. of dry peat

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 hours 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. 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):

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

where: C = height of soil samples in cm

V = volume of water passing through the column

H = head, height of water column in cm

S = cross sectional area of tube in cm^2

10.1.2 <u>Chemical Properties</u>

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

b. Base Saturation - Base saturation is reported as the sume 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 1976).

c. Nitrogen - Total nitrogen was determined according to the semi-micro Kjeldahl procedure (McKeague 1976).

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

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

10.1.3 Microbiological and Biochemical Properties

a. Bacteria plate count - Heterotrophic bacteria were counted by plate counts. A soil dilution is spread on agar containing various nutrients and each viable bacterial cell will reproduce until a visible colony is formed. These are counted and the number of colonies converted to bacteria per gram oven dry weight. The medium used for plate counts in these experiments was Plate Count Agar (Difco).

b. Fungi plate count (Martin 1950) - The medium of rose bengal streptomycin agar:

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

Sterilize, cool, and add Streptomycin to give a concentration of 30 mg/ml.

c. Measure of CO_2 evolution - This was measured on 100g moist peat enclosed 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 0.10N 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 is calculated from the consumption of HCl by the formula:

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

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:

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

where: $C\text{-}CO_2$ = mg CO_2 by soil

C = total carbon content in soil

d. Enzyme activity

1. Extraction of C_1 activity in soil - 10 g of fresh soil was weighed and put into a 50 ml Erlenmeyer flask with 20 ml of phosphate buffer solution (M/15 Na_2HPO_4 and M/15 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.
2. Extraction of Cx activity in soil - The same procedure was followed as for C_1 activity extraction, except that carboxymethylcellulose (Sodium salt CMC-FHSP) was used as substrate and the incubation time was 24 hours.
3. Determination of reducing sugar - The reducing sugar was determined by employing the copper reagent method described by Somogyi (1945).
4. Determination of B-glucosidase activity - B-glucosidase activity was determined by the method of Hoffman and Dedeken (1965) using Salicin as substrate.

10.2 TREATMENT DATA - MILDRED LAKE SITE.

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

11. 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.	HE 2.4	Athabasca Oil Sands Historical Research Project. Volume I: Design
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.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 4.2.1	Review of Dispersion Models and Possible Applications in the Alberta Oil Sands Area
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
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37.	HE 2.2.2	Community Studies: Fort McMurray, Anzac, Fort MacKay
38.	VE 7.1.1	Techniques for the Control of Small Mammals: A Review
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40.	VE 7.1	Interim Report on Reclamation for Afforestation by Suitable Native and Introduced Tree and Shrub Species
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42.	TF 1.1.4	Analysis of Fish 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

These reports are not available upon request. For further information about availability and location of depositories, please contact:

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