Proceedings of the First Annual Workshop of the Vegetation Technical Research Committee

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AOSERP

PROCEEDINGS OF THE FIRST ANNUAL WORKSHOP OF THE VEGETATION TECHNICAL RESEARCH COMMITTEE - AOSERP

Introduction

The extraction of bitumen from the Athabasca Oil Sands can be considered successful only if workable and economically feasible methods of reclamation of the area following mining are developed. This is the purpose of the Alberta Oil Sands Environmental Research Program's Vegetation Technical Research Committee.

The Workshop reported on in these proceedings gave the Project Leaders and their personnel an opportunity to:

a) discuss their research approach and methodology,
b) discuss their results to date, and
c) discuss their future research plans.

The papers presented here by no means cover the full extent of the Committee's research and result details to date, due to time considerations at the Workshop. They do, however, provide a good overview of the direction and reasons for direction of the research as it is being undertaken.

The editors wish to take this opportunity to thank Dr. G.T. Silver, Director of the Northern Forest Research Centre, for providing facilities for the Workshop. We would also like to thank Mr. F.W. McDougall, Chairman of the Vegetation Committee, for his opening remarks and chairing of the Workshop, Dr. A.H. Legge, University of Calgary, for his closing summary, and all participants who helped to make the Workshop a success.

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Project Leader: J.D. Lindsay
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VE 2.3 Vegetation Inventory of the Oil Sands Area
Project Leader:
Agency:

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Agency: Forest Land Use, Alberta Energy and Natural Resources

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SOILS INVENTORY OF THE OIL SANDS AREA

H. Yuksel and J.D. Lindsay

The project area covers some 11,000 square miles (approx. 2,800,000 ha) in the northwestern portion of Alberta (Fig. 1). This area is encompassed by townships 84 to 104 and ranges 6 to 18; and townships 105 to 115 and ranges 6 to 9, west of the 4th meridian. It is divided into three parts, depending upon the importance of their potential for the development for the crude oil production. These areas and their priorities are shown in Figure 2.

Physiography and Topography

Within the boundaries of the project areas there are two major physiographic regions of North America - the Canadian Shield and the Interior Plains.

The Canadian Shield is underlain by rocks of Precambrian age and is found in the northeast corner of the project area. This small area is the part of the Kazan upland which covers a wide expanse of rolling, lake spattered country. This region consists of great areas of massive rocks that form broad, sloping uplands and plateaux in the western portion of the Canadian Shield. The area slopes gently toward Lake Athabasca and the highest point seldom reaches 1,000 feet in elevation with relief rarely more than 200 or 300 feet (7).

The Interior Plains are underlain by flat-lying Paleozoic and Mesozoic strata. Most of the project area is found within this physiographic region which can be divided into several units. The Alberta High Plain is composed of Cretaceous sediments and is found west of the Athabasca River. On the north, the Birch Mountain Upland forms a high, disconnected escarpment with summits up to 3,000 feet in elevation, overlooking the Great Slave Plains to the south. A small portion of the Stony Mountain Upland is also found in the southeast corner of the project area. In between, Algar Plain forms a low lying gently undulating landscape which rises up to 1,600 feet in elevation form the Athabasca River towards the southwest corner. The eastern edge of the Alberta High Plain constitutes a step down to the Saskatchewan Plain, which is formed on Mesozoic sediments. This plain is lower and smoother than the Alberta High Palin. Although Muskeg Mountain can reach up to 1,500 feet, gently undulating Clear Water Lowland is usually less than 1,000 feet inelevation. A small portion of the Methy Portage Plain is also found between the Stony Mountain Upland and Clearwater Lowland. The third unit of the Interior Plains is the Athabasca Delta Plain which is underlain by rocks of Paleozoic age. This is a gently undulating plain with a very low local relief. Low scarps of resistant carbonate strata and small shallow lakes are characteristic of this unit. The elevation is generally below 1,000 feet (7).

The general physiographic divisionn of the project area is shown in Figure 3.

Present Studies

Field Work

The soil survey study of the project area was initiated in May, 1976, with the objective of characterizing and mapping the soils of the area at reconnaissance level. Consideration was given to the existing information relating to the soils and surficial geology. All the existing data was gathered and the 1:50,000 scale panchromatic black and white aerial photographs (about 900) were ordered from the National Aerial Photo Library in Ottawa in early June. These 1974 photographs cover approximately 2/3 of the project area (Fig. 4). In mid-June, a short familiarization field trip was taken.

During this trip soil inspections were made along all improved roads in the area. The aerial photographs were received from Ottawa in late June. Before the field season started, a general photo-interpretation of the southern part of the priority area was undertaken (Fig. 5). Major breaks in the land surfaces were delineated and the types and nature of the surficial deposits were determined. In addition, points and transects on which field sampling should be carried out were selected. Transects were selected to cross boundaries on pretyped aerial photographs and were intended to cover representative soil types, both well and poorly drained. In late July and August, extensive use was made of a helicopter to land on those selected seismic cutlines. In addition numerous spot checks were made by helicopter in remote areas. The soils were systematically studied in pits. The arrangement, thickness and texture of soil horizons, characteristics of the landscape and other useful information was recorded on specially designed computer sheets for future data handling. Soil samples were collected from the profiles considered representative of the different soil types. In total 78 soil samples were collected and approximately 400 soil sites were visited and described. After the initial photo interpretations were correlated with the field observations, soil boundaries were transferred to 1:50,000 topographic maps. The area mapped and classified so far is approximately 420,000 ha or 15% or the project area (Fig. 5).

Soil Mapping

The area to be mapped extends over a large, inaccessible wilderness region. Besides the regional climatic differences, the area represents very heterogeneous landscape as far as the parent material is concerned. In addition, the groundwater discharge from the adjacent uplands creates drainage problems and very complex soil patterns, especially in the central portion of the project area. All of these factors, therefore, present a considerable problem for the rapid and accurate presentation of the soil information in a relatively short time. Most of the above problems are believed to be overcome by accepting the Biophysical land classification criteria as a guideline for this reconnaissance survey.

Biophysical land classification has to rely on the use of aerial photographs and air photo interpretation techniques combined with supporting patterns of soils, landform, vegetation and water. This approach eliminates the possiblity of mapping in detail certain components of the soil and vegetation combinations of the landscape. Previous biophysical studies in Canada have led to the establishment of a relatively uniform methodology for carrying out this type of classification. Although there are some modifications of the method proposed and defined by Lacate (1969) (18), the hierarchy of the four basic classification units is still widely used. In this study, the approach will be patterned after that of Lacate, but some minor modifications will be made as suggested by various studies (22). All levels of classification are used, except that of land type, which is outside the scope of this study. In addition, the "land region" concept is modified and a new concept of "subregion" is introduced as suggested by various authors. The basic product of this study will be a land system map at a scale of 1:250,000. Although the ground checks and samplings are carried out at the "land type" level, these units will not be described in the final report. Instead they will be used to produce a "land system" map. Land system units, in turn, will be grouped into land districts on the basis of general physiographic features. Furthermore, land districts will be grouped into subregions on the basis of physiographic features and vegetation. Similarly, subregions will be grouped to produce land regions on the basis of climate, soil and vegetation. It can be seen from the above descriptions that the approach proposed here works from the lower levels of classification to the higher levels. It is believed that this is the most logical approach to the problem as the precise boundaries for the higher levels of classification become really meaningful only after a study of interrelationships in patterns of land types and land systems. However, a preliminary separation of the project area at the land regions and subregions level has been made at the initial stage of the study to provide a basis for the further separation of lower levels of classification. These separations are made purely on the existing data on climate, vegetation and soil. However, they will be modified as further information becomes available during the during the course of the biophysical survey.

<u>Land region</u> is defined as "an area of land with a certain type of vegetation which reveals a distinct regional climate". It is usually of large areal extent, and often includes several distinctive landscapes. Therefore it is more or less heterogeneous. In this study the broad land regions will be defined on the basis of dominant soil, vegetation and climatic data. The broad vegetation zonation will be after Rowe (25) and the soil characteristics will be derived from exploratory surveys of the area carried out by the Research Council of Alberta (19, 20, 21).

<u>Land subregions</u> are the subdivisions of land regions on the basis of vegetation, soil and major physiographic characteristics of the landscape. Although they have common patterns of soils, vegetation and physiographic structure, they are still very broad units and are more or less heterogeneous.

<u>Land districts</u> are defined as "a distinctive pattern of relief, geology, geomorphology and associated regional vegetation" (220). It is a subdivision of subregions based primarily on the separation of major physiographic patterns which characterize the subregion as a whole.

<u>Land systems</u> is the next lower level in this classification, rather than "soil associations" as suggested by Lacate (22). The physiographic districts were subdivided into land systems on the basis of soil profile characteristics, texture of the top meter of soil, and overall drainage. In most cases, each system has one soil order as dominant, but may have significant members of others. The parent material of each system is also defined. Therefore, the land system concept accepted here is a catenery sequence, reflecting differences in drainage and topography on a relatively homogeneous parent material. The main soil classification concept in this study in the "Soil Great Group" and Subgroups. No attempt was made to use lower level classification units as the intensity of sampling is somewhat restricted by inaccessibility and insufficient time.

Guidelines for the Preliminary Studies

Classification and Mapping Procedures

For a reconnaissance study of this type of survey, it is desirable to map certain combinations or patterns of the landscape which can be easily recognizable on aerial photographs and in the field. For the sake of convenience, four major physiographic districts were separated on the basis of major differences in relief and geomorphic origin:

A - Lacustrine plains
B - Eolian sand plains
C - Glaciofluvial sand plains
D - Morainal uplands

Within each district, soil associations were identified and mapped separately whenever possible. Soil associations were also subdivided into mapping units on the basis of the relative proportion and types of profiles occurring in each delineated area on the map. These map units usually represent different topography and drainage conditions within each system. Vegetation, usually but not necessarily, is part of the mapping unit, as changes in drainage are generally reflected in changes in the vegetation community.

Conventions Used in Mapping

1. Organic soil - this is soil material of organic origin greater than 60 cm thick if fibric peat or greater than 40 cm thick if mesic peat.
2. Peaty phase - this is used for gleysolic soils that have a surface organic layer thicker that 15 cm but less than that required for an organic soil.
3. Dominant Soil - this refers to the relative proportion of soil subgroup profiles as they occur in a map unit. They occupy over 40% or the unit.
4. Significant Soil - this refers to the relative proportion of soil subgroup profiles which occupy more than 15 but less than 40% of the unit.
5. Veneer - shallow parent material which is less than 1 m thick over another type of material.
6. Complexes - complexes of two land systems can occur. In this case the first system is dominant and the second system is significant.

Mapping Units

Glaciolacustrine Plain Physiographic District

This physiographic district consists of soil developed on materials deposited in glacial lakes. These landscapes usually consits of fine textured materials which were transported by streams into lakes bordering a glacier which has since disappeared. The following land systems are recognized and mapped:

Gl.1 Dominantly Gray Luvisols, with minor inclusion of gleyed Gray Luvisols.
Gl.2 Dominantly Gray Luvisols and gleyed Gray Luvisols, and significant gleysols.
Gl.3 Dominantly Rego Gleysols and significant Organic; minor inclusions of Gray Luvisols and gleyed Gray Luvisols.

Eolian Sand Plain Physiographic District

This district consists of landscapes that are found on generally medium to fine sand and coarse silt particles that are well sorted and poorly compacted. Generally, but not necessarily, dune forms are visible on the aerial photographs. The following land systems are recognized and mapped:

1) Soils developed on eolian sands:
Eo.1 Dominantly Eutric Brunisols; with minor inclusions of gleyed Eutric Brunisols and Gleysols.
Eo.2 Dominantly Eutric Brunisols and gleyed Eutric Brunisols, significant Gleysols, minor inclusions of Organics.
Eo.3 Dominantly Rego Gleysols and significant Organics; minor inclusions of Eutric Brunisols and gleyed Eutric Brunisols.
2) Soils developed on eolian veneer: (over glaciolacustrine)
Eov.1 Dominantly Eutric Brunisols and gleyed Eutric Brunisols, and significant Gleysols and Organics.
Eov.2 Dominantly Rego Gleysols and Organics; minor inclusions of gleyed Eutric Brunisols and Eutric Brunisols.

Glaciofluvial Sand Plain Physiographic District

This district consists of landforms which are produced by meltwater streams associated with and flowing from wasting glacier ice. Such stratified sediments are classed as outwash sediments. They include stratified materials, mainly well sorted sands and gravels deposited by streams.

1) Soils developed on sand and gravelly deposits of abandoned beaches:
Be.1 Dominantly Eutric Brunisols, with minor inclusions of gleyed Eutric Brunisols and Gleysols.
Be.2 Dominantly gleyed Eutric Brunisols and Eutric Brunisols, and significant Gleysols; minor inclusions of Organics.
Be.3 Dominantly Gleysols, and significant Organics; minor inclusions of gleyed Eutric Brunisols and Eutric Brunisols.
2) Soils developed on coarse textured outwash deposits:
Gf.1 Dominantly Eutric Brunisols with minor inclusions of gleyed Eutric Brunisols and Gleysols.
3)Soils developed on kame deposits:
Ka.1 Dominantly Eutric Brunisols with minor inclusions of gleyed Eutric Brunisols.
4) Soils developed on coarse textured, gravelly and bouldery meltwater channel deposits:
Me.1 Dominantly Eutric Brunisols; minor inclusions of gleyed Eutric Brunisols and Gleysols.
Me.2 Dominantly gleyed Eutric Brunisols and Eutric Brunisols, and significant Gleysols and Organics.
Me.3 Dominantly Gleysols and Organics; minor inclusions of Eutric Brunisols and gleyed Eutric Brunisols.

Morainal Upland Physiographic Districts

These districts consist of landscapes found on glacial till. These sediments generally consist of well compacted material that is non-stratified and contains a hetergeneous mixture of particle sizes, often in a mixture of sand, silt and clay that have been transported by a glacier, and are not modified by any intermediate agent.

1) Soils developed on medium textured till:
Tk.1 Dominantly Orthic Gray Luvisol; minor inclusions of gleyed Gray Luvisol and Gleysols.
Tk.2 Dominantly Orthic Gray Luvisols, significant gleyed Gray Luvisols and Gleysols; minor inclusions of Organics.

Tk.3 Dominantly Rego Gleysols and significant Organics; minor inclusions of gleyed Gray Luvisols and Gray Luvisols.

Organic Soils

There are two principle types of organic soils in the area: Bogs and Fens. They occur in separate, distinct areas, but commonly associated with mineral soils, occurring in depressions on very poorly drained gently slopes.

1) Bogs:

They are generally raised moss bogs that rise above the surrounding terrain and thus rely on precipitation for moisture and nutrients.

Bo.1 Dominantly Mesisols and Terric Mesisols on various material. (No attempt has been made to separate the different underlying material.) Minor inclusions of Gleysols and/or Fens.

2) Fens:

Fe.1 Dominantly Fen peat; minor inclusions of Bogs and/or Gleysols.

Miscellaneous Land Systems

A Alluvium: These are deposits of alluvial sand, silt and gravel occurring adjacent to the major rivers and streams. No attempt has been made to map different landforms on alluvial plains.

Co Colluvium: The colluvium unit includes areas that have accumulations of loose, heterogeneous material deposited by mass wasting at the base of steep slopes.

RB Rough Broken Lands: These include thin colluvial cover on steep valley slopes and some thin alluvial material along strems.

DL Disturbed Land: These are lands which are disturbed by the activities of man.

Literature Search

The following literature was extensively reviewed in order to obtain better information on the history and the general characteristics of the project area:

- History and the general description of the area: 1,6,12,14,16,23
- Preliminary studies: 17,24
- Geology: 10,12,13,15,26
- Surficial geology: 2,3,4,5,
- Physiography: 7
- Climate: 28,30
- Vegetation: 25
- Soils: 8,9,18,19,20,21,22,27,29.

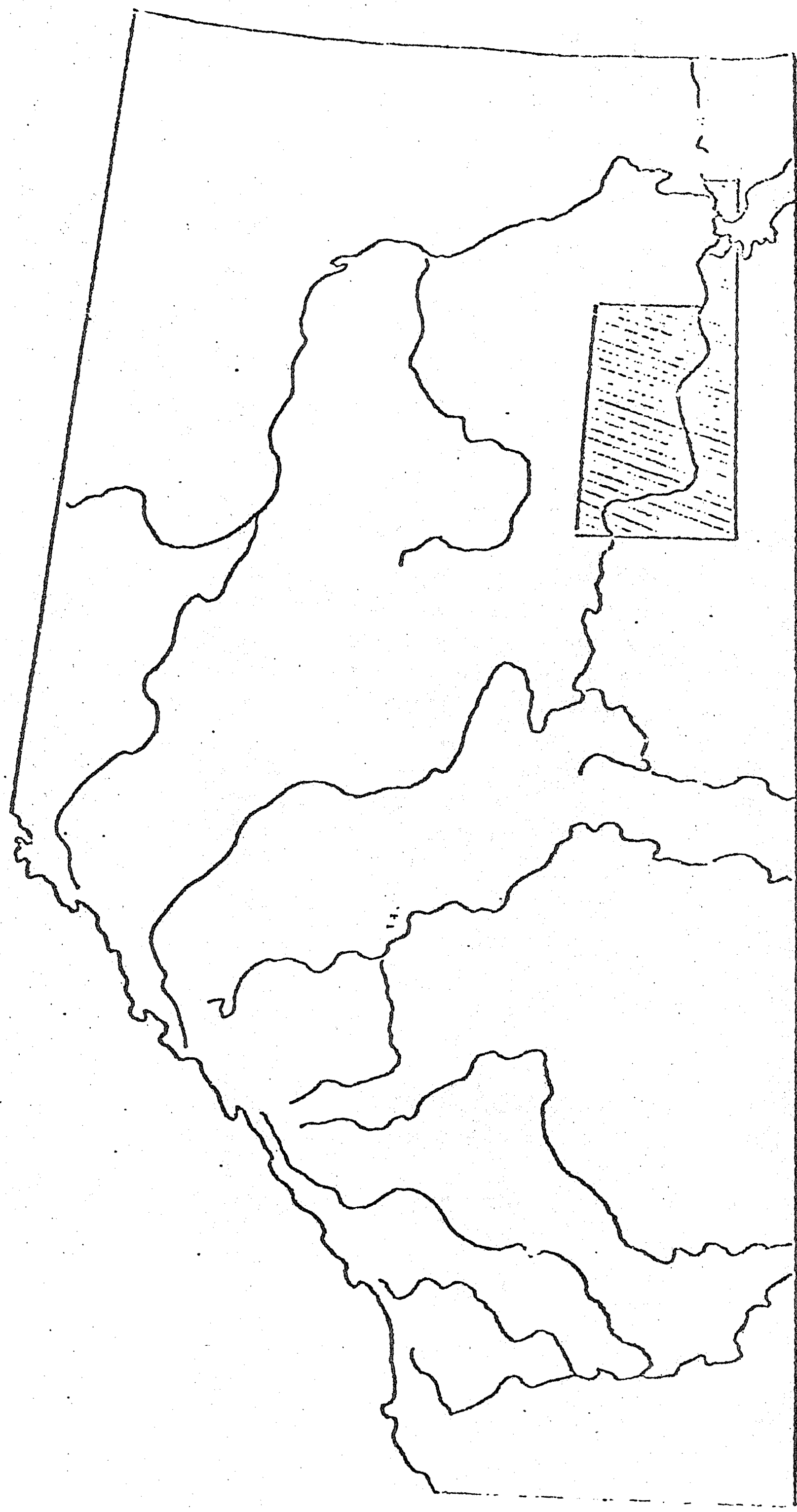

Figure 1. Location Map

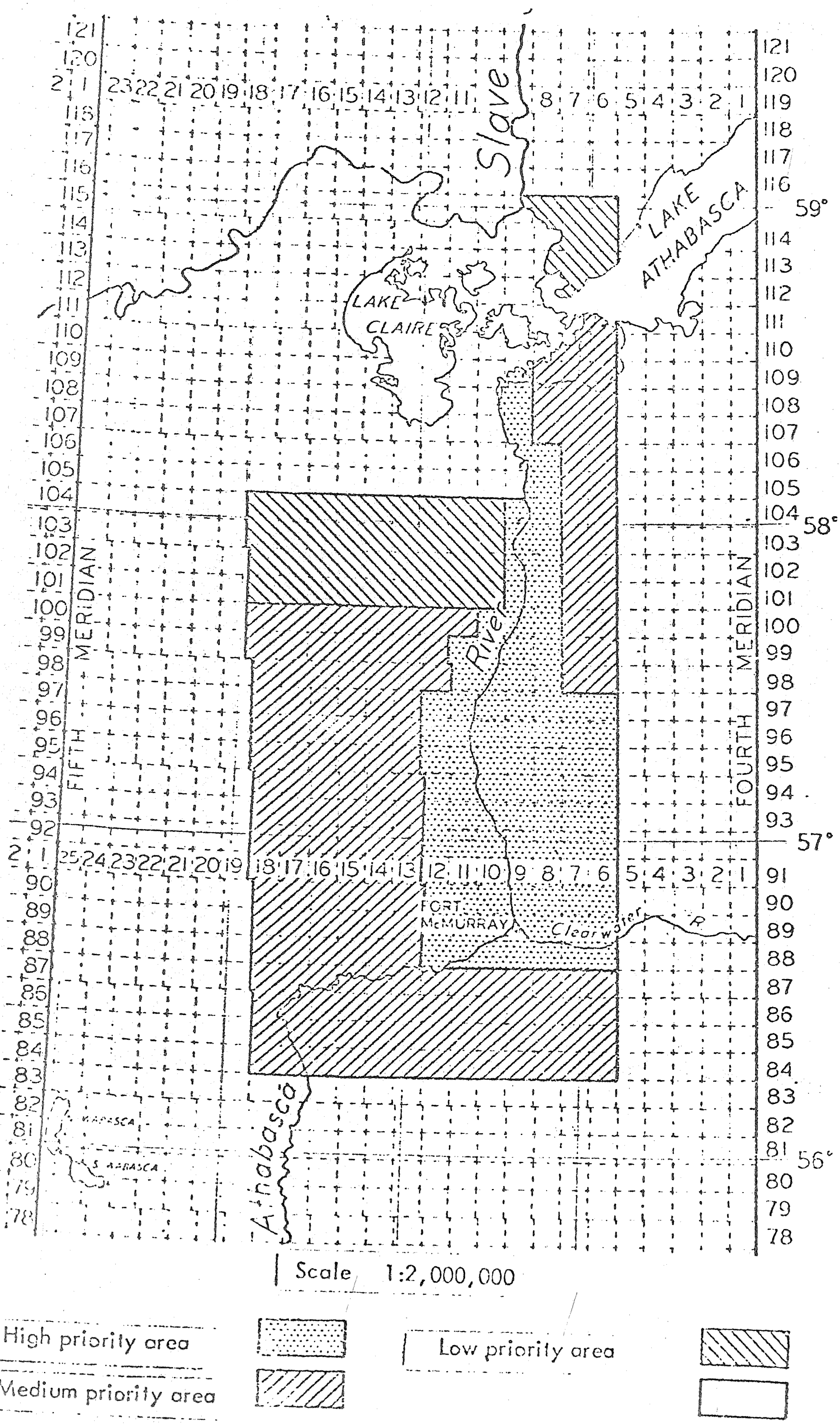

Figure 2. Priority Areas

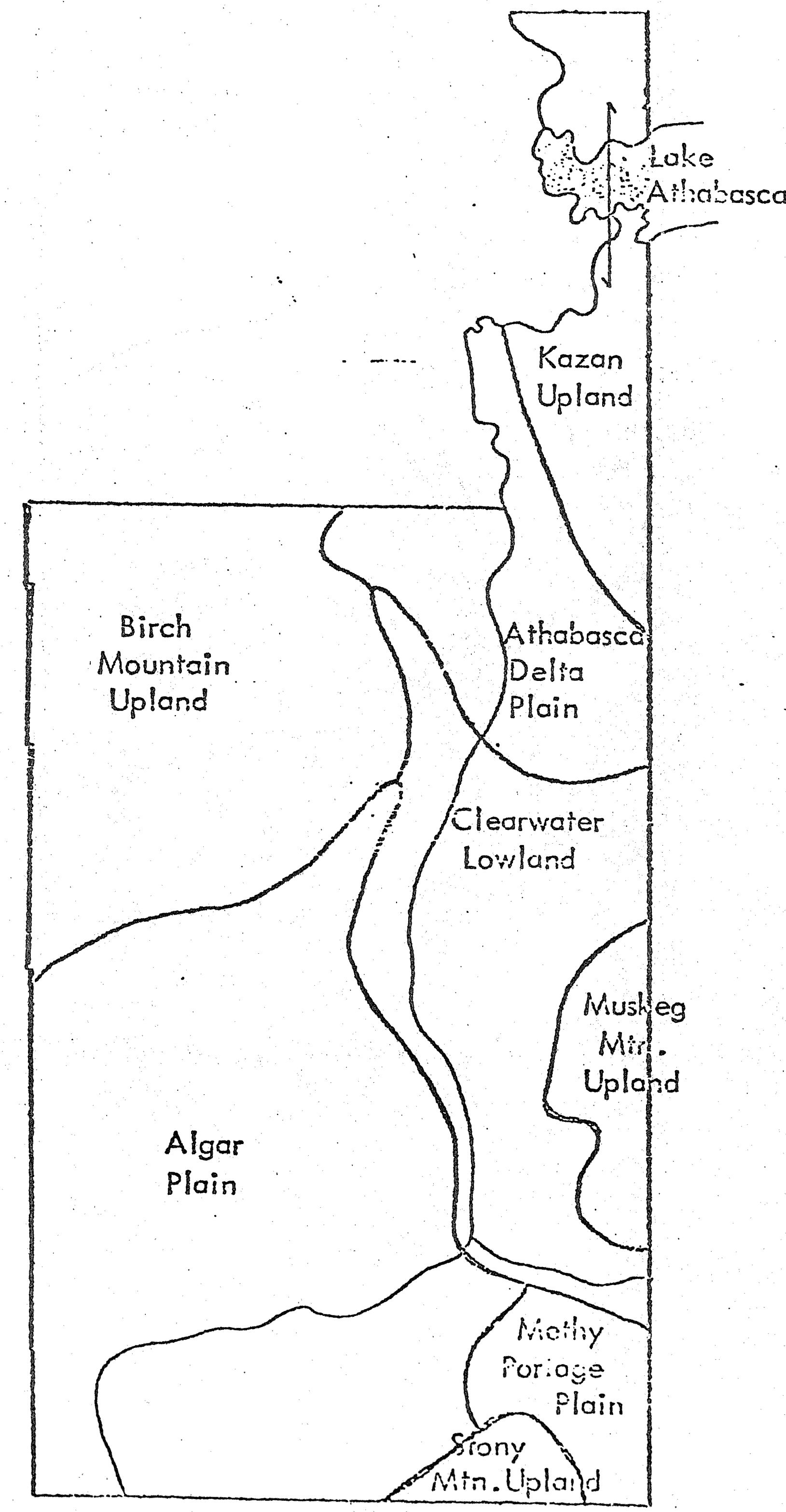

Figure 3. Physiographic Map of the Project Area

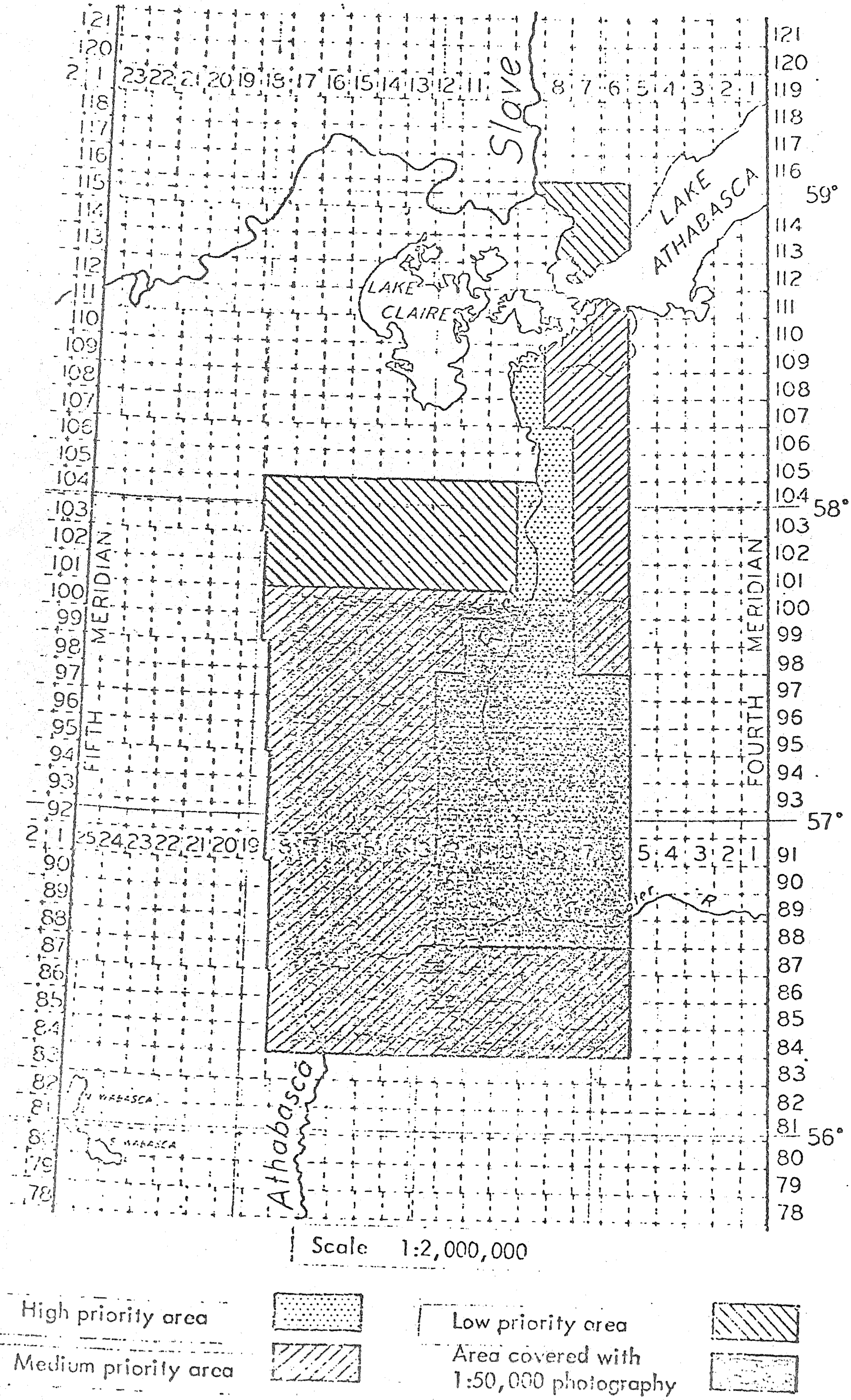

Figure 4 Existing Aerial Photography (1:50,000)

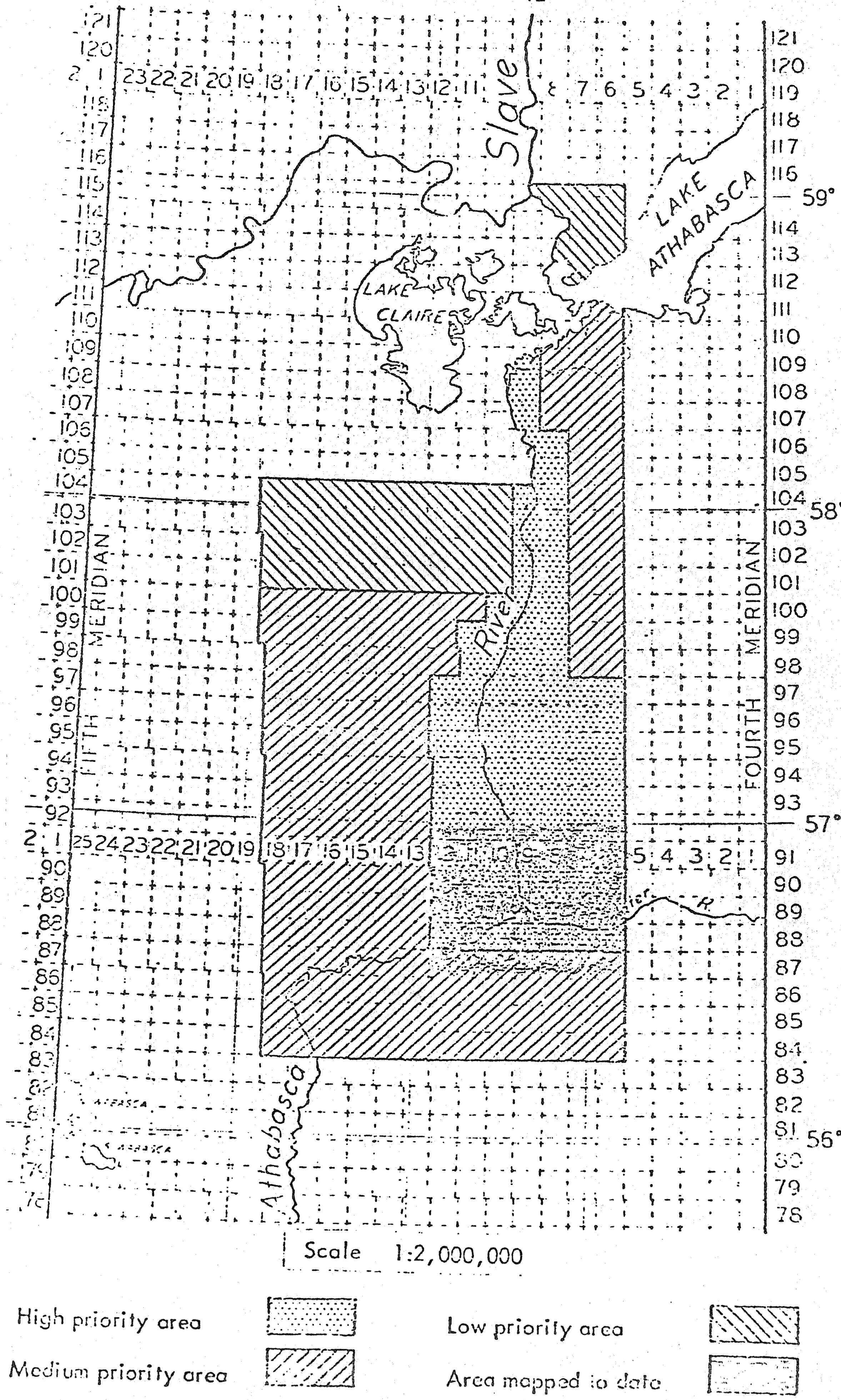

Figure 5. Area Mapped and Classified

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VE 2.3

VEGETATION INVENTORY OF THE OIL SANDS AREA

VEGETATION INVENTORY OF THE OIL SANDS AREA

A.W. Fedkenheuer

Some of you are aware that the Vegetation Committee deliberated for some time on this project. At the May 7, 1976 Vegetation Committee meeting, the Inventory Working Group, chaired by Mr. J.J. Lowe of the Alberta Forest Service, submitted a proposed plan of action which was approved in toal by the Committee.

The proposal separated the inventory into soils, vegetation and forestry. The soils portion, VE 2.1, was earlier reported on by Mr. Hluk Yuksel. The forestry portion doesn't get underway until at least next year and possibly now not until the following year.

The major thrust of the vegetation inventory was to obtain 1:15,000 colour and false colour infrared photography of the entire area between June 15 and August 15. We had been discussing the photography with Mr. Cal Bricker of the Alberta Remote Sensing Centre and he in turn with the Canada Centre for Remote Sensing (CCRS). As it turned out, once CCRS had the specifications in hand they declined to fly the area for us, saying that: 1) the scale required they fly too low for their Falcon aircraft and the Dakota would have to flown out, and 2) there would be too many photographs. This was approximately the end of June.

We then turned to the Technical Division, Alberta Energy and Natural Resources, to see if they could do the work. It turned out they were fully committed, but would assist us in putting our requirements out to tender. By the time all the paperwork was done and bids received it was early August and no bids were made, only an alternative proposal.

We then decided to go directly to a company with a small contract to fly a small portion of the area which was required by our researchers and for some winter work on developing plant community types for use in mapping next year. This requires a vegetation scientist to be hired and a position classification prior to being able to hire is pending.

The area flown in colour is shown on this overhead, followed by the false colour coverage on the next overhead.

Our plans for next year are to get an early start on tendering for the aerial photography and get as much vegetation type mapping done as we can.

VE 3.1, 3.3, 3.4

EFFECTS OF SO_2 ON VEGETATION

SYMPTOMOLOGY AND THRESHOLD LEVELS OF AIR POLLUTANT INJURY TO VEGETATION AND SPECIES TOLERANCE

S.S. Malhotra

The present federal and provincial air quality standards lack adequate experimental support. It is therefore highly desirable that in the light of Alberta species and climate, new air quality standards be established.

In order to delineate pollutant effects on vegetation in the field, we need to diagnose symptoms of pollutant injury. Since symptom expression and threshold levels of pollutant injury to vegetation is dependent upon a number of plant and environmental factors, it is absolutely necessary that such studies be carried out under controlled fumigation and environmental conditions.

A partial herbarium collection of both vascular and cryptogamic species has been made in the vicinity of oil sands operation and this as well as photographs of air pollution injury are the initial steps in defining the impact of pollutants on vegetation. However, the lack of information on the environmental conditions and SO_2 fumigation rates makes it impossible to quantify or define these symptoms. The control of environmental conditions and SO_2 exposure rates is therefore of great importance. For this purpose, we have designed a fumigation chamber and the contract for its construction has been let. The delivery of the chamber is expected by the end of October, 1976 after which it will be assembled, installed and tested for some preliminary SO_2 exposure trial runs this year.

The Siemen's gas exchange microchamber has been set up and calibrated for small scale fumigation purposes. The preliminary symptomology trial runs are currently underway. Next year, these chambers will be utilized to study the effect of air pollutants on physiology and symptomology of selected components of the forest vegetation.

PHYSIOLOGY AND MECHANISMS OF AIR POLLUTANT INJURY TO VEGETATION

S.S. Malhotra

The only pollutant studied so far under this project is SO_2. The future plans are to look at other air pollutants and various combinations there of.

There are a series of biochemical and physiological events that may be interferred with before the development of visual symptoms of SO_2 phytotoxicity. Our own work has provided sufficient experimental evidence to support this point of view. We believe that the SO_2 injury to vegetation occurs in a certain order of progression. The initial injury takes place at the biochemical or physiological level which then progresses to the ultra-structural and cellular levels followed by the visual symptom development. There seems to be a tendency to relate phytotoxicity of pollutants only to the visual symptoms. However, in greenhouse studies, growth and yield reduction have occurred in the absence of visible injury. Once the injury to vegetation starts to occur at the visual symptom level it may be irreversible. It is therefore essential that the initial detection of air pollutant injury be carried out at biochemical and ultrastructural levels.

The objectives of this study are (1) to establish biochemical or physiological threshold levels of air pollutant injury to vegetation and (2) to develop sensitive and reliable methods for detecting air pollutant injuries to the forest vegetation prior to visual symptom development and (3) to select revegetation species on the basis of their true tolerance to the air-borne pollutants.

Now I would discuss some of our own results in the light of these objectives. Since all our present work was carried out with aqueous SO_2, it becomes difficult to express results in terms of atmospheric concentrations. However, Saunders (1966) observed that in order to obtain similar effects on spores of the fungus Diplocarpon rosae the spores had to be exposed to 1000-fold higher concentration of SO_2 in aqueous phase than in the gaseous phase. Hocking and Hocking (1976, in press) have computed that at 25°C 1, 10 and 100 ppm SO_2 in water produced about .0012, .011, and .092 ppm respectively of dissolved but unreacted SO_2 (the biologically active species), or approx. 1000-fold lower concentration than the concentration of total SO_2 in water.

Hocking and Hocking (1976, in press) work provided a basis for adapting appropriate working concentrations for aqueous SO_2 and relating them to biological activity of SO_2 that might be observed in natural systems.

Effect on total chlorophyll content

The pine needles that were incubated in 10, 25, 50 and 100 ppm aqueous SO_2 remained green and looked quite normal whereas the higher concentrations caused increasing degrees of discoloration or bleaching.

The low concentrations (10-100 ppm SO_2) did not produce any appreciable change in total chlorophyll content. However, when SO_2 concentration was increased from 100 ppm to 250 and 500 ppm, there was a sharp drop in pH of the incubation medium as well as in total chlorophyll content (Table 1). At 500 ppm the pH dropped to 3.95 and the chlorophyll content was reduced to about half that of the control values. From these results it would appear that the decrease in chlorophyll content could be attributed to a drop in pH. However, the HCl control adjusted to the same pH as produced by 500 ppm SO_2 showed approximately 4% decrease in chlorophyll content compared to the regular control. It is therefore evident that the pigment destruction resulted from direct effects of SO_2 in addition to indirect effects such as increase in acidity.

Chlorophyll breakdown

In order to understand the mechanism of chlorophyll destruction, the effect of aqueous SO_2 on Mg^{++} loss from chlorophyll (conversion of chlorophyll into phaeophytin) was determined. Some of the mechanisms of chlorophyll breakdown are shown in Fig. 1. Acids such as hydrofluoric and hydrochloric acids have been shown to convert chlorophyll into phaeophytin with the release of Mg^{++}. Mg^{++} is replaced by 2 molecules of hydrogen with a resulting change in the light absorption spectral properties of chlorophyll molecules.

The data in Table 2 show the release of Mg^{++} from excised pine needles as a result of treatment with high concentrations of aqueous SO_2. The loss of Mg^{++} from needles treated with lower concentration of SO_2 (10-50ppm) was minimal (about 7% at 50ppm SO_2). However, the Mg^{++} loss became increasingly significant with increasing SO_2 concentration. The data also shows that even at very low pH, the conversion of chlorophyll into phaeophytin is due primarily to SO_2 and only to a small extent to acidity.

Effect on various pigments

The data in Fig. 2 show changes in the content of chlorophyll *a* (A), chlorophyll *b* (B), chlorophyllide *a* (C), chlorophyllide *b* (D), and phaeophytin *a* (E) and phaeophytin *b* (F) as affected by various concentrations of aqueous SO_2. The amount of chlorophyll *a* and chlorophyll *b* both decline with increasing concentration of SO_2. However, chlorophyll *a* is more sensitive to SO_2 attack than chlorophyll *b*. At 500 ppm SO_2, the chlorophyll *a* was almost completely destroyed, but only one-half of the chlorophyll *b* was destroyed.

Low concentration of SO_2 (10-100 ppm) did not have any appreciable effect on phaeophytin *a* (E) content. However, the content of this pigment was considerably increased at 250 and 500 ppm concentration. Phaeophytin *b* was absent in the control tissue and its content remained unchanged with SO_2, suggesting conversion of only chlorophyll *a* to phaeophytin *a*. Since no chlorophyllide *a* (C) was detected in the control tissue and SO_2 did not show any effect on its content, it is suggested that chlorophyll *a* was destroyed by processes other than simple transformations. The amount of chlorophyllide *b* (D) increased with increasing concentration of SO_2 to a maximum at 50 ppm followed by a drop at 100 ppm that was sustained up to 500 ppm SO_2. The increase in the amount of chlorophyllide *b* indicates that at least a part of the chlorophyll *b* was converted into chlorophyllide *b*.

Effect on chlorophyllase activity

The results in Fig. 2 indicate that part of the chlorophyll _b_ is converted into chlorophyllide _b_ and this conversion was maximum at 50 ppm SO_2. Since chlorophyllase is capable of such conversion it was thought desirable to determine if SO_2 has any effect on the activity of pine chlorophyllase. Chlorophyllase activity was measured in terms of chlorophyllide formation.

Concentrations of 10-50 ppm SO_2 stimulated the chlorophyllase activity while higher concentrations (100-500 ppm) inhibited it (Fig. 3). The maximum stimulation was obtained at 50 ppm. The activity dropped to a value close to the control value at 100 ppm and then exhibited significant inhibition with increasing concentrations of SO_2. The maximum inhibition of about 30% was obtained with 500 ppm SO_2. This inhibition was at first attributed to the low pH of the incubation medium caused by high concentration of SO_2, but HCl control showed inhibition of less than 10%. Therefore, the inhibition of chlorophyllase activity at high concentrations of SO_2 is not entirely due to pH effect. It appears that SO_2 has a direct effect on chlorophyllase activity.

The present results clearly indicate that the chlorophyllase activity index is a very sensitive indicator of SO_2 concentrations. This method may be useful for detecting SO_2 pollution before the development of visual symptoms. The SO_2 concentrations that produce maximum stimulation of chlorophyllase could be considered the biochemical threshold limits for SO_2 phtotoxicity.

These biochemical studies suggest that low concentrations of SO_2 which normally do not produce any visual symptoms on the foliage can cause injury at the molecular levels by affecting chlorophyllase and perhaps other enzyme systems. Since low concentrations of SO_2 were shown to have no appreciable effects of Mg^{++} loss, injury may be a result of increased activity of chlorophyllase. On the other hand, high concentrations of SO_2 that are capable of producing visual symptoms may cause senescence by inhibiting the activities of important enzyme systems, by destroying chlorophyll pigments, and thereby resulting in a net drop in photosynthetic efficiency.

Ultrastructural studies

Electron microscopy has been used to demonstrate the extent of ultrasturctural injury caused by air pollutants such as peroxyacetyl nitrate and ozone. However, very little is known about SO_2 effects on ultrastructural organization and metabolic activities of cells.

According to biochemical and cytological examinations, the tip of pine needles is composed of old and fully differentiated cells and the base contains very young and actively growing cells. About 1 cm sections exised from the tip and base of pine needles were incubated in different concentrations of aqueous SO_2 solutions and the ultrastructural changes in chloroplasts were examined by means of electron microscopy.

At aqueous concentrations of 100 and 500 ppm, SO_2 caused swelling of thylakoid discs and disintegrated other intrachloroplast membranes, resulting in the formation of small vesicles (in older, matured tissue). Chloroplast structural injury was more pronouced in old tissue than in younger and metabolically active tissues. In general, electron microscopy has shown that older, fully matured tissue is more sensitive to SO_2 injury than the younger actively growing tissue. This was shown by disorientation of chloroplast structure, dislocation of chloroplasts and absence of mitochondria in the older tissue treated with high concentrations of SO_2. The detrimental effects of SO_2 on the ultrastructural organization of pine needle cells appeared to be significantly different from the effects of low pH alone (HCl control).

Possible relationship between structural disorganization and disruption of biochemical activities of chlorophlasts from SO_2-treated young and old tissues were determined by measuring the photosynthetic activity of isolated chloroplasts. The biochemical observations (photosynthetic activity) were in good agreement with the cytological observations.

Effect of SO_2 on tissue glycolipids and permeability properties

The chloroplast membranes are sites of many enzymatic reactions and are made up of two very important structural components namely lipids and proteins. It is possible that structural disruption due to SO_2 has been preceded by changes in a number of biochemical events.

The chloroplast lipids are mostly glycolipids namely monogalactosyldiglycerides (MGDG), digalactosyldiglycerides (DGDG) and sulphoquinovosyldiglyceride (SQDG). These lipids are known to be involved in the structure and function of chloroplast membranes. However, nothing is known about the effect of SO_2 on metabolism of these compounds. We therefore decided to study the effect of SO_2 on (1) the level of these lipids in pine needles and (2) permeability properties of pine needle tissues.

The data in Fig. 4 show changes in the levels of glycolipids from fully developed and young needles as affected by various concentrations of aqueous SO_2. The concentrations of MGDG, DGDG and SQDG declined sharply with increasing concentrations of SO_2 up to 25 ppm. Further increase in SO_2 concentration (100 ppm) resulted in only small changes in the concentration of these glycolipids. An interesting observation is that the effect of SO_2 on the level of SQDG was more pronounced in the fully developed tissues than in the young tissues. The reverse was true of the DGDG fraction. These differences clearly indicate that the biosensitivity of various cellular metabolites to SO_2 depends on the age of the needles. It is also interesting to note that a dramatic decrease in the level of all these lipids was obtained at a very low concentration of SO_2 (50 ppm). Such low concentrations did not produce any visual symptoms on pine needles.

The influence of SO_2 on cellular metabolites such as soluble sugars was determined to ascertain whether the effects of SO_2 discussed above were confined to the glycolipids or whether other cellular metabolites were also influenced. The effect of SO_2 on the release of sugars would indicate the changes in cellular permeability. The incubation of tissues from both fully developed and young needles resulted in a release of soluble sugars from the tissues, even in the absence of SO_2 (Fig. 5). However, the presence of SO_2 in the incubation solution caused a dramatic increase in the amount of sugars released from both the tissues. The release of soluable sugars from tissues of both ages might have occurred due to a decrease in glycolipid concentration in the SO_2-treated tissues. However, the amount of sugars released from the young tissues was considerably higher than the glycolipid losses, suggesting that SO_2 caused a release of some other bound form(s) of sugar.

The difference in biochemical responses to aqueous SO_2 between the fully developed and young pine needle tissues indicates that the phytotoxicity of SO_2 is at least partially dependent upon the stage of plant tissue development. In view of the importance of galactolipids for the structural integrity of the chloroplast thylakoids, any changes in these lipids caused by SO_2 would result in structural and functional injuries to the bio-membranes. We feel that the process of hidden SO_2 injuries such as swelling of thylakoid discs and disintegration of intrachloroplast membranes may be initiated as a result of alterations in glycolipid components. Since very low concentrations of aqueous SO_2 (10-25 ppm) usually do not produce any visual symptoms but cause marked changes in the glycolipid content and composition, the analysis of such lipids may provide an effective tool for determining the extent of hidden SO_2 injury to vegetation.

The fumigation chamber (presently under construction) facilities will allow us to carry out some of these studies with the gaseous SO_2 and various air pollutant mixtures. The information thus obtained will be utilized to establish biochemical or physiological threshold levels of air pollutant injury to vegetation before the appearance of visual symptoms. We also believe that this type of information will be very valuable in selecting the revegetation species on the basis of their true tolerance towards air pollutants.

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2. Saunders, P.J.W. 1966. The toxicity of sulphur dioxide to Diplocarpon rosae Wolf causing black spot of roses. Ann. appl Biol., 58, 103.

Table 1.

THE EFFECT OF VARIOUS CONCENTRATIONS OF SO_2 ON TOTAL CHLOROPHYLL CONTENT OF PINE NEEDLES

Treatment	pH of Incubation Medium	Chlorophyll Content (MG/L)	% of Control
Control	7.20	65.27	100.00
10 ppm SO_2	7.18	64.13	98.25
25 ppm SO_2	7.13	63.50	97.29
50 ppm SO_2	7.10	63.82	97.78
100 ppm SO_2	7.00	63.38	97.10
250 ppm SO_2	6.60	47.98	73.51
500 ppm SO_2	3.95	34.69	53.15
HCl Control	3.95	62.71	96.08

Table 2

THE EFFECT OF VARIOUS CONCENTRATIONS OF AQUEOUS SO_2 ON Mg^{++} LOSS FROM PINE NEEDLE CHLOROPHYLL

Treatment	pH of Incubation Medium	Mg^{++} Loss (Mg/L)	% of Control
Control	7.20	7.94	100.00
10 ppm SO_2	7.18	8.07	101.64
25 ppm SO_2	7.13	8.26	104.03
50 ppm SO2	7.10	8.37	105.42
100 ppm SO_2	7.00	9.05	113.98
250 ppm SO_2	6.60	26.81	337.66
500 ppm SO_2	3.95	32.76	412.59
HCl Control	3.95	9.73	122.54

Figure 1

CHLOROPHYLL BREAKDOWN

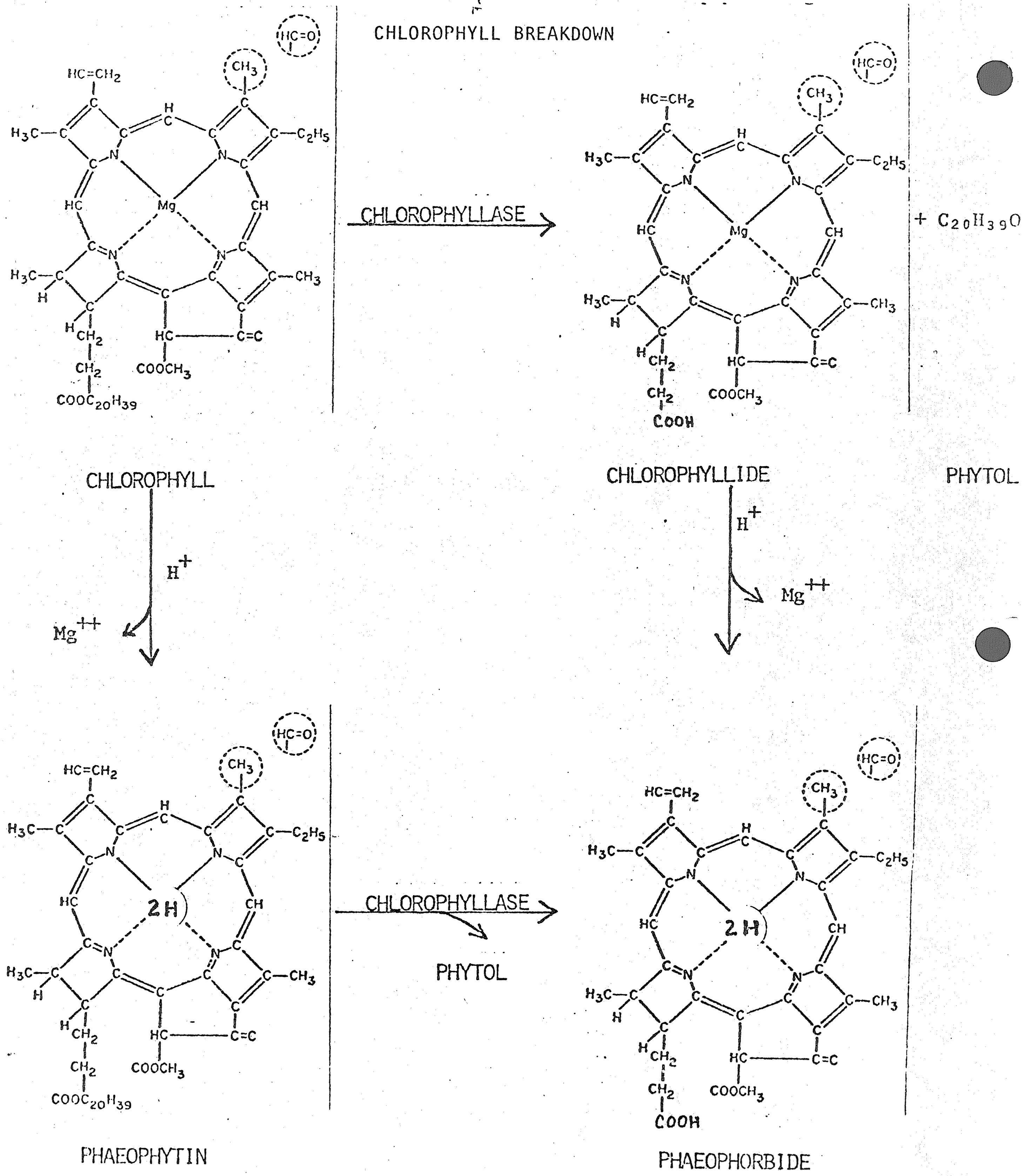
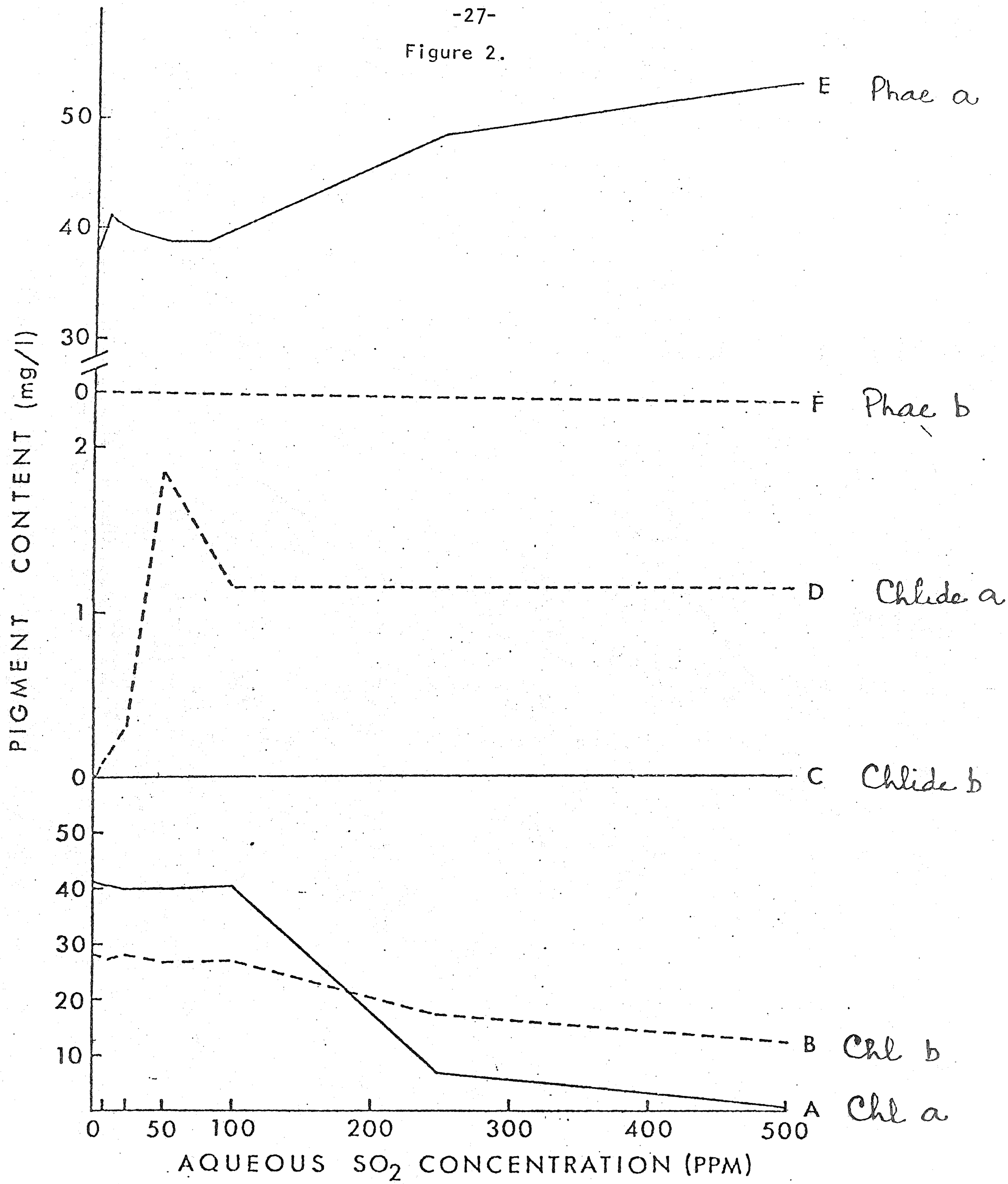


Figure 2.


E Phae a
F Phae b
D Chlide a
C Chlide b
B Chl b
A Chl a
PIGMENT CONTENT (mg/l)
50
40
30
0
2
1
0
50
40
30
20
10
0 50 100 200 300 400 500
AQUEOUS SO_2 CONCENTRATION (PPM)

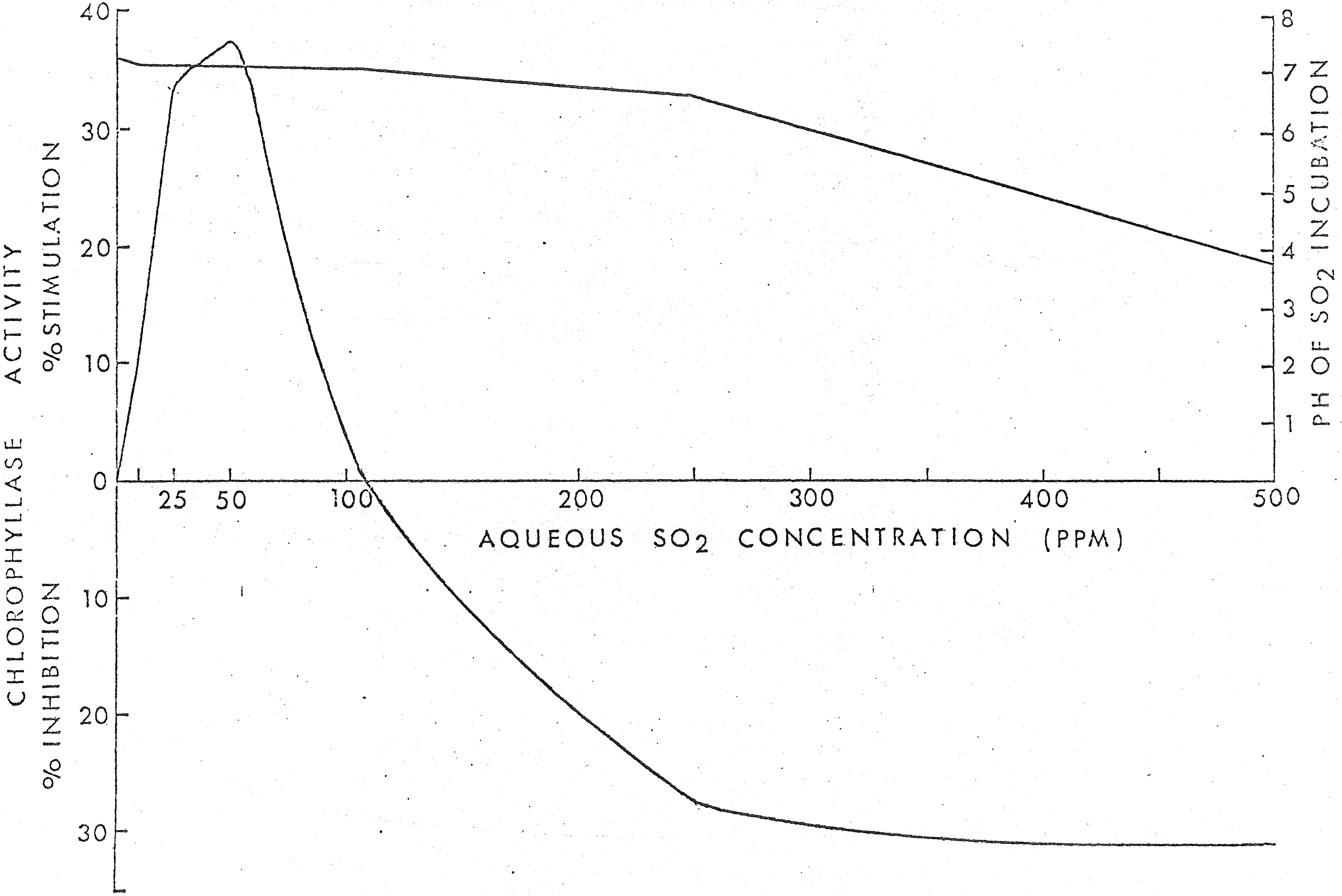
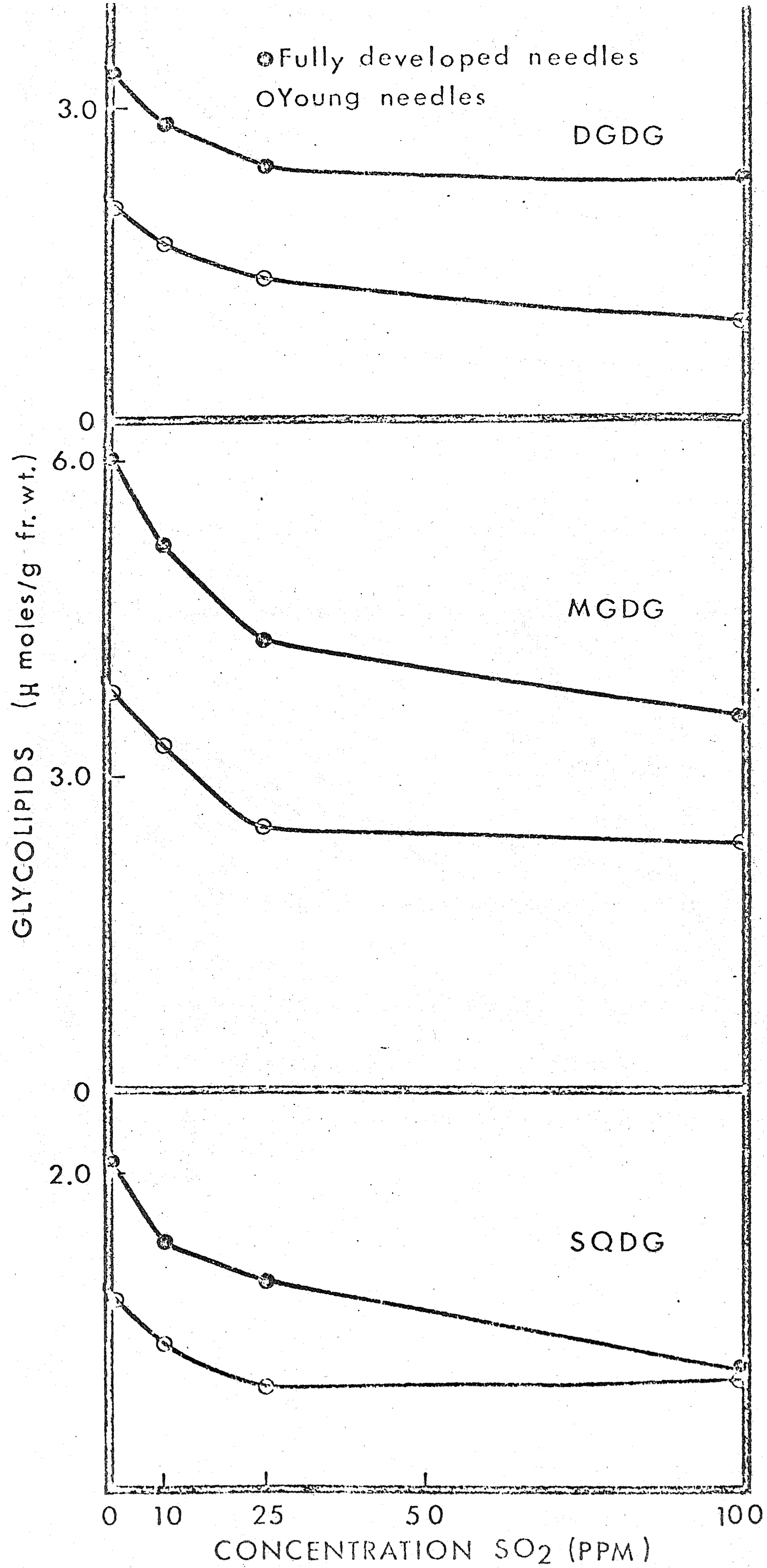

CHLOROPHYLLASE ACTIVITY
% STIMULATION
% INHIBITION
40
30
20
10
0
10
20
30
25
50
100
200
300
400
500
AQUEOUS SO2 CONCENTRATION (PPM)
PH OF SO2 INCUBATION MEDIUM
8
7
6
5
4
3
2
1

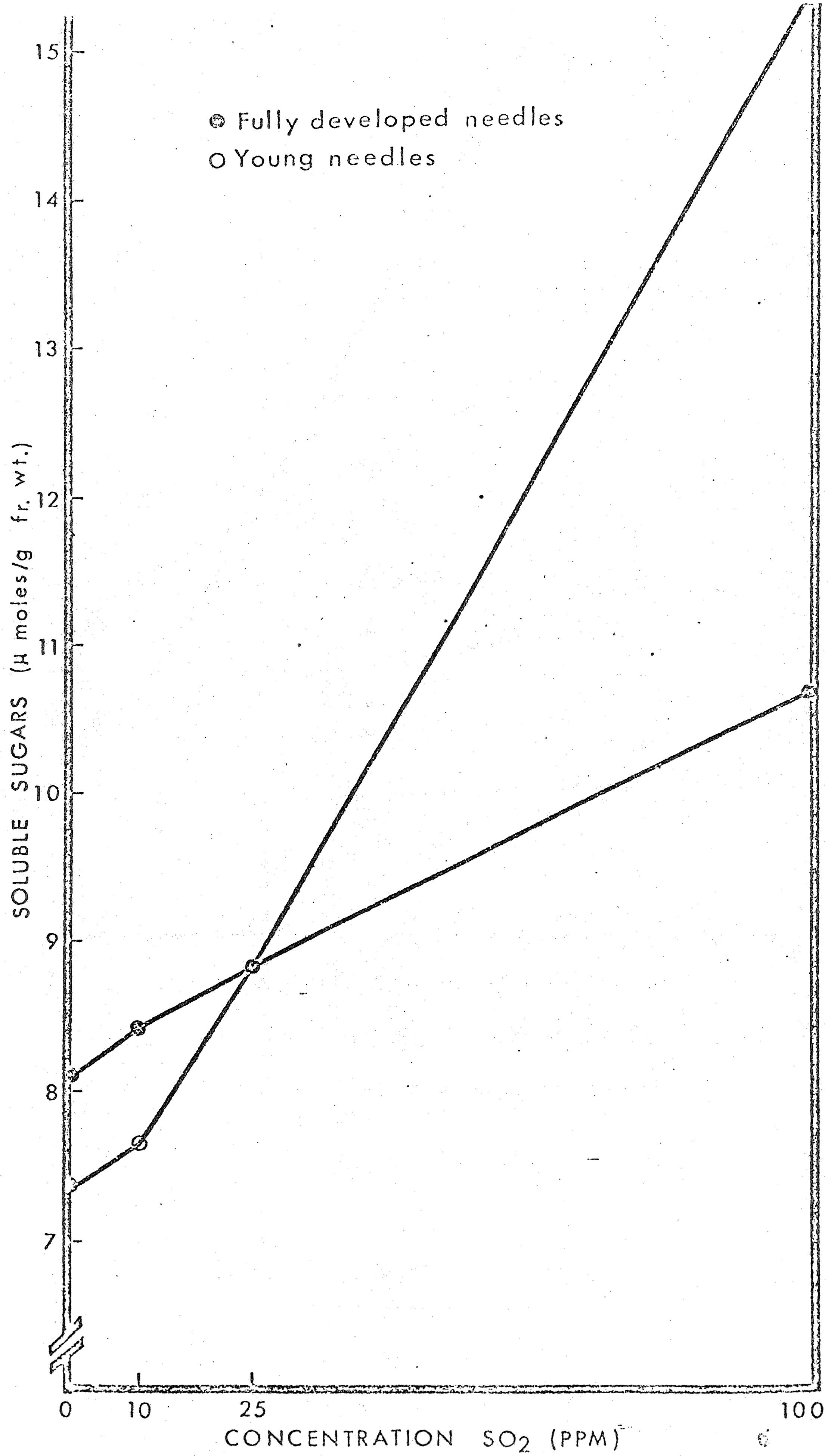
Figure 3.

Figure 4.



The effect of aqueous SO_2 on the levels of glycolipids in fully developed and young needles

Figure 5.



The effect of aqueous SO_2 on the release of soluble

ECOLOGICAL BENCHMARKING AND BIOMONITORING FOR DETECTION OF SO_2 EFFECTS ON VEGETATION AND SOILS

P. Addison

The aims of the field portion of this project were to:

1) determine the impact of air pollution, characteristic of oil sands operations, on two of the major plant communities in the Ft. McMurray area; and
2) establish an air pollution biomonitoring system for the Boreal Forest Ecosystem.

The two plant communities selected for study were jack pine and black spruce stands. These stands were dominant vegetation types in the AOSERP Study Area and represented the ends of both exposure and soil moisture gradients. Because of the exposure of jack pine stands, there is a high probability of fumigation whereas black spruce stands may be influenced more by air pollution because of the affinity of SO_2 to water and the potential for accumulation of pollutants in drainage areas.

METHODS

Description of Vegetation

During the summer of 1976, 12 areas where both jack pine and black spruce stands occurred, were selected for permanent plots (Fig. 1). The location of these areas was chosen based on prevailing wind direction (A.E.S. data), topography and distance from the Great Canadian Oil Sands processing plant. There appears to be a general west to east airflow in the area and hence, the establishment of the majority of plots to the east of the Athabasca River. In 9 of these areas (#1-9), a 20 x 20 m plot was established in the jack pine stand and vascular and cryptogamic species lists, stand density and age, soil characteristics and type, and cover and frequency of lower stata species were determined. Description of all black spruce stands as well as of jack pine stands 10-12 (Fig. 1) was left until the spring of 1977.

In the vicinity of each permanent plot, 10 branches with a lichen community of mainly fruticose and foliose types were selected. Frequency of various species and cover of species groups (Table 1) were determined for the site. Cover was determined from the photographs of the lichen community on a 15 x 20 cm quadrant.

Approximately 60 miles of low level photography (1:2000) was flown at the end of July 1976 (Fig. 1). At the same time as the 60 x 0.6 mile transect was flown, stereo pairs at 1:500 were taken every 2000 m. The aim of the aerial photography was to determine the stand condition of the various communities in the area and to act as a baseline with which to compare future photography. It is expected that the route will be rephotographed every 2-5 years.

In addition to the sites established in 1976 (jack pine and black spruce stands), sites that had been established in 1974 and 1975 (aspen and white spruce stands; Fig. 2) were re-examined with respect to their vascular species present and condition of ground vascular, bryophyte of corticolous (bole) lichens.

FIGURE 1. Map of the Athabasca Oil Sands Area showing the position of sites and aerial photography flown, Summer 1976.

1. Firebag river
2. Bitumount tower
3. Hartley creek
4. Ft. McKay
5. Mildred AOSERP camp
6. Fina airstrip
7. Muskeg mountain
8. North Steepbank river
9. Gordon lake
10. Birch mountain
11. Ells river
12. Thickwood hills

\- aerial photography taken at the end of July, 1976 (1:2000 and 1:500)

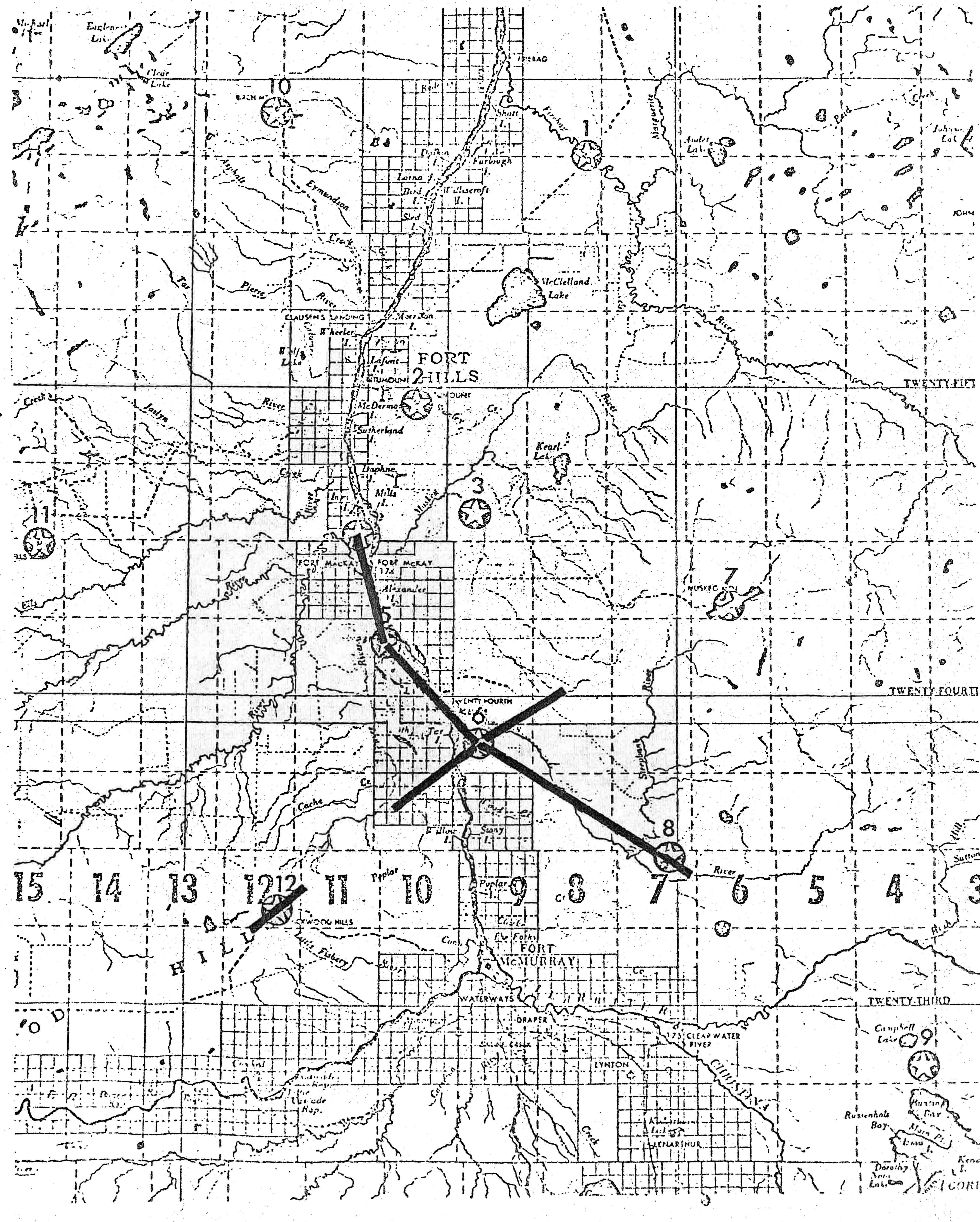


Figure 1. Map of the Alberta Oil Sands Area showing the position of sites and aerial photography flown, summer, 1976.

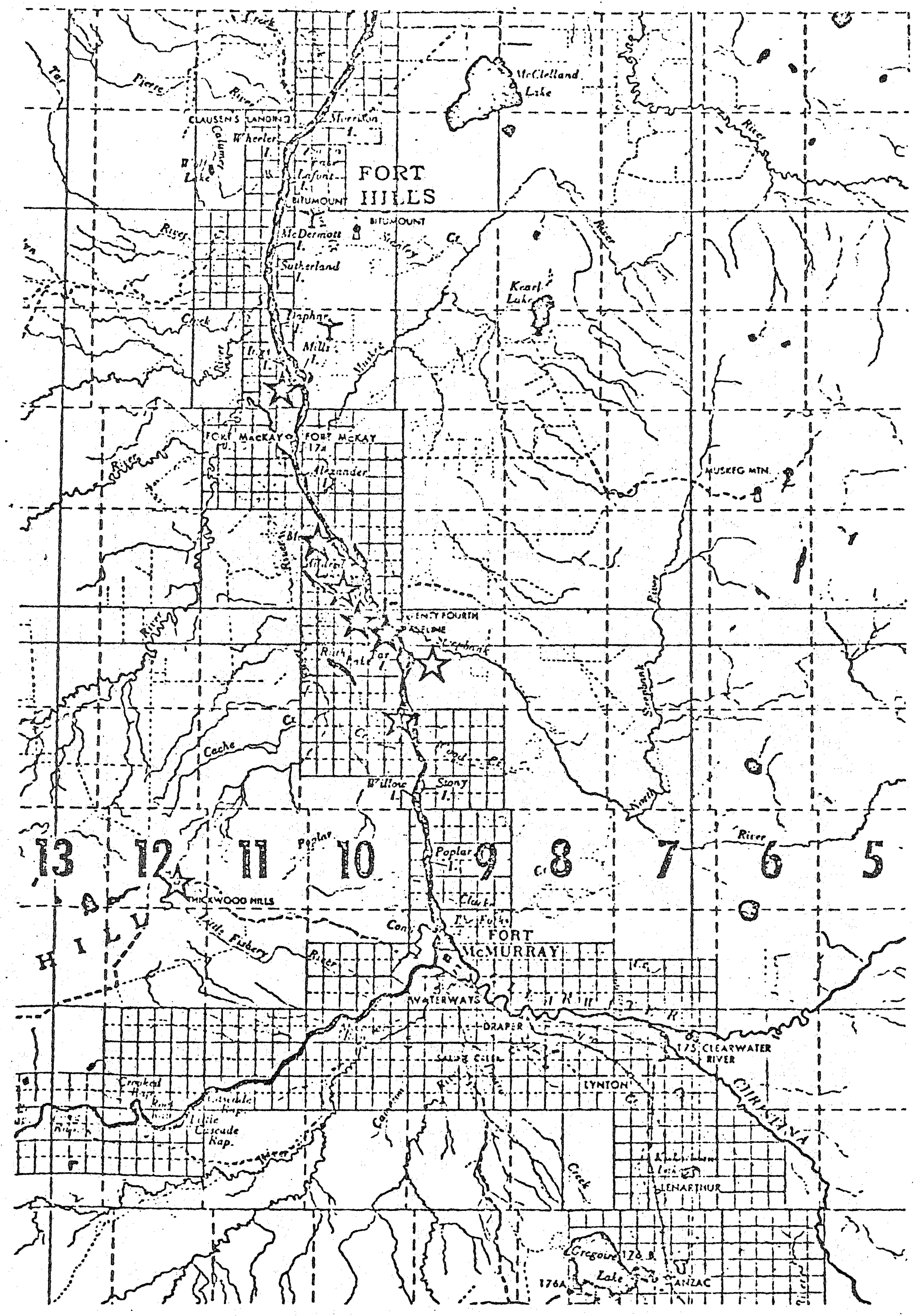


FIGURE 2. Map of the Athabasca Oil Sands Area showing the position of lichen transplant sites (☆) and sites established before 1976 (☆).

Biomonitoring

Preliminary studies on the development of a biomonitoring system were carried out during the summer of 1976. Vegetation samples from all tree species and from understory species of jack pine and black spruce stands were collected and analysed for total sulphur content and several heavy metals (Al, Fe, V, Ti). Five replicates were collected for each species (Table 2).

Branch lichen plots described above were also expected to yeild a measure of atmospheric purity as a result of the indicated sensitivity of lichens to air pollution; especially sulphur dioxide. It is expected that it will be possible to correlate changes in species composition and cover of branch lichens with sulphur dioxide concentrations as determined by both the network of SO_2 constant monitors and of lead acetate SO_2 constant monitors and of lead acetate SO_2 absorbers in the area.

Since many plant communities have naturally depauperate branch lichen floras (i.e. aspen and mixed wood stands), a branch lichen transplant study was initiated. Branches of black spruce collected at Ft.McKay established in five microsites at each of 4 locations at varying distances from the Great Canadian Oil Sands processing plant (Fig. 2). Two branches were placed in a clearing and under jack pine, white spruce, black spruce and aspen at a height of 1.5 m. A species list and cover of each species or species group was determined for each branch or plot as described above. Photography will be carried out at 4 month intervals.

Soil Chemistry

Description of both water soluble and exchangeable cations (Ca, Mg, Na, K, Al and Fe) and anions (S,P,N) are being carried out for 4-6 soil depths at each of 8 sites established in 1976. The selection of these ions was based on their concentration in precipitation that was also collected at each site on a monthly basis.

The impact of pollutants carried into the soil by precipitation will be determined by: 1) comparing the baseline data as outlined above with similar measurements taken in the future and, 2) comparing the ion concentration in an introduced soil exposed to precipitation with pollutants with that in the same soil where pollutants have been excluded by an ion exchange resin column.

In general, the main emphasis of the field work has been in establishing baseline information on the condition of the vegetation and soils in the oil sands area and in testing various methods of using vegetation and soils as indicators of the level of atmospheric pollution.

Future Work

Future work (1977) includes the establishment and description of permanent jack pine plots at Birch Mountain, Ells River, Thickwood Hills and at two other new sites; one ca. 40 mi. south of Ft. McMurray (reference site) and the other ca. 9 mi east of Milred Lake camp facilities. Black spruce plots at all sites will be established and described.

Sampling of vegetation as well as photography and description of lichen plots will be continued at each site in 1977. Some changes in species sampled are expected after full analysis of 1976 vegetation samples. The lichen transplant study will be either expanded or deleted from the project.

Aerial photography will likely be flown in either 1978 or 1979 but posssibly earlier if vegetation damage is detected.

Table 1. Corticolous branch lichens on jack pine, and black and white spruce in the Ft. McMurray Oil Sands area.

Species	Species Groups
Usenea cavernosa *Evernia mesomorpha* *Ramalina fastigiata* *Ramalina roesleri*	Usnea-Evernia-Ramalina
Cetraria halei *Cetraria pinastri*	Cetraria
Parmelia sulcata *Hypogymnia physodes*	Parmelia-Hypogymnia
Alectoria nidulifera	Alectoria

Table 2. Samples collected for sulphur and heavy metal determination during the summer of 1976 in the oil sands area.

Species	Sites 1	2	3	4	5	6	7	8	9
Trees									
Pinus banksiana	X	X	X	X	X	X	X	X	X
Picea glauca	X	X	X	X	X	X	X	X	X
Picea mariana	X	X	X	X	X	X	X	X	
Populus tremuloides	X	X	X	X	X	X	X	X	X
Betula papyrifera	X	X			X				
Larix laricina					X	X			
Shrubs									
Vaccinium vitis-idaea	X	X	X	X	X	X	X	X	X
V. myrtilloides	X	X	X	X	X	X	X	X	X
Ledum groenlandicum	X	X	X	X	X	X	X	X	X
Arctostaphylos uva-ursi	X	X	X	X	X	X		X	X
Alnus crispa	X	X	X		X	X	X		X
Salix spp.							X	X	
Lower plants									
Feathermoss	X	X	X	X	X	X	X	X	X
Ground Lichens	X	X	X	X	X	X	X	X	X
Branch Lichens	X				X	X		X	X

From an experimental basis, it is expected that controlled fumigations with SO_2 will be carried out in a control area in the field. The conditions when the plants are most susceptible to SO_2 damage will be determined in the laboratory and fumigation in the field will be carried out under those conditions. The impact of SO_2 (time and concentration) will be determined for trees, medium to high shrubs and ground vegetation. The major aim of this component of the work is to test the acceptability of both federal and provincial emission control regulations.

VE 4

SOILS RESEARCH RELATED TO REVEGETATION OF THE OIL SANDS AREA

ACIDIFICATION OF SOILS BY SULPHUR DIOXIDE EMISSIONS IN THE ALBERTA OIL SANDS AREA

S.K. Takyi and M. Nyborg

The work in the soil project related to sulphur dioxide emission is concerned with: measuring the amount of the gas deposited in the soils of the Oil Sands area; determining the extent of damage done by the gas to the soils; determining changes in soil acidity levels and other chemical properties; and studying countermeasures for any damage to the soils in the area. Initially, efforts have been aimed at evaluating the potentially damaging situations in order to identify the research and monitoring requirements of the project.

Emphasis on the work to date has been placed on measuring the amounts of sulphur deposited by different means: rainfall, direct absorption of gas, and dry particulates. Measurements are being made of the pH of the forest floor cover in the Oil Sands area (soils, mosses and lichens), which has been exposed to sulphur dioxide emissions. Measurements of their sulphur concentrations are also being made. In essence, measurements are being made to determine if in fact soils in the area are being acidified by sulphur dioxide emissions and to find if acidification of the soils is a major environmental problem.

Researchers have shown that the rate of soil acidification from sulphur dioxide emissions should be of concern in Scandinavian countries. Preliminary results of the past two years (up to the end of 1975) of work in the Oil Sands Area generally indicate that the rate of soil acidification in the area will be even faster than in Scandinavia, and in fact could be an important environmental problem resulting from development of the Oil Sands.

Work carried out near the GCOS plant (up to the end of 1975) has shown that rains are not very acid and the deposition of sulphur as sulphate-sulphur is about 5 kilograms per hectare per year. However, in intercepted rains (throughfall and stemflow), two to three times as much sulphur from sulphur dioxide emissions is detected. The stemflows, especially spruce stemflows, are very acid in areas most exposed to the sulphur dioxide emissions.

Bare soils contained in canisters and exposed under rain-protected shelters in the Oil Sands area have absorbed sulphur dioxide from the air, as indicated by slight increases in acidity and sulphate-sulphur levels. Similar results have been obtained under controlled conditions in the laboratory with bare soils, live moss and lichens, which are the major cover of forest soils in the Oil Sands area. Work elsewhere has indicated that soils absorb sulphur dioxide at great distances downwind from emission sources, so that soil acidification from sulphur dioxide emissions from Oil Sands plants could be a major problem in other areas far outside the immediate Oil Sands area.

Measurements of sulphur have been of the sulphate forms, but much of the sulphur absorbed by the soils ends up in the soil organic matter. This form is difficult to measure with accuracy because of the small amounts of sulphur involved in short-term experiments. In undisturbed soils in the field, because of the natural variations in soil sulphur among samples taken even within inches of one another, the slight increases over two years in sulphur in different forms are difficult to measure accurately.

The main damage to soils from sulphur dioxide emissions is the resultant acidity of the soils caused by the sulphuric acid produced. Different plant species have different tolerances to acidity, but when very strongly acid conditions are produced very few plants could grow; this could conceivably be the case for the sandy soils in a relatively short time.

It would take up to about 1,000 kilograms of sulphur per hectare as sulphuric acid for most agricultural soils in Alberta to become too acid, a situation readily rectified by liming. On forest soils, with moss and lichen cover and different tree species, the situation is different. Preliminary experiments with moss-covered soils indicated that 200 kilograms of sulphur per hectare could depress pH by about two units, which would result in the moss being killed, an indication that some of these forest soils could reach a damaging level of acidity in a relatively short time. A preliminary short-term field experiment has indicated that light applications of lime (calcium carbonate) would neutralize the acidified moss layer with no harm to live plants in the moss layer. As part of the long-term field experiments for the coming years, very low rates of lime application will be used at selected sites to determine if forest soil acidification can be averted without lime damage to the forest undergrowth and the trees.

In order to determine movement of sulphur absorbed by soils as sulphur dioxide and the changes it undergoes in the soils, six lysimeters have been set up at each of nine locations in the Oil Sands area to collect leachates over several years. The leachates are to be analyzed for their chemical constituents, especially the bases, and for any changes broughtabout by the varying amounts of sulphur added by rain at the different locations. In other sets of lysimeter experiments set out in the field, several soils (with the natural sequence of horizons unchanged) from the Oil Sands area are to be subjected to different levels of simulated acid rains. Leachates from these lysimeters are also to be collected for analyses, and after two years are to be taken apart by depth, including the surface native plant cover, for complete analyses for differences in chemical properties, including acidity and sulphur levels.

Long-term field plots to study changes in soil chemical properties (including sulphur and pH levels) of the natural undisturbed soils of the Oil Sands area have been established on several soils. Once every two years, these plots are to be sampled at various specified soil depths, including the surface litter and moss or lichen cover, for complete chemical analyses to determine the extent of damage from sulphur dioxide emissions.

SOILS RESEARCH RELATED TO REVEGETATION OF THE OIL SANDS AREA

L.W. Turchenek

Introduction

Our objectives in soils research related to revegetation of the Oil Sands area are two-fold: (1) to characterize, in detail, undisturbed soils and soil materials to be reclaimed, and (2) to develop ways of improving soil factors affecting the eventual production of a stable soil-plant system. With regard to the first objective, samples of some soil profiles and of subsurface materials such as glacial till, shale from the Clearwater formation, limestone from the Waterways formation, and lean tar sand were collected during both 1975 and 1976. Most of these were analyzed during winter, 1976, and the data are now available as base-line information for other experiments. Soil materials to be reclaimed consist mainly of tailing sand and overburden materials. The tailing sand problem has received most attention thus far, overburden materials being considered more as potential amendments for tailing sand rather than as being problems in themselves.

The second objective, that of reclamation research, constitutes the major part of this project. The production of a stable soil-plant system is the principle aim of this work, this requiring thorough investigation of the problems associated with tailing sand.

Nature of the Problems

The deficiencies of tailing sand as a medium for plant growth are apparent from an analysis of a fresh sample from the GCOS mine (Table 1). Analysis of material from an overburden pile are presented for comparison. The sand content is very high, and clay and silt low, resulting in properties such as low water holding capacity. Low nutrient status is apparent from low N and exchangeable cation contents, although the content of P was relatively high. The low nutrient status arises largely from the lack of both organic and inorganic colloids which act as a "sink" in the cycling of nutrients. The high pH could lead to nutrient availability problems. Another problem not indicated by the analysis is the non-wetting nature of the sand. The overburden material is not as deficient in colloids and nutrients, N being an exception. These analyses show that research efforts should be directed toward building up the nutrient status and water holding properties of the tailing sand.

Dealing with problems more specifically, the effect of leaching of ions in tailing sand is important because whatever nutrient supply initially available plus that added in the from of fertilizers can easily be lost by percolation of water through this rather coarse textured material. At the same time, leaching would have the beneficial effect of lowering the pH.

The water storage capacity can be improved by mixing colloids (clays) or organic materials such as peat into the sand. Also, according to reports from the literature and from observations in the field (see A.H. MacLean's report) layers of fine texured material below the soil surface can produce perched water tables, thus making more water available for plant use.

Table 1. Some Properties of Tailing Sand and Overburden Materials

Property	Tailing Sand	Overburden	Supertest Till	Mesic Peat
Particle Size Distribution (%)				
Sand	96.3	68.7	48.4	-
Silt	2.7	18.8	31.7	-
Clay	1.0	12.5	19.9	-
pH	9.2	7.8	8.3	5.9
Conductivity (mmhos/cm)	0.6	1.9	0.3	0.6
Organic C (%)	0.19	1.29	1.01	45.09
Nitrogen (%)	0.003	0.024	0.028	2.33
C/N	57.8	53.3	36.7	19.3
$CaCO_3$ equiv. (%)	0.08	4.08	12.17	0
Extractable P (ug/g)	28	26	25	36
Extractable SO_4^{--}(%)	0.05	0.08	0.04	0.09
CEC (me/100g)	0.3	6.5	10.5	133.3
Exchangeable Cations (me/100g)				
Na^+	0.5	0.1	0.05	0.6
K^+	0.03	0.2	0.25	0.1
Ca^{++}	0.5	13.2	36.2	99.6
Mg^{++}	0.3	2.0	6.4	23.5
Ions in Saturation Extract (ppm)				
Na^+	105	35	10	56
K^+	6	3	2	2
Ca^{++}	4	46	49	69
Mg^{++}	2	106	24	23
Cl^-	0	0	0	53
SO_4^{--}	173	1269	44	213

With regard to nutrient supply, the following factors are important; (1) levels of nutrients in the soil solution; (2) pH; (3) ability of soil to retain nutrients; (4) rate of return of nutrients to the soil by decomposition of organic matter; and many other factors. Fertilization may be necessary in the initial stages of reclamation, but in the long run, development of a soil system in which nutrients cycle as they do in natural systems would be preferrable. The use of clays and organic matter to improve water properties, as discussed above, should also be beneficial in nutrient supply and cycling. The nutrient cycling information that is necessary is (1) data on cycling rates in natural soil-plant systems and in systems that may develop in the area, and (2) methods of developing and controlling such systems.

Methodolgy and Results

1. Lysimeter experiments.

Lysimters are being used to study the tailing sand problems. These are devices for measuring the percolation of water through soils and determining the soluable constituents removed in the drainage water. With suitable instrumentation, physical properties can also be measured. The lysimeters were constructed from steel, are 76 cm (30 in) wide by 91 cm (36 in) deep and have conical bottoms with outlets incorporating a porous ceramic cup (1 bar entry value) for collection of drainage water. A column of water is maintained in a 50 cm length of tubing connected to the porous cup, thus producing a constant 50 mbar tension of the soil at the bottom of the lysimeter. The inside surfaces of the lysimeters were coated with an epoxy resin to prevent chemical interactions between the soils and the steel walls. The lysimeters were filled with tailing sand and amended as follows:

1) No amendment
2) Glacial till mixed into top 15 cm (1:4, till:sand ratio)
3) One subsurface till layer (2.5 cm) at 65 cm depth
4) Two subsurface till layers (1.25 cm) at 35 and 65 cm
5) Mesic peat mixed into top 15 cm (1:20, peat:sand ratio).

Some analyses for the glacial till, obtained from Supertest Hill, and the peat, obtained from a sphagnum bog about 1 km north of Beaver Creek along the main road, are presented in Table 1. The five treatments were duplicated and the lysimeters were installed indoors and watered artificially to begin the leaching process. They were moved outdoors in May, 1976, and one set of the duplicates was sown with brome grass at a rate of 10 kg ha^{-1} and fertilized with N,P,K, and S at rates of 100, 40, 100 and 10 kg ha^{-1} respectively. Rainfall was the only source of water after installation outdoors. Tensiometers were placed at 10 and 20 cm depths in all lysimeters, and at lower depths in a few. Leachate was collected weekly or bi-weekly and stored until analysis was carried out for pH, conductivity and contents of C, N, P, Ca, Mg, Na, K, Fe, Mn, Si, Al, Cl, and SO_4.

Some changes in leachate properties from March to the end of June for non-amended tailing sand without brome grass are given in Table 1. Increases were noted in pH, conductivity and monovalent cation contents, particularly Na. Carbon contents were variable and N and P were not detected. Contents of divalent cations increased in concentration. Sulphate contents have not been determined yet. Similar types of changes occurred in the other lysimeters although sufficient leaching has not occurred yet to produce great differences among the amendments.

Table 2. Changes in Lysimeter Leachates from March to June, 1976, after 50 cm of Combined Artificial and Natural Precipitation.

Property	March	June
pH	8.4	7.8
Conductivity (mmhos/cm)	1.8	1.0
Carbon	variable in the range 45-78ug/ml	
Nitrogen	nil	nil
Phosphorus	nil	nil
Ca^{++}	40-50	60-70
Mg^{++}	19	35
Na^{+}	450	200
K^{+}	25	20
Fe^{++}	variable in the range of 0.1-0.4	
Mn^{++}	0.4	0.6

The growth of brome grass in the lysimeters was tallest and most dense in the peat-amended sand (Treatment 5). Growth in the tailing sand alone and the treatments with buried layers was relatively good, but that in the amendment of till mixed into the surface was poor. These observations through the summer were cofirmed by amounts of dry matter produced; i.e., tops harvested on October 7, 1976 (Table 3). The surface pH was also determined at the time of harvest to determine if it was a factor in plant production (Table 3). The pH had dropped in all lysimeters, but remained at the relatively high level of 8.0 in the till surface amendment (Treatment 2). The effect of pH on availablity of plant nutrients may be one factor in producing poor growth. The leaves of the plants in Treatment 2 also showed purple coloring which may indicate P deficiency and which in turn may be related to interactions of phosphate with carbonate in the till. Yet another possibility, which will be investigated further, is the effect of Na^{+} from the tailing sand on dispersing clay from the till, resulting in formation of a dense impervious surface unsuitable for plant growth.

Tensiometers installed in the lysimeters showed that the driest conditions were attained by the surface peat treatment (Table 4). After a period of rainfall, tensions in all lysimeters were low. During drier periods, tensions increased considerably in all lysimeters except Treatment 2. Tensiometer data are rather difficult to interpret and in this case may

Table 3. Dry Matter Production and pH of Soil Surface in Lysimeters.

Lysimter	Weight of Brome Grass (g)	pH
1	116	7.0
2	62	8.0
3	106	6.8
4	116	6.7
5	128	6.0

simply reflect lower or higher rates of water use by plants in the different lysimeters. The data do not show whether or not perched water tables have formed in Treatments 3 and 4 and suitable instrumentation for measuring actual water contents at different depths in these lysimeters is needed. The soil moisture tensions in all treatments increased to fairly high levels after a relatively long, dry period (September readings, Table 4).

In spite of the apparent detrimental effect of adding glacial till to tailling sand, the effect could be short term only. To study other combinations of amendments, other lysimeters of a different design have been installed at the Mildred Lake research site. The treatments in these are:

1) tailing sand - no amendment
2) mesic peat mixed into top 30 cm (1:1 volume ratio)
3) glacial till mixed into top 30 cm (1:5 volume ratio)
4) glacial till plus peat mixed into top 30 cm (in above ratios)
5) peat mixed into surface plus 5 cm till layer at 45-50 cm.

The purpose in establishing these lysimeters is simular to that for the first set, but they will be studied under the actual environmental conditions of the area.

The Mildred Lake lysimeters are constructed from fibreglass, have no bottom, the base of the tailing sand column lying on natural sand, and have been installed in the soil so that their surfaces are level with the land surface. Leachate is collected by means of a permanently installed soil water samples and water properties will be monitored by tensiometers and neutron probe measurements. Measurements will begin in spring, 1977, after sowing and fertilizing a mixture of grasses and legumes.

2. Nitrogen experiments

Of the plant nutrients, nitrogen deserves intense study because of its quantitative importance and because of factors such as expense when added in the form of fertilizer. The alternative to fertilizing, at least in the long run, is to produce a cycling N system. Studies of the N cycle in natural systems are being carried out to obtain basic data. Several experiments involving N cycling in tailings sand have also been started. No results of these are available yet, but a short description of each experiment is given below.

Table 4. Tensiometer Data for Lysimeters - Month of August, 1976

Date	Pptn mm	Lys 1		Lys 2		Lys 3		Lys 4		Lys 5	
		10 cm	20 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm
1											
2											
3	8.2										
4	5.0	20	20	20	23	20	26	20	20	23	44
5											
6	0.1										
7	0.8	45	25	31	23	39	29	37	23	19	11
8	4.1										
9	3.5										
10	tr	101	76	32	30	50	66	32	70	484	502
11											
12											
13		444	258	52	34	225	183	381	297	648	596
14											
15	0.8										
16	16.7										
17	7.4										
18	0.4										
19	3.7										
20	0.7										
21											
22	0.2										
23	tr	325	229	64	42	86	590	192	515	584	484
24	0.2										
25	17.2										
26	8.9										
27	tr										
28											
29											
30	0.2										
31		454	108	54	32	82	270	231	206	656	587
Sept 10		730	295	751	584	550	492	725	640	824	787

Experiment 1. Determination of natural mineralization and immobilization under natural conditions from forest litters. After labelling leaf litter under aspen, pine, spruce and mixed-wood sites with $(^{15}NH_4)_2SO_4$, ^{15}N distribution among plant tops, roots, litter and subsurface horizons is measured after sampling 4 times during the summer.

Experiment 2. Study of the effect of soil treatment on N uptake efficiency by grasses and legumes which are potential candidates for revegetation and on the recycling rate of N through this system. This also will involve ^{15}N tracer techniques and will be conducted on small plots of tailing sand amended in the same way as Mildred Lake lysimeter treatments 2, 4 and 5.

Experiment 3. Study of the effect of time of N application on its efficiency of uptake by an established stand of grasses and legumes in the Fort McMurray area. This involves spring, summer and fall application of ^{15}N-labelled fertilizer to determine the most effective time of fertilization.

Experiment 4. Determination of decomposition rates of ^{14}C- and ^{15}N-labelled plant materials added to sand-peat mixtures in the field. Grass tops labelled with ^{14}C and ^{15}N will be added to tailing sand with surface peat amendment and fate of the labelled material will be determined with time.

Experiment 5. Determination of effect of till on rate of remineralization of immobilized N in sand-till mixtures (and of peat and peat + till mixtures with sand). This is a laboratory experiment involving incubation of soil mixtures labelled with ^{14}C-acetate and $(^{15}NH_4)_2SO_4$.

Experiment 6. Study of the rate of N turnover through established grasses (mainly creeping red fescue) on steep sandy slopes. The experiment is designed to determine rate at which N consumed by plants is converted to organic matter and remineralized in the soil for succeeding crops under field conditions. It is being conducted on the GCOS dyke and will be of three years duration, the first year having been completed.

Experiments 1, 2 and 3 will be carried out in a 10 m x 7 m x 1.5 m deep plot of tailing sand, with the various amendments, that was established in summer, 1976, at the Mildred Lake research site. These experiments will not actually commence until spring, 1977, when a stand of grasses and legumes will be fairly will established.

3. Other Nutrients

Although we are presently concentrating on the N nutrition problem in reclamation, incorporation of P and K studies in the experiments described above is being planned. It will also likely be necessary to study, at a later stage, micronutrients in a reclaimed tailing sand system.

SOIL PHYSICS

A.H. MacLean

Greatest importance has been attached to selection of suitable field sites where information on soil moistures and temperatures could be obtained. These sites had to be readily accessible, while at the same time covering a range of conditions occuring within the Oil Sands area.

Several sites were selected near Richardson's tower because these could be serviced at the same time as those for sub-project VE 6.1 (Table 1). One of the sites is on flat ground under jackpine vegetation and two have a north-east aspect and are under Birch and Aspen. In this way they compliment the VE 6.1 sites which are on a south-west facing slope.

Three sites at Mildred Lake are within the AOSERP camp area while two are just outside its boundaries. All are on sand, but at one of the sites, a layer of tar sand creates a thin perched water table at a depth of 3 meters, while at another site a thin layer of pink clay may have a similar effect. A range of vegetative covers are included. Supertest Hill is the only site where the soil parent material is till. Since till is fairly extensive west of the river and is included in overburden piles, there is good reason for obtaining some information on it. The remaining two sites are on opposite ends of the GCOS dike, and we are greatful to GCOS for their permission to use these areas. These sites allow soil physical conditions on the mined sand to be compared with conditions on sites in the surrounding areas.

The instrumentation consists of:

a) thermocouples at depth intervals down to 600 cm, or as close to that depth as it was possible to auger,
b) neutron probe access tubes to measure moisture content, also to 600 cm or to the water table where this was less than 600 cm deep,
c) a perforated pipe to measure the position of the water table,
d) at all except 3 sites, tensiometers to a depth of 300 cm or where there was a water table close to the surface, 200 cm, together with psychrometers at depth of 50 cm and less.

All instrumentation except thermocouples and water table tubes are now in duplicate.

Some of the results we are getting at these sites is shown. The 11 of August (Table 2) was chosen because moisture stress was fairly high at that time and fell later in the month. Greatest tensions occurred on the south-east slope of the dike in spite of a water table at a depth of around 200 cm. Moisture stress on the north-east of the dike was similar to that in nearby forested areas on sand.

The least stress occurred under mature spruce where the water table was within 200 cm of the surface.

Note that the tensiometers give a useful indication of the position of saturated layers whether these are thin perched layers or the true table.

Ground temperatures for August 11 are shown in Table 3. It is interesting that deep temperatures (which are presumably fairly close to mean ground temperatures) are higher on the dike than elsewhere. Possibly gound water movement is having some influence, and continuing measurement should clarify this.

Unfortunately a thermocouple could not be installed to 600 cm on the south-east slope of the dike with the means at our disposal.

During April, some time was spent monitoring snow-melt infiltration at Richardson's tower, partly in conjection with VE 6.1 sub-project. The thaw occured during the first week in April and in spite of rapid melting on the steep south-west facing sand slope, little surface runoff was observed. Neutron probe data (Figure 1) suggested that infiltration water was penetrating fairly quickly, well into the underlying frozen zone.

In May, gravimetric sampling was carried out at 3 separate sites, all on sand. The data (Figure 1) suggests that infiltrating water may either accumulate and remain at the top of the frozen zone as suggested by the first site, or penetrate into it as suggested by the second two sites. In all three instances, the 'bulge' is sufficiently large to contain most of the 5 to 6 cm of water provided by melting snow. (Rainfall amounts in the month following the thaw were very small.)

It is hoped to continue this study at selected sites, one of which would be on the dike, next spring.

While making installations on level ground near Richardson's tower, saturated or near saturated layers were encountered in the sand between dry layers, though no true water table was found. Detailed gravimetric moisture determinations made at one site are shown in Figure 2. A particle size analysis will be carried out on the samples to see if this can explain the position of the "wet" layers.

In the laboratory, pressure cells have been used to obtain moisture retension curves in the range of 0 to 1 bar. Figure 3 shows the curves for three sands, one from Richardson tower, one from near Mildred Lake, while the third is tailing sand from the GCOS dike. It can be seen that at low tensions, tailings sand has better moisture retaining properties than the other sands. Information beyond 1 bar tension has not yet been obtained, but should be obtained this winter. Samples will be equilibrated over salt solutions since the pressure apperatus does not give good results beyond a bar because of the low hydraulic conductiviy of sand at high tensions.

Some information on unsaturated hydraulic conductivities has been obtained using the method of Elrich and Bowman (1964). The curves for the Richardson material were obtained under sub-project VE 6.1 and those for tailings sand under this sub-project (VE 4.1). Note that hydraulic conductivity is on a log scale (Figure 4). At around 50 millibars tension, the sand from Richardson falls off in conductivity to 1/10,000 that at saturation. For many practical purposes it therefore has a true 'field capacity' at around this tension.

Although the saturated hydraulic conductivity of dike tailings sand is less than that of Richardson sand, the fall-off in conductivity as tension increases is less marked so that unsaturated conductivities are greater in tailings sand.

The effect of small additions of till and peat to tailings sand on its moisture retension have been investigated. The effect of a till high in silt and clay is shown (Figure 5). An addition of 10% till, approximately doubles moisture held in the range 100 to 1000 millibars tension. However, another till (Figure 6) which contains less silt and clay is much less effective in raising moisture holding capacity.

Only a 2.5% by weight addition of peat more than doubles moisture holding capacity between 100 and 1000 millibars (Figure 7). Information on tensions greater than 1 bar will be obtained with salt solutions in the near future.

As far as the work ahead is concerned, readings in the field will continue to be made over the winter with intensive study during the thaw period next spring. Next summer, it is proposed that effort be made to obtain information closer to the soil surface (where the bulk of the roots are) than present instrumentation will allow.

Laboratory work on moisture retension will continue, as well as investigations into methods of increasing it.

More information will be obtained on hydraulic conductivities as well as factors affecting the hydraulic conductivity of tailings sand.

Reference

Erilich, D.E. and D.H. Brown. 1964. Soil Sci Amer Pro 28, 450.

Table 1. Details of Sites

LOCATION	MATERIAL	VEGETATION	ASPECT	WATER TABLE
Richardson's tower	Sand	Jackpine	Flat	6 m
"	Sand	Birch/Aspen	NE	2 m
"	Sand	Birch/Aspen	NE	6 m
Mildred L. N of Camp	Sand	Aspen	SW	6 m
" Camp	Sand	Jackpine	Flat	6 m
" Camp	Sand	Birch/Aspen	Flat	Perched 3 m
" Camp	Sand	Mature Spruce	Flat	2 m
" S of Camp	Sand	Aspen	Flat	3 m
Supertest Hill	Till	Aspen	Flat	2 m
GCOS Dike 1	Sand	Grass	NW	6 m
" 2	Sand	Grass	SE	2 m

Table 2. Moisture Tensions (bars) at Six Sites on 11 August, 1976.

DEPTH cm	SITE 2 AOSERP CAMP PINE SAND	SITE 3 AOSERP CAMP ASPEN/BIRCH SAND	SITE 4 AOSERP CAMP SPRUCE SAND	SUPERTEST HILL ASPEN TILL	GCOS DIKE NW ASPECT GRASS TAILINGS	GCOS DIKE SE ASPECT GRASS TAILINGS
10	6.7	5.0	1.4	4.8	4.8	11.0
20	3.8	1.7	0.68	3.3	3.6	10.4
50	0.14	0.17	0.09	2.2	0.09	0.17
100	0.07	0.12	0.09	0.63	0.07	0.039
200	0.07	0.06	(-0.006 &-0.012)*	0.08	0.08	(0.00 & 0.014)*
300	0.052	(-0.01 & 0.08)*				

* Saturation at one or both replicates.
(At Site 3, there is a perched saturated layer overlying tar sand while the water table is the cause at Site 4 and GCOS, SE.)

Table 3. Ground temperature °C at Six Sites on 11 August, 1976.

DEPTH cm	SITE 2	SITE 3	SITE 4	SUPERTEST HILL	GCOS DIKE NW ASPECT	GCOS DIKE SE ASPECT
20	15.2	14.2	11.1	12.8	16.5	16.2
50	-	12.3	10.6	11.1	15.7	18.4
100	11.2	10.2	8.0	8.9	13.6	16.5
200	9.4	-	4.7	6.2	11.3	15.0
300	7.2	5.4	3.4	4.8	9.7	13.8
450	5.1	3.9	2.5	3.6	8.1	13.3
600	3.9	3.2	2.1	3.2	7.3	-

Figure 1. Moisture Profiles at Three Sites Following the Thaw.

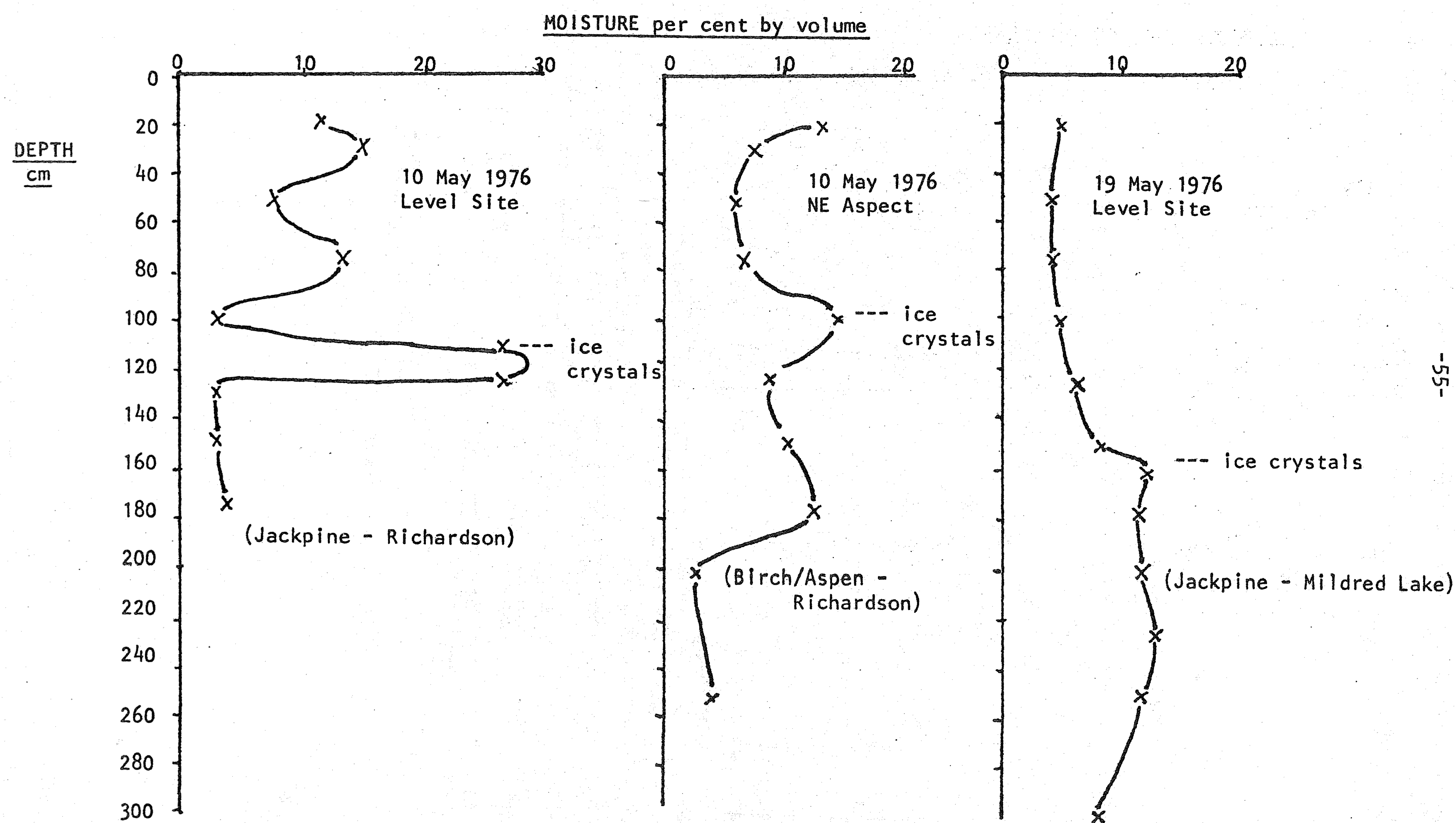


Figure 2. Moisture Profile at a Level Site in Sand Near Richardson's Tower. 4 August 1976

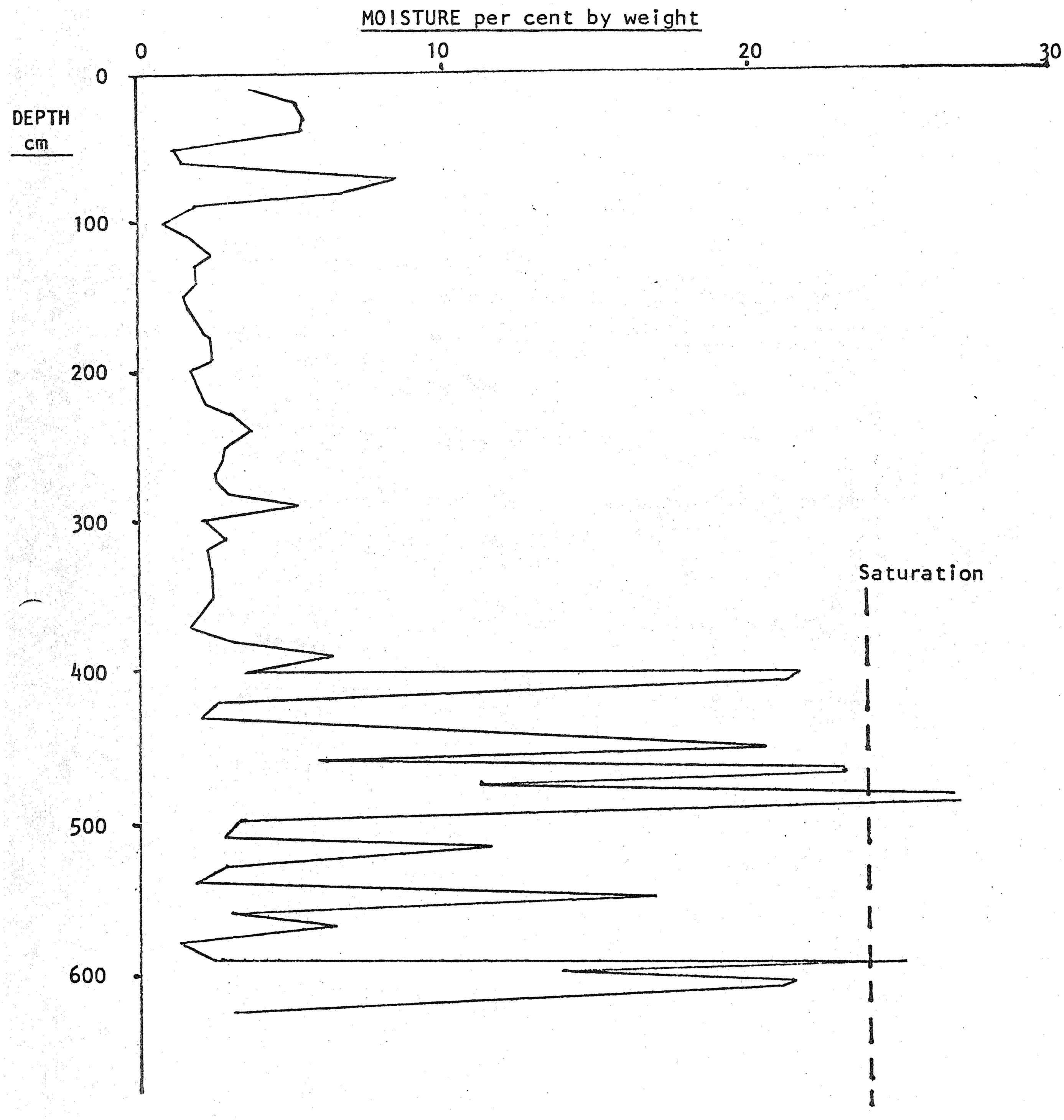


Figure 3. Moisture Retention Curves for Dike Tailings Sand, Sand from near Richardson's Tower and Sand From near Mildred Lake.

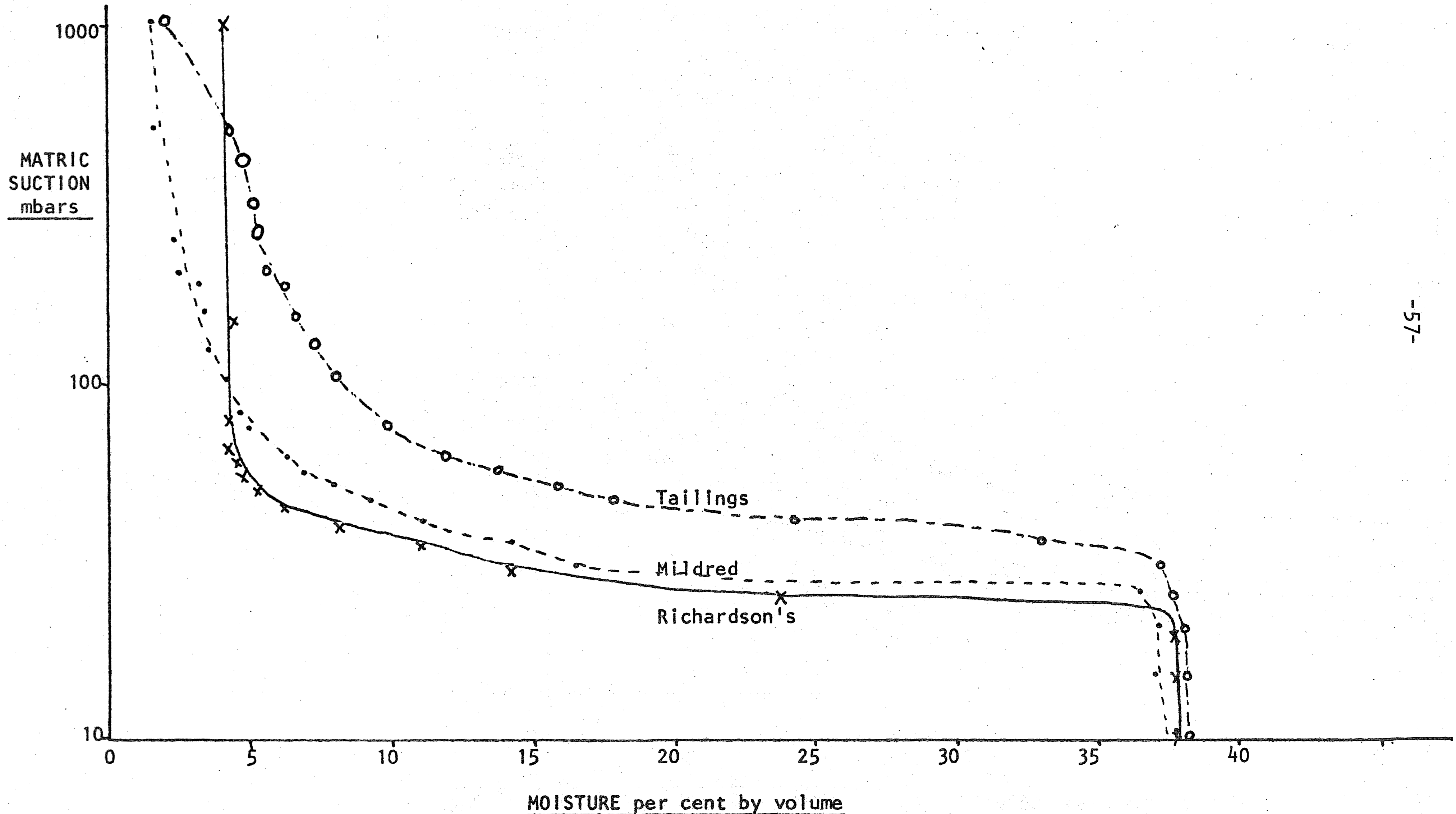


Figure 4. Relationship Between Hydraulic Conductivity and Moisture Tention for Tailings Sand and Sand from near Richardson's Tower.

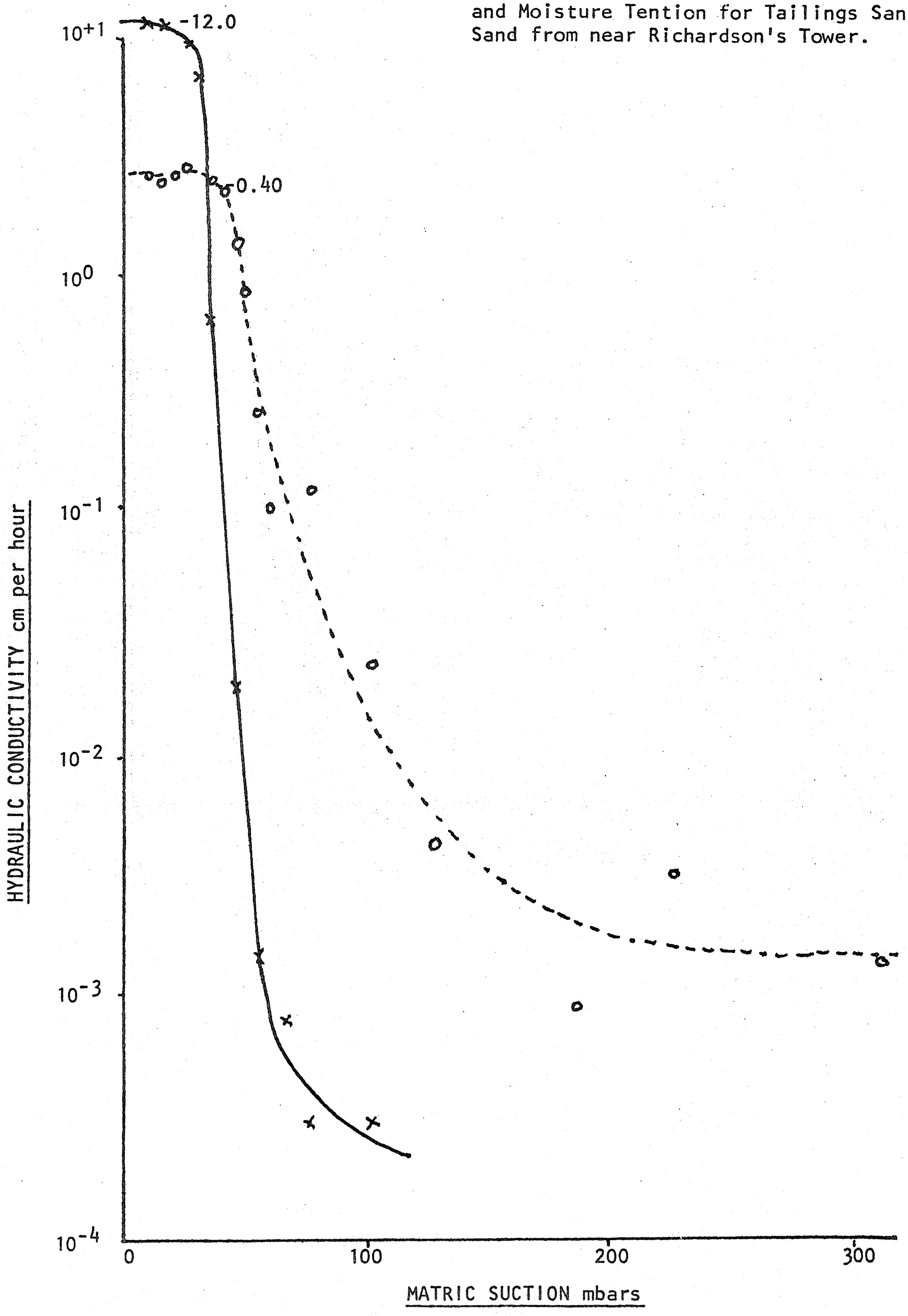


Figure 5. Effect of Additions of Till to Tailings Sand on the Moisture Rentention Curve.

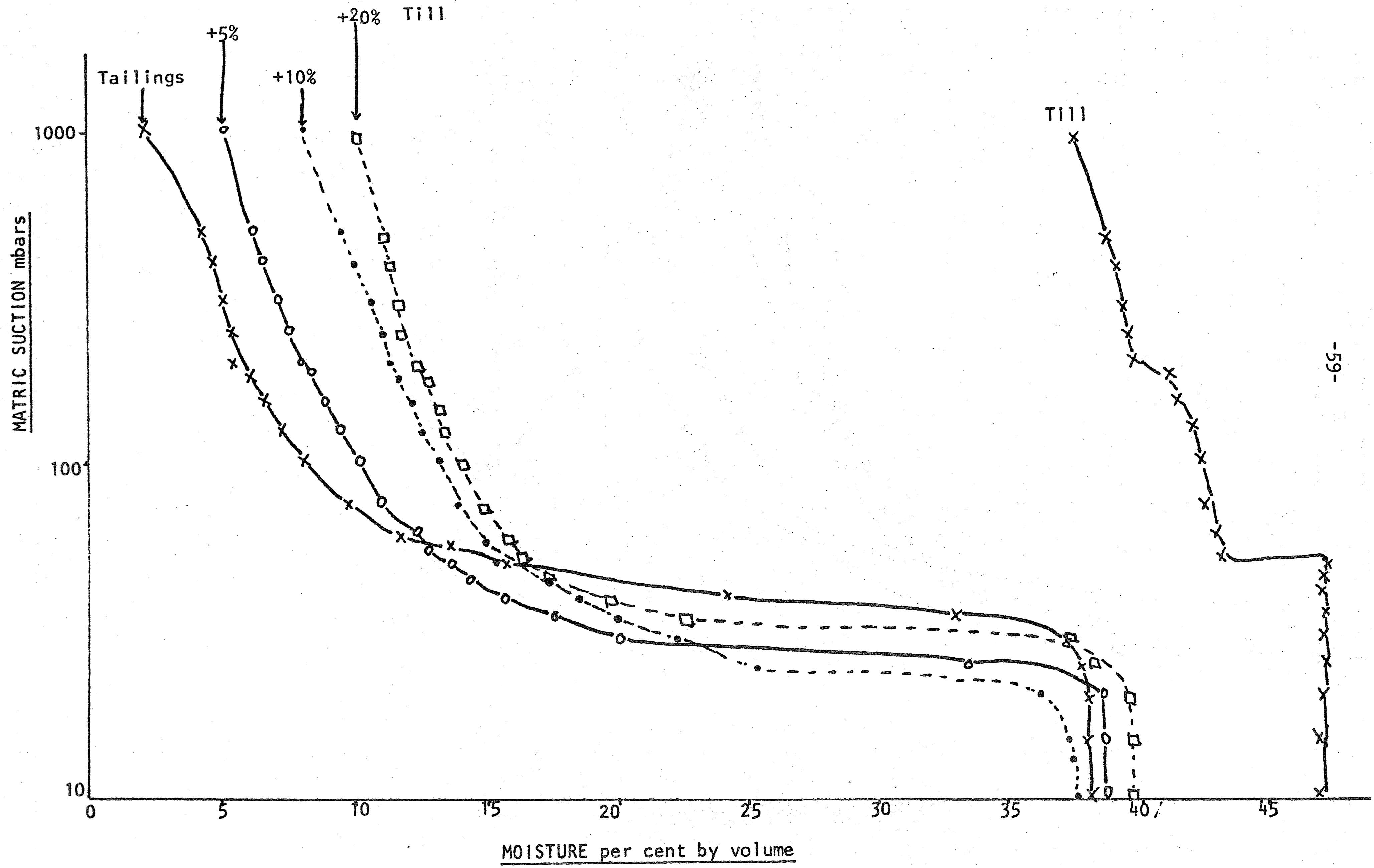


Figure 6. Effect of Additions of Till (Supertest Hill) to Tailings Sand on the Moisture Retention Curve.

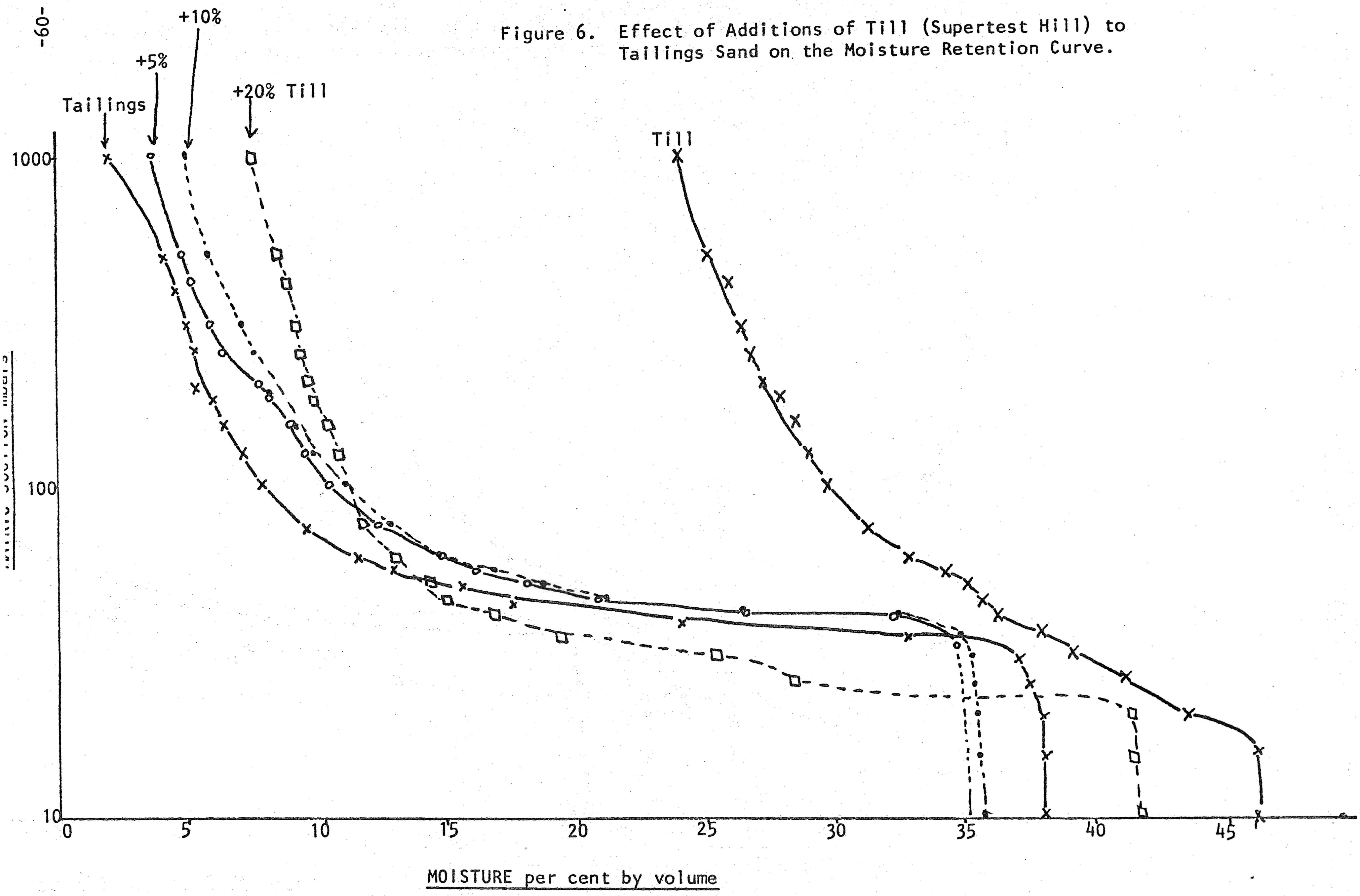
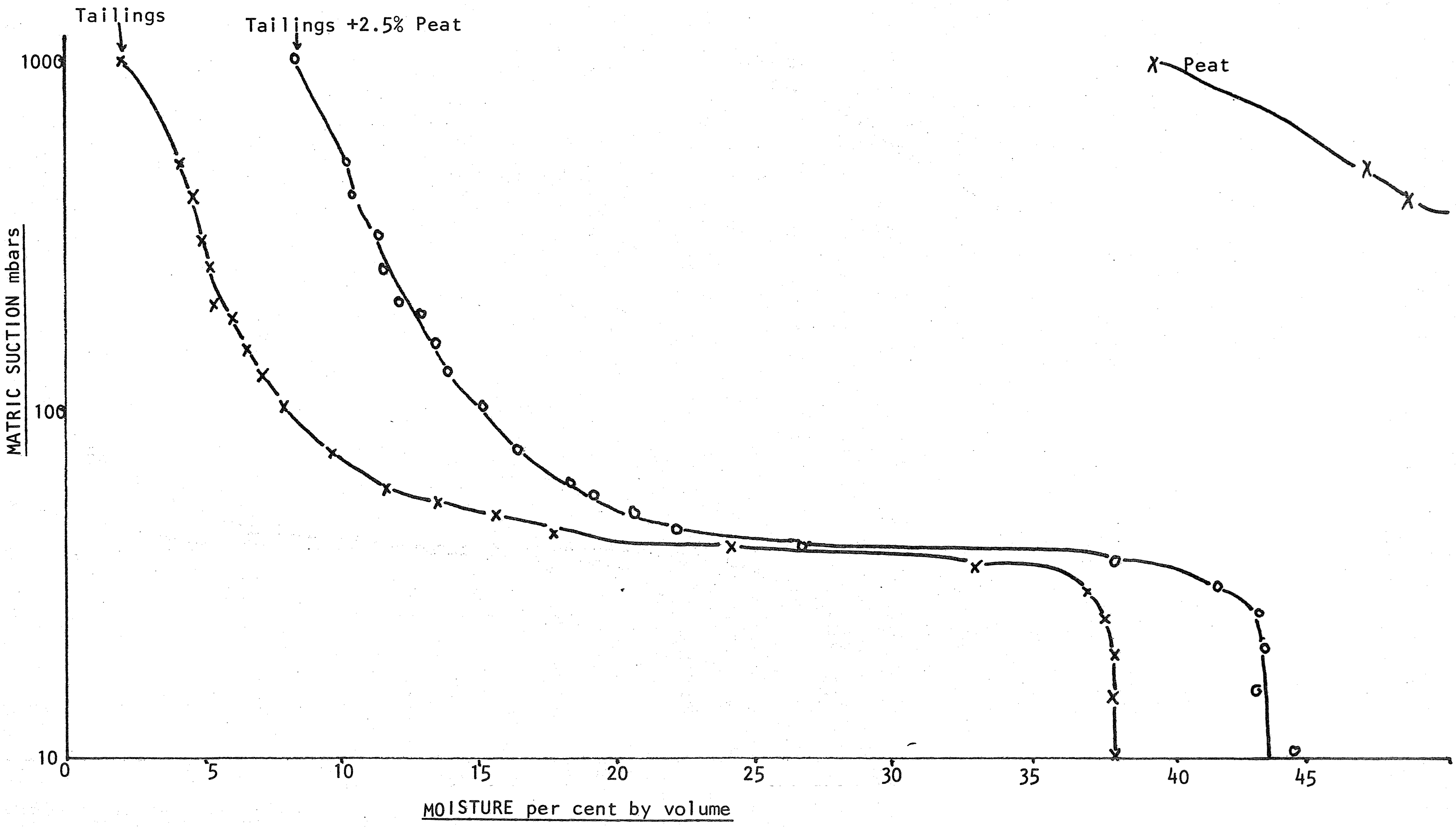


Figure 7. Effect of Additions of Peat to Tailings Sand on the Moisture Rentention Curve.



VE 5.2

CHARACTERIZATION AND UTILIZATION OF PEAT IN THE OIL SANDS AREA

CHARACTERIZATION AND UTILIZATION OF PEAT IN THE OIL SANDS AREA

Introduction

This project was initiated in October, 1975. The full time staff consists of Dr. Kong, Research Associate, and Miss R. Parnell, technician. In addition, Messrs. J.D. Lindsay and L.J. Knapik of the Soils Division, Research Council of Alberta, and Dr. W.B. McGill of the Department of Soil Science, University of Alberta are part of the project group. A summer student, Mr. M. Lam was engaged for laboratory assistance for the summer months , May to August, inclusive.

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 and to evaluate changes that may take place in the material during periods of prolonged storage and to relate these changes to potential use of the materials for reclamation in the tar sands area.

Research Approach

The approach to this study is basically one of investigating changes in peat properties (chemical, physical and microbiological) that occur during storage and as much as possible to quantify factors controlling them.

Initially, a portion of the Oil Sands area was inspected for the purpose of determining the major or most commonly occuring types of peat in the area. For this purpose the Canadian System of Soil Classification was employed. This system classifies peat according to botanical origin and stage of decomposition. Basically, three stages of decomposition are recognized: 1) Fibric - relatively undecomposed, 2) Mesic - partially decomposed, and 3) Humic - well decomposed. Each of these groups has its own physical and chemical properties. In addition, at the highest level of abstraction the peats are recognized as being of moss or fen (carex) origin.

Field Study

In the Fort McMurray area to date research has been carried out on three major types of peat deposits:

1) Sphagno - Fibrisol - These soils consist of uniform fibric organic material derived dominantly from Sphagnum spp. moss. They lack subdominant mesic or humic layers.
2) Typic Mesisiol - These soils consist of dominantly mesic organic material throughout the control section.
3) Fenno - Fibrisol - These soils consist of uniform fibric organic material, derived dominantly from rushes, reeds and sedges (carex).

In terms of "stored" peat or storage piles containing peat, three sites are under investigation as part of this project. These are located on the lease of Banff Mining and Quarrying at Evansburg, Alberta, the Syncrude Canada Lease at Mildred Lake and the GCOS lease at Fort McMurray.

1) Evansburg Site - The Evansburg site was established in mid-June at which time some delays were being encountered in respect to access to peat storage piles in the McMurray area.

   In cooperation with Banff Mining and Quarrying personnel, a peat storage pile some 4 meters in height was constructed. The peat for this pile is dominantly Silvo-Fibrisol consisting of relatively uniform fibric peat derived from sphagum moss with a fairly high content of wood.

The peat pile has been instrumented with fibreglass temperature-moisture cells, and weekly readings have been made since late June. Cellulose discs have been placed in the pile to provide a means of measuring the rate of cellulose decomposition. A 15 cm diameter plastic pipe has been installed in the pile to facilitate sample removal from the same site over two to three years.

Hydraulic conductivity measurements were carried out at three sites at Evansburg in order to establish the rate of water movement in the peat. This type of information is useful in assessing degree of decomposition of peat. Fertilizers experiments have also been initiated to evaluate the effect of liming and of added nutrients on the rate of decomposition of the peat. Sixteen duplicated treatments have been set up for this purpose.

In addition a 7 year old peat pile is also being studied at Evansburg. This pile, it is hoped, will provide information on long term storage in regard to changes that will not be available from recently contructed peat piles.

2) Syncrude Canada Ltd. Lease - Mildred Lake - The investigation of the peat storage piles on the Syncrude Canada site was initiated in mid-August. The material in the piles at this site is different from that at Evansburg because of the mixing of (substantial amounts) of glacial fluvial sand, glacial till and some lean tar sand with the peat. The presence of this mineral soil material has presented some problems in terms of uniformity of sampling. However, the piles have been sampled extensively in order to determine the heterogeneity of the material.

Soil temperature-moisture instrumentation has been established at 5 sites in the Mildred Lake area. Four sites are located in the peat storage area and one on an undisturbed bog area adjacent to the storage piles. Instrumentation was limited to a maximum depth of 150 cm because of the frost in the peat below this depth.

Cellulose discs have also been imbedded in the piles. Hydraulic conductivity measurements have been carried out at 3 undisturbed sites in the Mildred Lake area. These include Sphagno-Fibrisol, Typic Mesisol and Fenno-Fibrisol peat types that characterize much of the Oil Sands area.

3) Great Canadian Oil Sands Lease - Fort McMurray - Samples from the storage area on the GCOS lease were obtained during the winter. A deep drilling program presented the opportunity to obtain samples to a depth of 15 meters. This material also contains a significant proportion of mineral materials and will be difficult to assess in terms of peat properties.

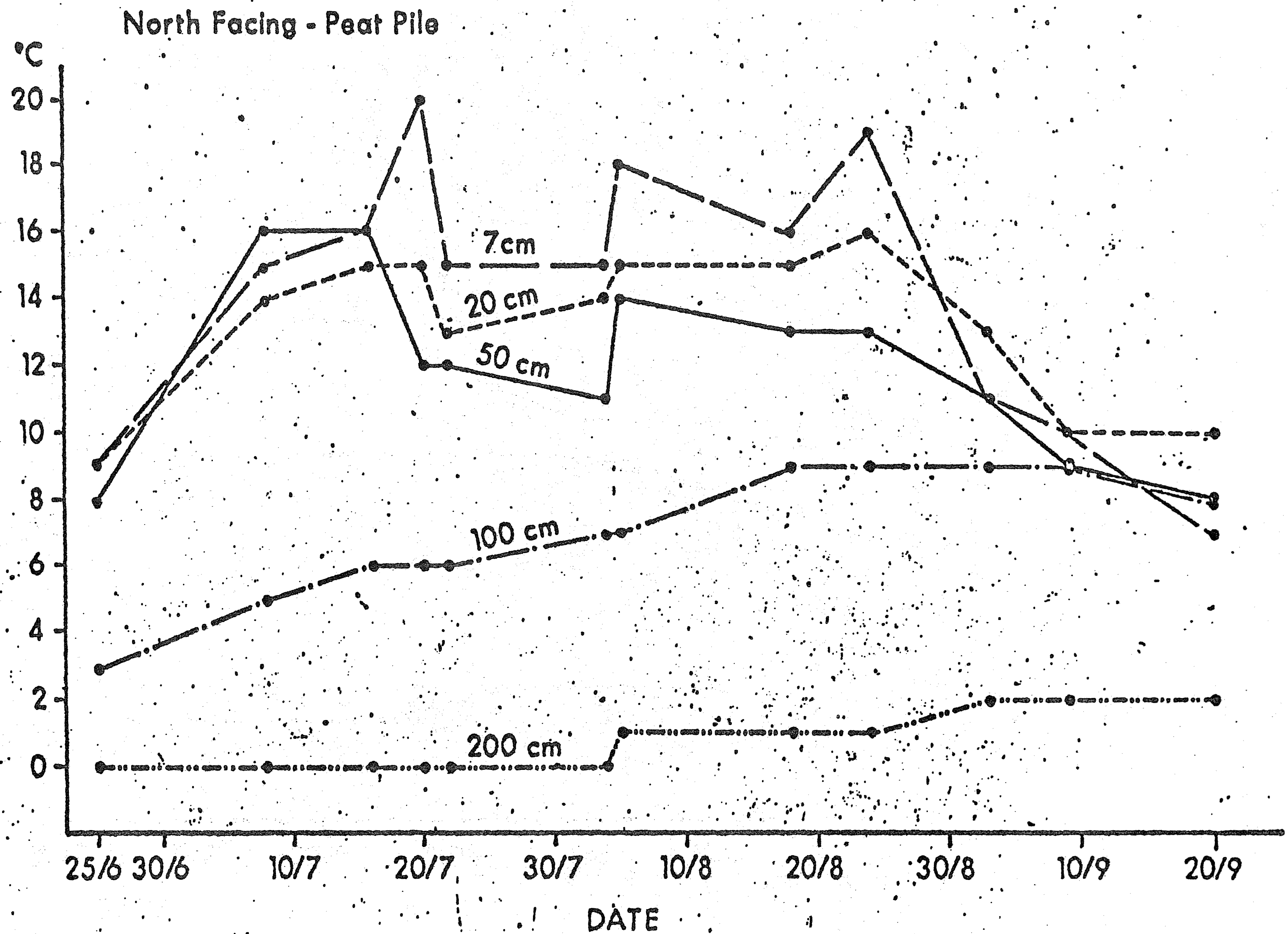
Results

Results obtained to date must be considered preliminary because of the limited time the project has been underway. However, some of the information obtained thus far is presented herein.

Temperature and Moisture - Peat Pile, Evansburg, Alberta.

Temperature and moisture readings on the north facing slope of the peat pile and at an undisturbed site adjacent to the pile are shown in Figures 1, 2 and 3. Generally, the temperatures near the surface, that is at depths of 7, 20 and 50 cm, reflect or correlated with the air temperature whereas at depths of 100 and 200 cm there appears to be less influence from the daily fluctuation in

FIGURE 1 Temperature Data - Evansburg, Alberta



-66-

FIGURE 2

Temperature Data - Evansburg, Alberta

Undisturbed Site

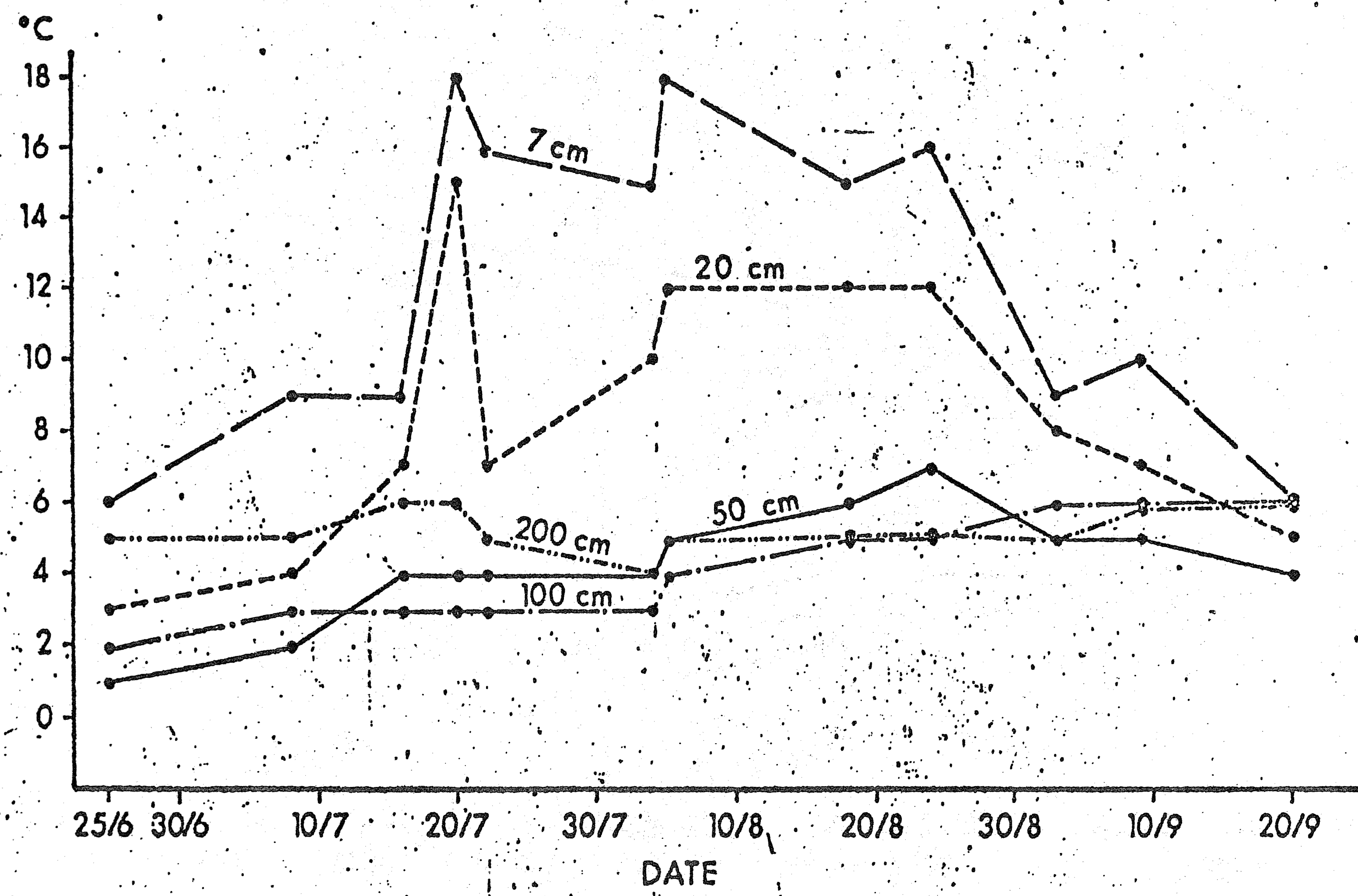
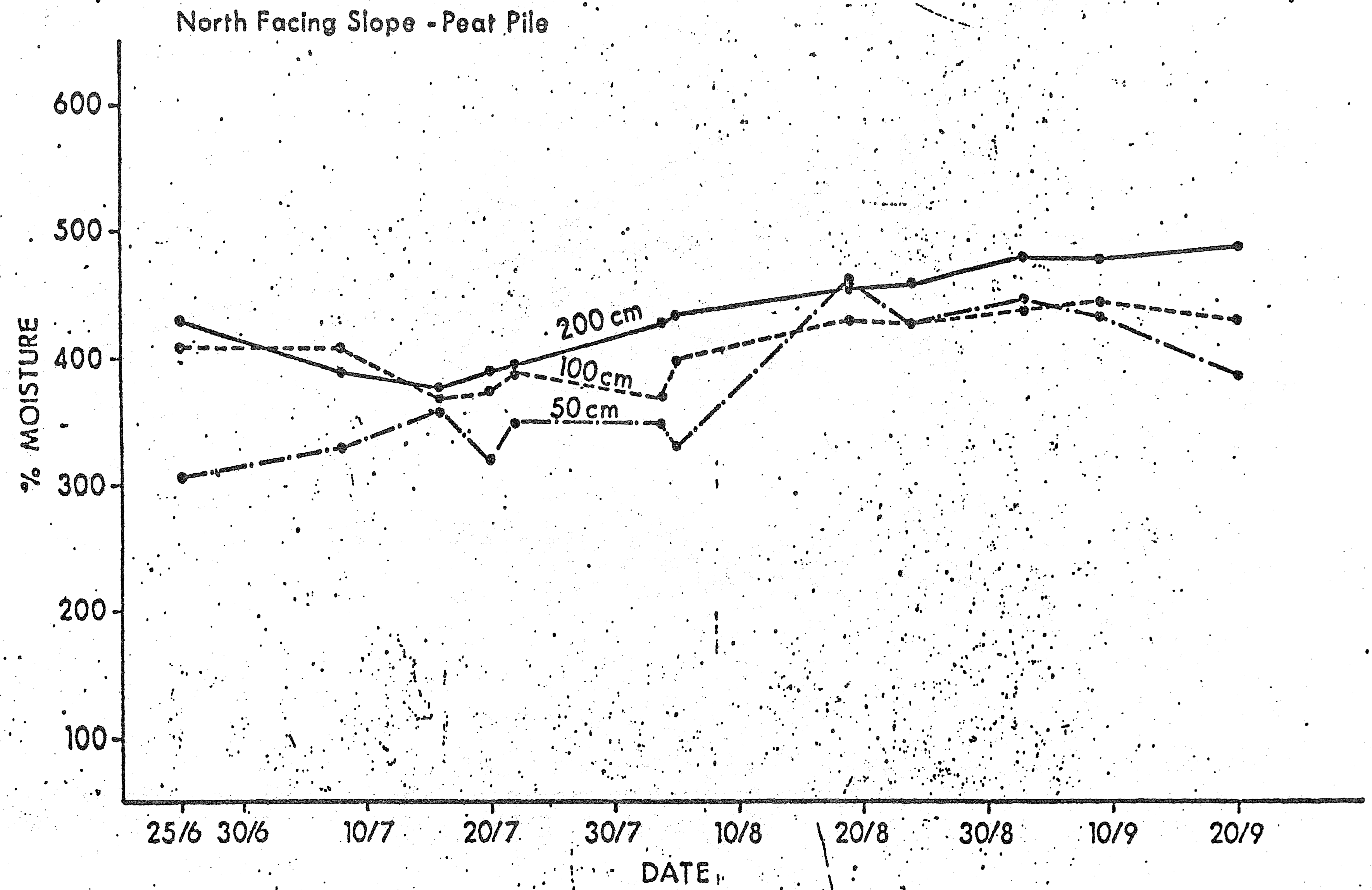


FIGURE 3

Moisture Data - Evansburg, Alberta



-60-

air temperature. It is interesting to note that at the 200 cm depth the peat which was frozen at the time the pile was constructed remained frozen until about August 5 and from the date until September 20 only increased in temperature by 3°C.

At the undisturbed, tree covered site, the 7 and 20 cm depths were again strongly influenced by air temperature but the 50, 100 and 200 cm depths appear to be relatively unaffected or only slightly affected by the daily fluctuation in air temperature. It should be noted that early in the summer season the lowest temperatures are recorded at the 50 and 100 cm depths. The field inspection at this site indicated that the depth of seasonal freeze is about 100 cm and below this depth the peat remains unfrozen at the Evansburg site.

Changes in moisture content at the 100 and 200 cm depths appear to be minimal during the summer months. At the 50 cm depth, however, the flucturations in moisture content would appear to correlate with periods of relatively high air temperature and with the occurrence of rainfall in late August.

Characterization Storage Pile - GCOS Lease

As mentioned earlier, the field inspection at the GCOS site indicated that the material was fairly heterogeneous and would appear to have serious limitation for use as a medium for studying peat characteristics. An analysis of ten samples from this site is given in Table 1 and indicates the heterogeneous nature of this material. The Canadian System of Soil Classification uses 17 percent organic carbon as the minimum for inclusion in the Organic Order of soils. On this basis only four of the samples analyzed would meet this criteria. The ash content of the samples confirms the relatively low content of organic matter in most of the soil samples. For comparison purposes the ash and organic carbon contents of three pure peats from the Fort McMurray area are presented.

Physical Properties of Peat

Table 2 shows that the moisture content in a fibric peat layer is higher than in the mesic and Fenno-Fibrisol. The typical characteristics of a fibric layer are a high fiber content and air capacity, but a low bulk density and ash content, so humification rate in this layer is low. The mesic layer shows increasing bulk density and ash content. Water capacity is also higher than in the fibric layer. The rubbed fiber in the fenno-fibrisol is under 10%, but the bulk density and ash content are higher than in both the fibric and mesic layers of sphagnum peat.

In the Evansburg peat pile, the measurement of physical properties has been carried out from the top layer (0 - 60 cm) to the bottom (150 - 180). Comparisons are being made with the undisturbed peat (control site) near the peat pile. Table 3 shows the moisture content and water capacity are low in the top layer; fiber content is higher than other layers of this pile. The middle and bottom layers appear to have similar physical properties, except for the fiber content.

According to the change of fiber content, we may observe some humification in the middle portion at 90 to 150 sm. Strong evaporation and draining may cause drying in the top layer of peat pile. In this case the decreasing microbial activities may slow down the biodegradation of organic matter in this region.

TABLE 1 CCOS - Storage Sites

Site #1							Site #2						
ple th ters)	% >5mm	% 2-5mm	% <2mm	% Ash	% C	Bitumen Content %	Sample Depth (meters)	% >5mm	% 2-5mm	% <2mm	% Ash	% C	Bitumen Content %
.7	6	25	69	43	31	2.22	3.0	62	10	28	95	3	1.34
.0	22	11	67	76	18	0.78	7.2	27	13	60	85	14	0.59
.5	26	15	59	71	13	2.06	9.0	61	10	29	83	18	0.47
.9	15	17	68	82	11	0.74							
.2	47	6	47	82	11	0.35							
.2	17	11	72	84	19	0.49							
.0	32	17	51	88	7	0.36							

PEAT

	% Ash	%C
Sphagno Fibrisol	3	43
Typic Mesisol	5	46
Fenno Fibrisol	11	46

Table 2. Physical properties of peat from the Fort McMurray area.

Classification	Moisture Content %	Specific Gravity g/cc	Bulk Density g/cc	Pore Volume %	Air Capacity %	Water Capacity %	Fibre Content (100 mesh) (%) unrubbed	rubbed	Ash Content %
Fibric layer	1168	1.50	.046	96.9	40.0	56.9	95	80	3
Mesic layer	554	1.63	.072	95.3	33.0	62.3	85	50	5
Fenno-fibrisol	934	1.60	.106	93.4	23.0	70.1	35	10	11

Table 3. Physical properties of peat from Evansburg peat pile.

Peat Layer	Depth cm	Moisture Content %	Specific Gravity g/cc	Bulk Density g/cc	Pore Volume %	Air Capacity %	Water Capacity %	Fiber Content % unrubbed	rubbed
Top	0-60	350	1.55	.090	93.6	26.7	66.9	90	60
Middle	90-150	418	1.60	.097	93.9	19.6	74.3	75	40
Bottom	150-180	419	1.58	.097	94.5	21.3	73.2	85	60
Undisturbed	field	580	1.52	.064	95.8	32.1	63.7	95	85

TABLE 4.

HYDRAULIC CONDUCTIVITY STUDY IN FORT McMURRAY AND EVANSBURG PEATS

Peat Site	K cm/sec. (Total 31 measurements)
Ft. McMurray	
1. Sphagno-fibrisol	2.2E - 03 to 5.9E - 04
2. Terric mesisol	1.4E - 03 to 7.9E - 05
3. Fenno-fibrisol	3.3E - 04 to 4.8E - 05
Evansburg	
4. Silvo-fibrisol	8.4E - 04 to 1.8E - 05

Hydraulic Conductivity

Hydraulic conductivites (K) calculated using Kirkham's (1946) equation:

$$K = \frac{r^2 1nhi/hj}{A(tJ - ti)}$$

where h = head; measured between the water level in the tube during the experiment and the water table within the tube.
r = radius of cavity.
t = time recorded from the start of experiment.
A = shape function estimated from Young (1968).

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

The purpose of this research is to characterize the peat in the Fort McMurray and Evansburg areas.

The following results show the different hydraulic gradients in four types of peat. These sphagno-fibrisols were located to the north of Mildred Lake. In this area hydraulic conductivities were uniform from the top to the bottom of the layer.

A terric meisol with black spruce cover showed hydraulic conductivities were high near the surface layer (40 cm) but progressively decreased with depth (80 cm). A dominant mesic material was developed throughout the middle and bottom tiers.

The fenno-fibrisol consists of a somewhat decomposed material in the middle and bottom tiers with the water table near the surface. The hydraulic conductivity in this peat is low, probably because of intense activity of anaerobe microflora in the bottom layer.

The Silvo-fibrisol, at Evansburg, consists of a fibric layer near the top and considerable wood in the middle tier. The hydraulic conductivity was highest at the top and lowest at the bottom.

Hydraulic conductivity measurements for sites at Fort McMurray and Evansburg are shown in Table 4.

Chemical Properties of Peats

The Sphagnum peat examined is fibric and mesic in character. Both are acid (pH value less than 3.7 in $CaCl_2$, 0.01 M). Nitrogen content is low, C/N ratio up to 74. The degree of base saturation in both the fibric and mesic peat layers is low (34 to 44% compared to Fenno-fibrisol at 96%). The fibric layer is biologically inactive, probably because of a high water level and poor nutrition, especially nitrogen. This results in incomplete transformation of organic residue in this layer.

The Fenno-fibrisol present has a high pH value and organic matter is transformed completely due to high nitrogen content and degree of base saturation.

Some chemical properties of representative samples of various peat from the Fort McMurray area is given in Table 5.

Enzymatic Activity

The important enzymes in organic soil are mainly invovled in the carbon and nitrogen cycle. Hydrolyzing enzymes can break up organic matter in soil and produce simple sugar (glucose). Many workers use soil enzumes produced by soil microorganisms to investigate the nitrogen mineralization and the humification of organic carbon.

Soil microorganisms can only use reducing sugar as an energy source for their metabolism. Many of these energy sources originate from the degradation of cellulose material in the soil.

In this study the activity of cellulose C_1, Carboxymethylcellulose C_x, and B-glucosidase were examined essentially by the methods of Sorensen (1957) and Hoffman (1965). The C_1 components are essential for attack on highly ordered forms of cellulose, such as unmodified cotton. The C_x components, which can attack only swollen or chemically modified forms of cellulose such as carboxymethylcellulose. The following diagram helps to illustrate the different enzyme activities investigated in this study:

Native cellulose $\xrightarrow{C_1}$ linear cellulose chains $\xrightarrow{C_x}$ Cellobiose $\xrightarrow{\text{B-gluecosidase}}$ glucose

Reducing sugars are determined by the Spectronic-70, copper reagent method of Somogyi which covers the range 0.05 to 0.3 mg of glucose per ml.

The following substrata have been used in this work:

1) Cellulose powder: Whatman CC41
2) Carboxymethylcellulose: Sodium salt CMC-7HSP, Hercules Powder Company
3) Salicin S 30-5. Aldrich Chemical Company Inc.

Cellulase C_1 and B-glucosidase activities are very low in sphagnum peat (fibric and mesic layers) but they are high in Fenno-fibrisol. The distribution of enzyme may be related to their chemical properties, such as pH, N, Ca, P_2O_5 content. Further research is required to illustrate the role of cellulose decomposition in peat.

Some preliminary results with respect to enzyme activity in three samples of peat from the Fort McMurray area are given in Table 6.

Microbiological Study

The two major groups of microorganisms present in peat are bacteria and fungi. Actinomycetes are also present, but make up a very minor part due to the low pH and generally anaerobic environment. Several methods are used to estimate the sizes of the populations of the various microorganisms.

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) - an undefined "junk" medium which allows the growth of a great variety of soil microorganisms, although those with requirements for vitamins, carbon sources or energy sources not met by this medium will not grow. Also, the incubations were aerobic and some bacteria will not grow in the presence of oxygen. Although plate counts are not total counts, they do give an indication of the size of the population and of increases or decreases which may occur after treatment.

Most Probable Number (MPN) techniques were used to estimate numbers of more specific groups of organisms. This is a statistical method which is not as accurate as plate counts but is much more flexible. The organisms are grown in test tubes containing a medium. Quite often if aerobes are growing near the top of the tube, the conditions at the bottom are anaerobic enough to allow the growth of anaerobes. Also the growth medium can be tested for the presence of products such as ammonia or nitrate.

Table 5. Chemical properties of peat from the Fort McMurray Area.

Classification	pH		Cation Exchange Capacity* m.e./100g						Total		
	H_2O	$CaCl_2$	Ca^{++}	Mg^{++}	K^+	Na^+	T.E.C.**	% Base Sat.	N%	C%	C/N
Fibric layer	4.4	3.4	36.51	5.75	0.24	0.31	126	34	0.58	42.66	74
Mesic layer	4.7	3.7	61.32	6.13	0.07	0.25	153	44	1.03	45.73	44
Fenno-fibrisol	6.6	5.8	94.22	10.94	0.13	0.38	110	96	2.80	46.49	17

* Extracted with NH_4OAc-N solution.

**Total Exchange Capacity - Extracted with NaCl-N solution.

Table 6. Enzyme activities in three McMurray peats.

Sample	Peat type	ENZYME ACTIVITIES		
		Cellulose C_1 mg reducing sugar/g/5 days	Carboxymethyl Cellulase C_x mg reducing sugar/g/24 hr	B-glucosidese mg saligenin/g/3hr
Fort McMurray 1	fibric layer	0.332	0.580	0.131
	mesic layer	0.341	0.764	0.161
Fort McMurray 2	fenno-fibrisol	0.574	0.694	0.575

Several types of organisms can be measured in this way. Cellulose decomposers can be measured either by MPN's or by plate counts, but they are very slow growing and unless the humidity is controlled the plates dry out before counts can be obtained. For this reason, cellulose degraders were estimated by the MPN technique using test tubes with a mineral salts solution and a strip of filter paper as a carbon source. Growth is visible on the filter paper after about a month of incubation.

Other organisms for which this method was used include sulfate reducers, sulfur oxidizers, iron reducers, denitrifiers, ammonifiers, nitrifiers, and nitrogen fixers. Numbers of these organisms are important not only as an index of the level of microbial activity of a soil, but many of them also affect the availability of other elements required by plants.

Several methods are used to measure the amount of fungi in soils but all have some disadvantages. Plate counts are often used, but a colony on a plate will result from an intact hyphae, a piece of hyphae, or a spore. A high count may therefore indicate either conditions suitable for fungal growth and a large amount of hyphae, or conditions unsuitable for growth and a large number of spores.

The other common method of measuring fungi is the Jones and Mollison technique. This involves making a suspension of soil and agar and distributing this on a microscope slide to a known thickness. This agar film is dried, examined microscopically either after staining or under phase-contrast, and the amount of fungal hyphae measured. Staining over-estimates the amount of viable hyphae since some dead hyphae is also stained, while phase-contrast microscopy allows the measurement of all hyphae and gives a better estimate of the total fungal biomass present.

All of these methods were used in the freezing/nutrition experiment. A pot of each treatment was set up and treated in the same manner as the other portions of the experiment. Samples were taken at the beginning, before and after the first 24 hour freezing, before the addition of nutrients, a week after nutrient addition, and a week after glucose addition. At each of these times plate counts for bacteria and fungi were done, and samples were placed in a fixative for the Jones and Mollison technique. At four of these times, MPN's for cellulose decomposers were set up.

Fungal plate counts were so low for most of the samples that accurate estimates could not be obtained and no significant change occurred throughout the experiment.

Figure 4 shows the changes in the three treatments of mesic peat. During the initial incubation, the normal did not change, while the drying treatments showed a small increase. Freezing for 24 hours caused little significant change in the numbers of organisms. At the end of the freezing period, the normal had risen slightly while the drying treatments showed little further change. In all three treatments, the addition of nutrients caused a marked rise in the number of bacteria. The addition of glucose caused a rise in numbers in the normal, but had little effect on the drying treatments, although they continued to evolve CO_2 at a high rate. It would appear that the drying selected a population with a higher turnover rate than the normal, and less net change in the numbers of bacteria.

Figure 5 shows the normal treatments of all three peats. It can be seen that the mesic and fibric are very similar throughout the experiment. This is also the case for the air-dried and freeze-dried treatments. However, the fen is different in all cases.

TABLE 5. CHEMICAL PROPERTIES OF PEAT FROM THE FORT McMURRAY AREA

Classification	pH		Cation Exchange Capacity * m.e./100 g					% Base Sat.	Total N %	C %	C/N
	H_2O	$CaCl_2$	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	T.E.C.**				
Fibric layer	4.4	3.4	36.51	5.75	0.24	0.31	126	34	0.58	42.66	74
Mesic layer	4.7	3.7	61.32	6.13	0.07	0.25	153	44	1.03	45.73	44
Fenno-fibrisol	6.6	5.8	94.22	10.94	0.13	0.38	110	96	2.80	46.49	17

* Extracted with NH_4OAc-N solution.

** Total Exchange Capacity - Extracted with NaCl-N solution.

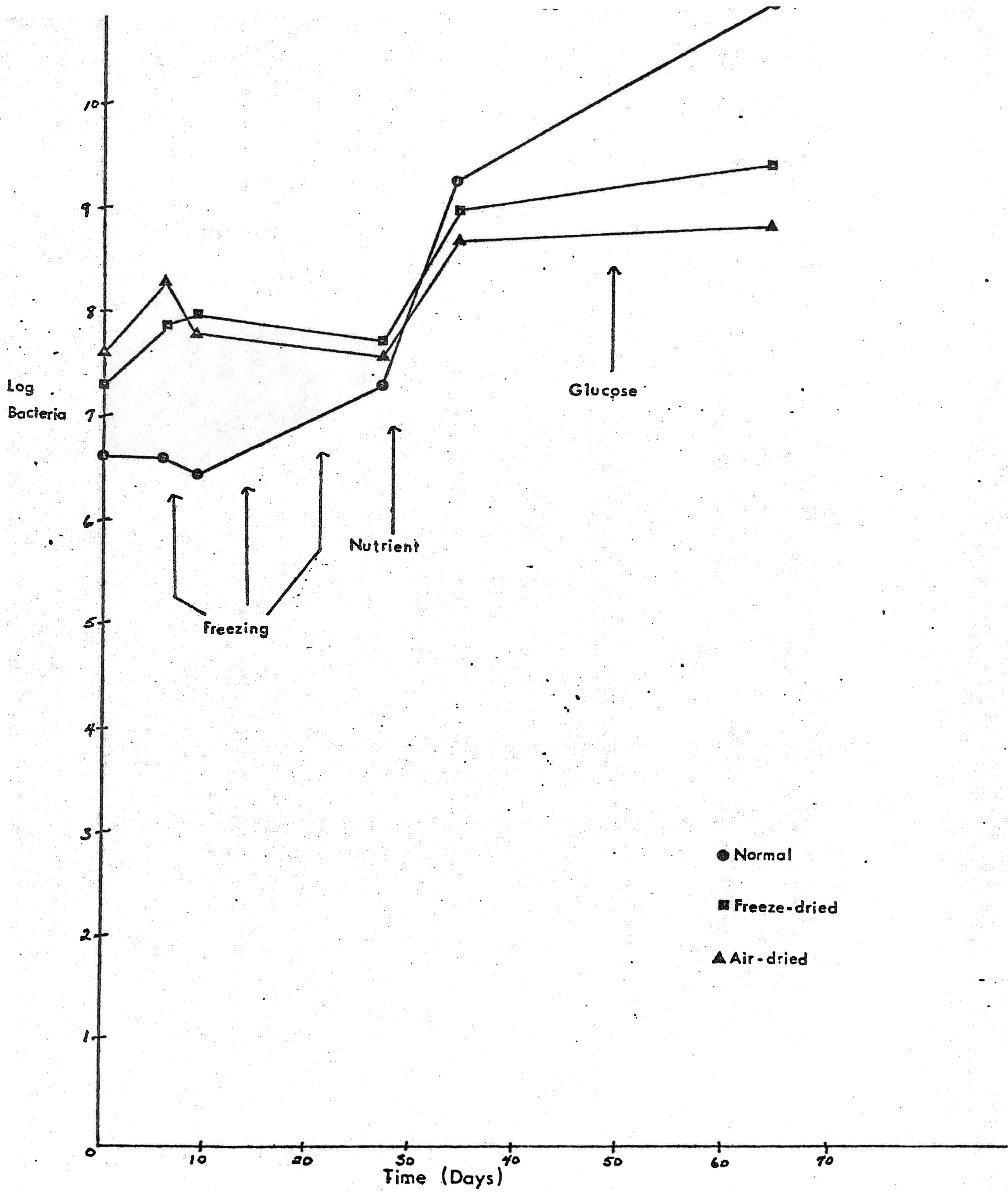


Figure 4 – Changes in numbers of organisms in mesic peat with three types of treatment.

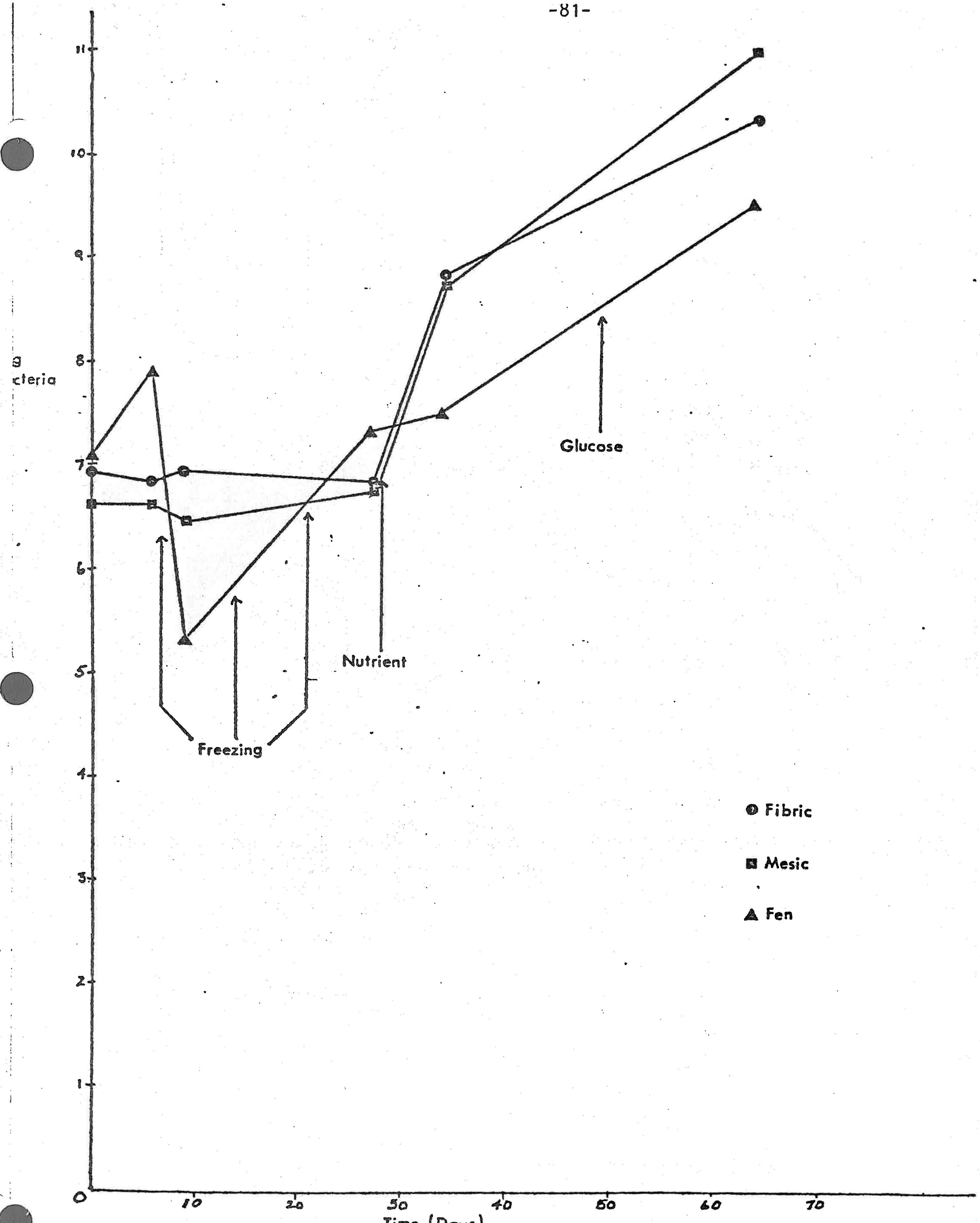


Figure 5 – Changes in numbers of organisms in fibric moss, mesic moss and fen peat following treatment.

ria

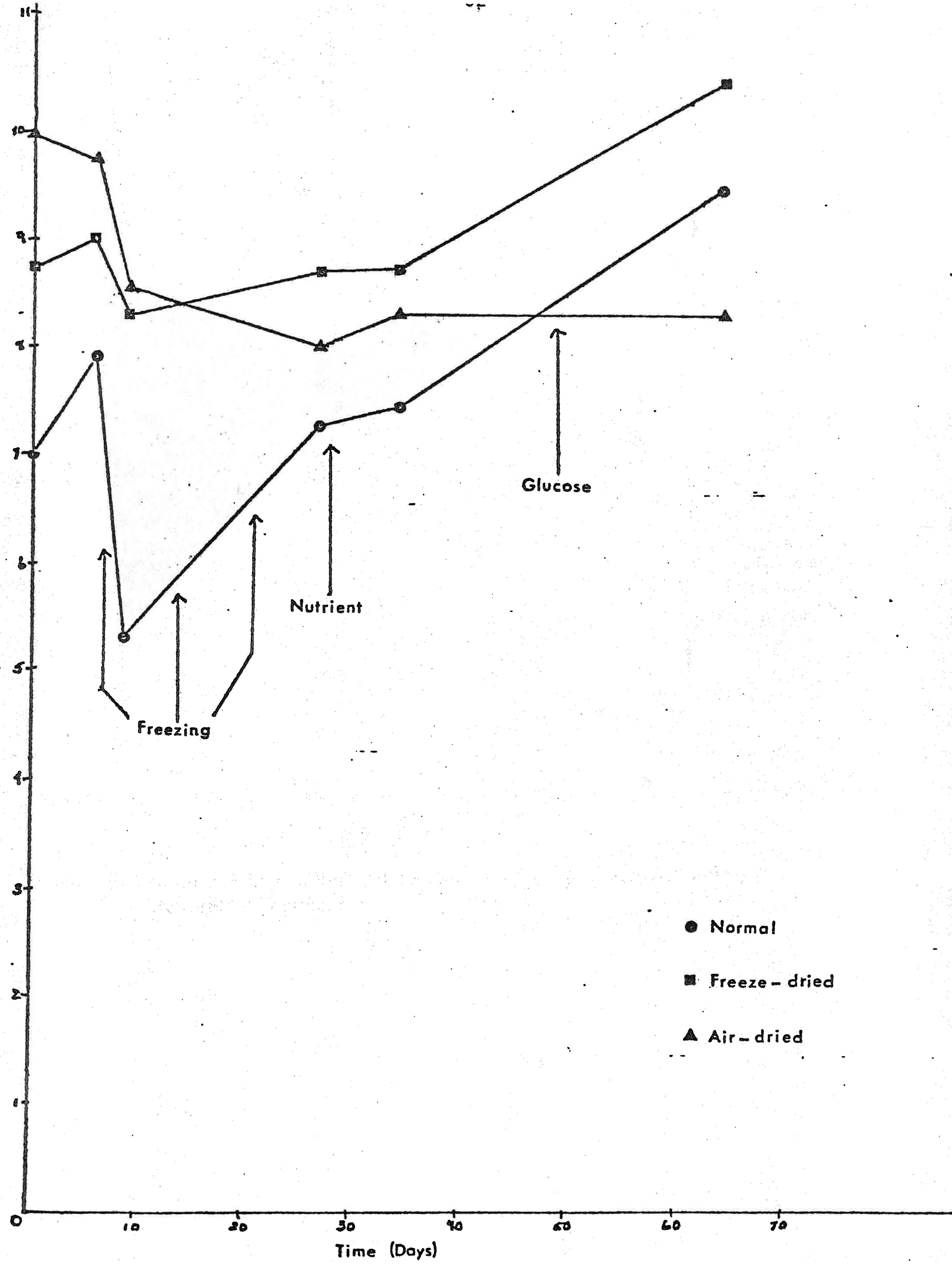


Figure 6 – Changes in numbers of organisms in a fen peat following different treatments.

Figure 6, the three treatments of fen peat, shows quite significant drops in the numbers of bacteria during the first 24 hour freezing, with no significant increase in the air-dried treatment throughout the rest of the experiment. None of the treatments reacted to nutrient addition (unlike mesic and fibric), while only the normal and freeze-dried showed an increase in numbers when glucose was added.

The numbers of cellulose decomposers were also determined. The fibric peat had such a small number that the MPN technique was unreliable and no conclusions could be drawn. After addition of nutrients, the fen responded slightly and the mesic sharply (Fig. 7). However, after addition of glucose, the numbers in the mesic peat continued to rise, while those in the fen dropped.

Measurement of fungal length began only recently, but some preliminary results have been obtained for a few samples. Lengths so far are about 10 times those reported for other soils, and there appears to be a significant drop from the beginning to the end of the experiment (Table 7). The mesic peat contains the most, then the fibric, and although lengths are not reported for sedge, they are less than 10% of those in the other peats.

Table 7. Hyphal lengths by phase-contrast microscopy km/g dry weight.

Peat	Day 0	Day 64
Fibric normal	27	20
Mesic normal	45	36

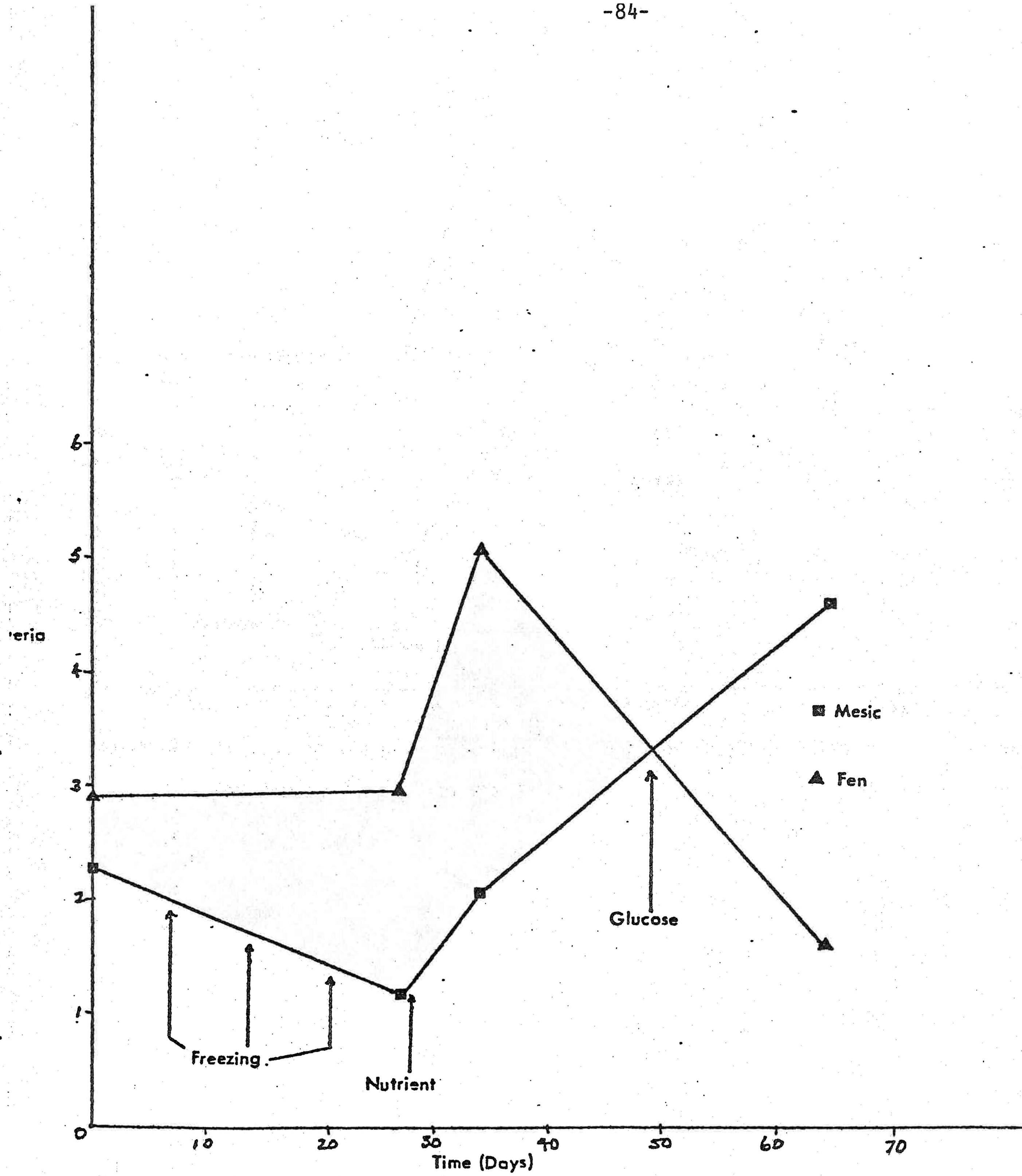


Figure 7 – Changes in numbers of cellulose decomposers in mesic moss and fen peat following treatment.

EFFECT OF SIMULATED MANAGEMENT PRACTICES ON PHYSICAL PROPERTIES AND DECOMPOSITION PROCESSES AFFECTING THE USE OF VARIOUS PEATS IN LAND RECLAMATION: PRELIMINARY RESULTS

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Introduction

Peat has proven useful in vegetating the dikes at the GCOS mine site at Fort McMurray, Alberta. The main benefit derived from peat is physical, with some chemical, biological and nutritional advantages also associated with certain peats. Desirable physical properties include: high hydraulic conductivity and porosity, low bulk density and high fibre content. The most desirable physical peat properties are generally associated with minimal decomposition. Desirable chemical properties such as high cation exchange capacity, buffering capacity and nutrient supplying power are generally associated with more thoroughly decomposed and humified peats.

Proper use of peat in land reclamation requires an ability to predict changes occurring in peat as a result of the way it is stored and used. This is turn requires quantitative information on factors and processes causing changes in the physical and chemical characteristics of peat. Changes occurring during storage and after use as a surface amendment result primarily from biological alteration of the peat.

The ultimate objectives of this project are a) to be able to make assessments of the changes occurring in peat during long term storage; b) to study the effect that overburden admixtures in peat piles have on the usefulness of the peat; and c) to study in conjunction with the Soil project (VE 4) the long term fate and usefulness of various types of peat when mixed with a range of overburden materials and tailings sand.

The immediate objective of the study reported here is to find out what effect freezing and thawing, wetting and drying, and addition of a readily available supply of nutrients and energy in combination had on the physical nature of peat and to some extent how this effect was caused. This experiment was conducted in the laboratory. The treatments were applied sequentially so that conditions more closely resembling a field situation could be simulated. Conducting the experiment in the laboratory allowed considerable acceleration of rates of change in peat properties.

Materials and Methods

Peats:

Peat samples F1, M4 and F2 were fibric, mesic and fibric materials respectively obtained from the surface near Wabamun Lake, Alberta in a black spruce (Picea mariana) bog. Samples F and M were obtained from a black spruce bog near Mildred Lake, Alberta and sample FEN from a fen near the Mildred Lake airstrip. Some chemical and physical properties of the peats are presented in Table 1. The peat was stored moist at 4°C until used in these studies (about 5 months).

TABLE 1. SOME CHEMICAL AND PHYSICAL PROPERTIES OF PEATS USED

Sample	pH*	CEC**	% base Sat.	% N	C/N	Ext. P ppm	% Ash	Db g/cc	Pore Vol.	Air Cap.	% Fiber (100 mesh) Unrubbed	Rubbed
F1	4.0	115	14	1.3	36	3	5	0.071	95.4	33.7	90	50
M4	7.1	165	91	2.2	16	4	22	0.097	93.5	35.1	65	28
F2	6.2	137	73	1.6	29	2	10	0.084	94.4	32.4	75	60
F	4.4	126	35	0.6	74	18	3	0.046	96.9	40.0	95	80
Composite M M1, M2, M3	4.7	153	44	1.0	44	5	5	0.072	95.3	33.0	85	50
FEN	6.6	110	96	2.8	17	4	11	0.106	93.4	23.0	35	<10

* Determined in H_2O

** milliequivalents/100 g dry wt.

Analytical:

pH was determined in water, using a water:field moist peat ratio of 2.5:1. Base saturation is reported as the sum of Ca + Mg + K + Na extractable with $C_2H_3ONH_4$ at pH 7.0 calculated as a % of the total exchange capacity determined with NaCl (McKeague, 1976, p. 69 & 74). Nitrogen was determined according to the semi micro Kjeldahl procedure (McKeague, 1976, p. 124) and total carbon using a Leco carbon analyser (McKeague, 1976, p. 106). Phosphorus was extracted with 0.002 N H_2SO_4 and the orthophosphate measured calorimetrically using the Molybdate blue method (Jackson, 1958). Ash is reported as the percentof the original material remaining as residue after heating at 450°C for 4 hours in an electric muffle furnace.

Bulk density was measured in the following manner: moist peat was placed into a 2 l. container with drainage at the bottom and allowed to sit submerged for 24 hours. The container was then removed from the water and allowed to drain for 2 hours. The bulk density is reported as the oven dry weight of peat per unit wet volume after 2 hours of drainage. The wet weight was also recorded and used to calculate the volume of water retained. Pore volume was calculated from

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

where Vp = pore volume
Dp = particle density determined using a 100 ml volumetric as a pycnometer
Db = bulk density.

Air capacity is reported as the difference between pore volume and water capacity. Water capacity was calculated using data collected during the bulk density determination according to the following formula: (Puustjarvi, 1968)

$$\text{Water Capacity} = \frac{\text{Wt. of wet peat - Wt. of dry peat}}{\text{Wet volume x density of } H_2O} \times 100\%$$

Fiber content is expressed as the % of the organic material retained by a 100 mesh screen either with or without rubbing according to the method used in the System of Soil Classification for Canada.

O_2 consumption was measured using an electrolytic respirometer (Harris, 1966) with each unit containing 100 g moist peat maintained at a constant moisture content and at a temperature of 25± 0.5°C. CO_2 production was measured on 100 g moist peat enclosed in a 600 ml plastic container with a tightly sealed lid. Evolved CO_2 was collected in 10 ml of 0.2 N NaOH contained in a 50 ml beaker. The unused NaOH was back titrated with 0.10N CHl to the phenolphthalene end point after precipitating carbonates with $BaCl_2$. Containers with only NaOH were used as controls and were otherwise treated in the same manner as those containing peat. Incubation temperature was 25±0.5°C. The NaOH was changed daily. 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, pp. 249-259). Counting efficiency was measured using the sample channels ratio method (Middleboe *et al.*, 1976, pp. 86-87). The scintillation cocktail consists of 0.2 g of POPOP (1,4-bis - (methl-5-phenyloxazolyl) - benzene) and 8,0 g of PPO (2,5-diphenyloxazole) dissolved in 2 l of Toluene (scintillation grade) after which 1 l TritonX-100 was added as an emulsifier. One ml samples of the NaOH solution containing $^{14}CO_3$ was added to 15 ml of this solution in 20 ml scintillation vials and counted for 1 min (10,000 cpm).

Plate counts of bacteria were performed by making suspensions containing 10^{-4}, 10^{-5} and 10^{-6} g soil per ml. A 0.1 ml aliquot of each dilution was spread over different plates (replicated 4 time) containing Difco plate count agar at 1.5%. This produced dilutions of 10^{-5}, 10^{-6} and 10^{-7} g soil per plate. The plates were incubated for 8 days at room temperature and the numbers of colonies counted.

Results and Discussion

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. This could jeopardize the long-term stability of the area and may result in severe erosion on steep slopes where peat is especially beneficial. Normally the rate of decomposition of organic residues in soil is inversely related to the amount of alteration that has taken place. As more and more of the material is converted to microbial biomass and humus, the rate of decomposition slows. Therefore one might expect a fibric peat to decompose more rapidly than a humified peat. 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 (Fig. 1) but there was a close relationship between O_2 consumption and numbers of bacteria in the various samples (Fig. 2). Therefore it appeared that factors of the peat and its environment other than fiber content were responsible for its rate of decomposition and that amendments added to peat or sand-peat or overburden-peat mixes may substantially affect the rate of peat alteration. Variables affecting size and activity of microbial populations were considered as important or more so in controlling rate of peat alteration as the initial peat properties.

During reclamation, at least as presently practixed, fertilizer is added to provide nutrients to hasten plant establishment. At times, lime is added to either adjust an acidic soil to a neutral pH or to act as a buffer to overcome effects of S oxidation in soil. Both of these practices affect soil microbial populations and their activities provided energy is not limiting. Therefore, they will likely also affect peat decomposition. To determine if this indeed happens, two peats were incubated with and without additions of N, P and $CaCO_3$. Oxygen consumption over 8 days was measured and is reported in Figure 3 and Figure 4.

In both peats, additions of P increased repiration rate. Only in the acidic peat with low nitrogen content and high C/N ratio did additions of N 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 $NH_3 + H^+ \rightleftharpoons NH_4^+$ equilibrium. Also NO_2^- may have accumulated and caused some toxicity. Although the pH is on the low side for NO_2^- consumption (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 this peat had a slight inhibitory effect on respiration rate.

Results of these incubations indicate that there is likely a strong interaction between some of the chemical properties of peat and the effect that management practises have on the rate of its alteration.

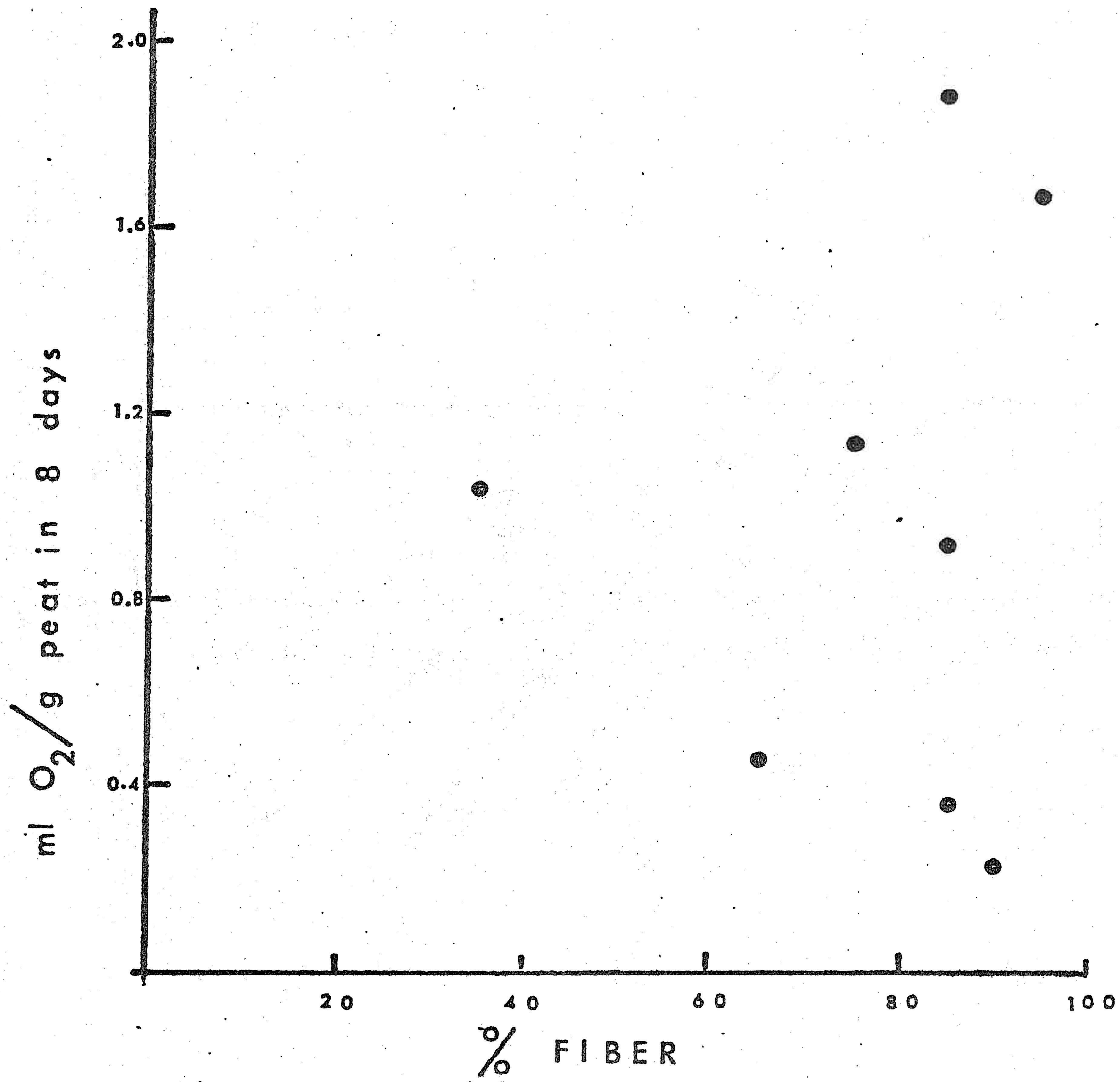

FIGURE 1. Relationship between unrubbed fiber content and O_2 consumption over 8 days in 8 peat samples incubated in the laboratory at $25 \pm 0.5^{\circ}$ C.

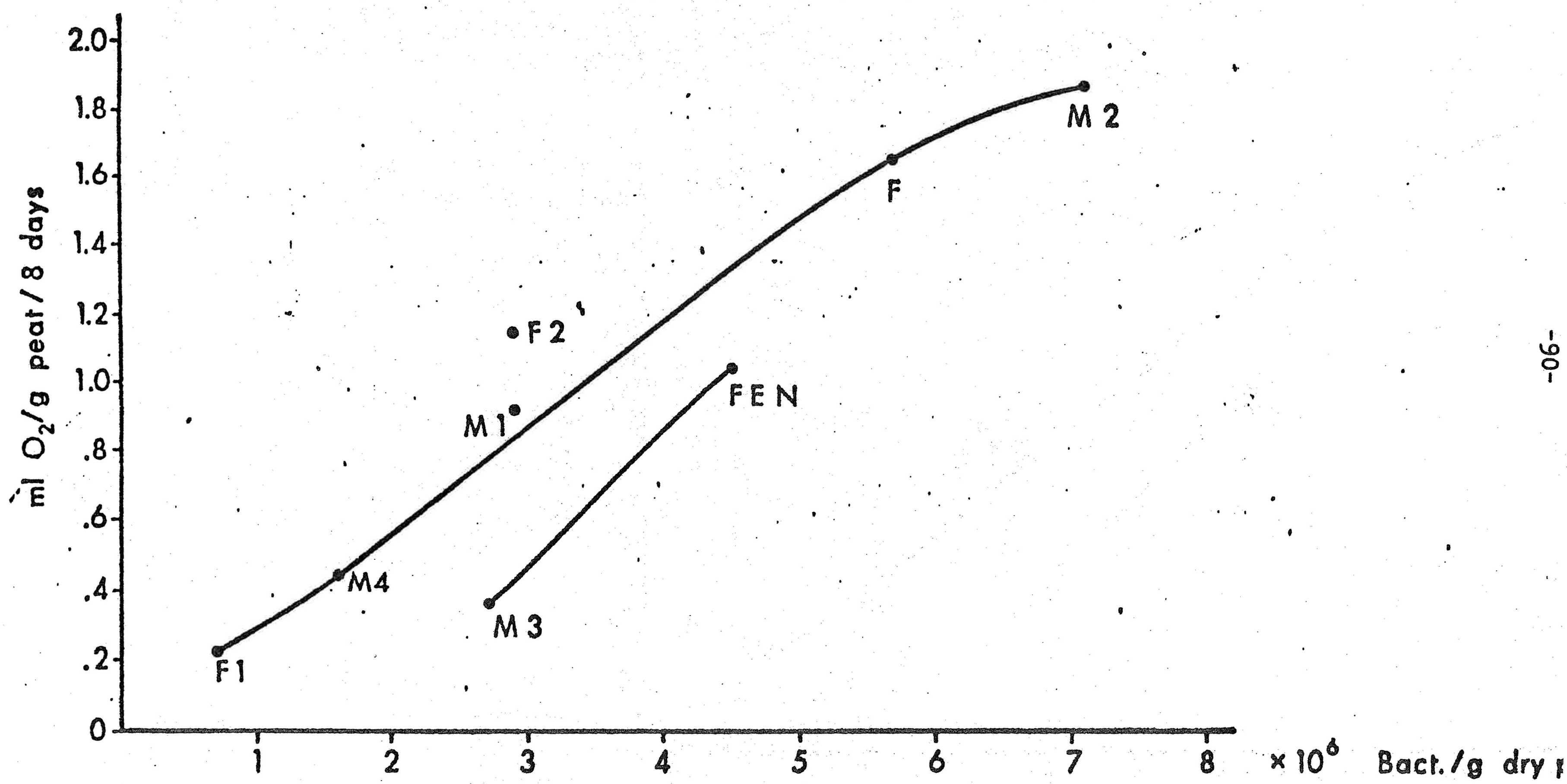

FIGURE 2. Relationship between number of bacteria as determined by plate counts and O_2 uptake by 8 peat samples incubated at 25 $\pm$ 0.5° C. The sample designations correspond to those used in Table 1.

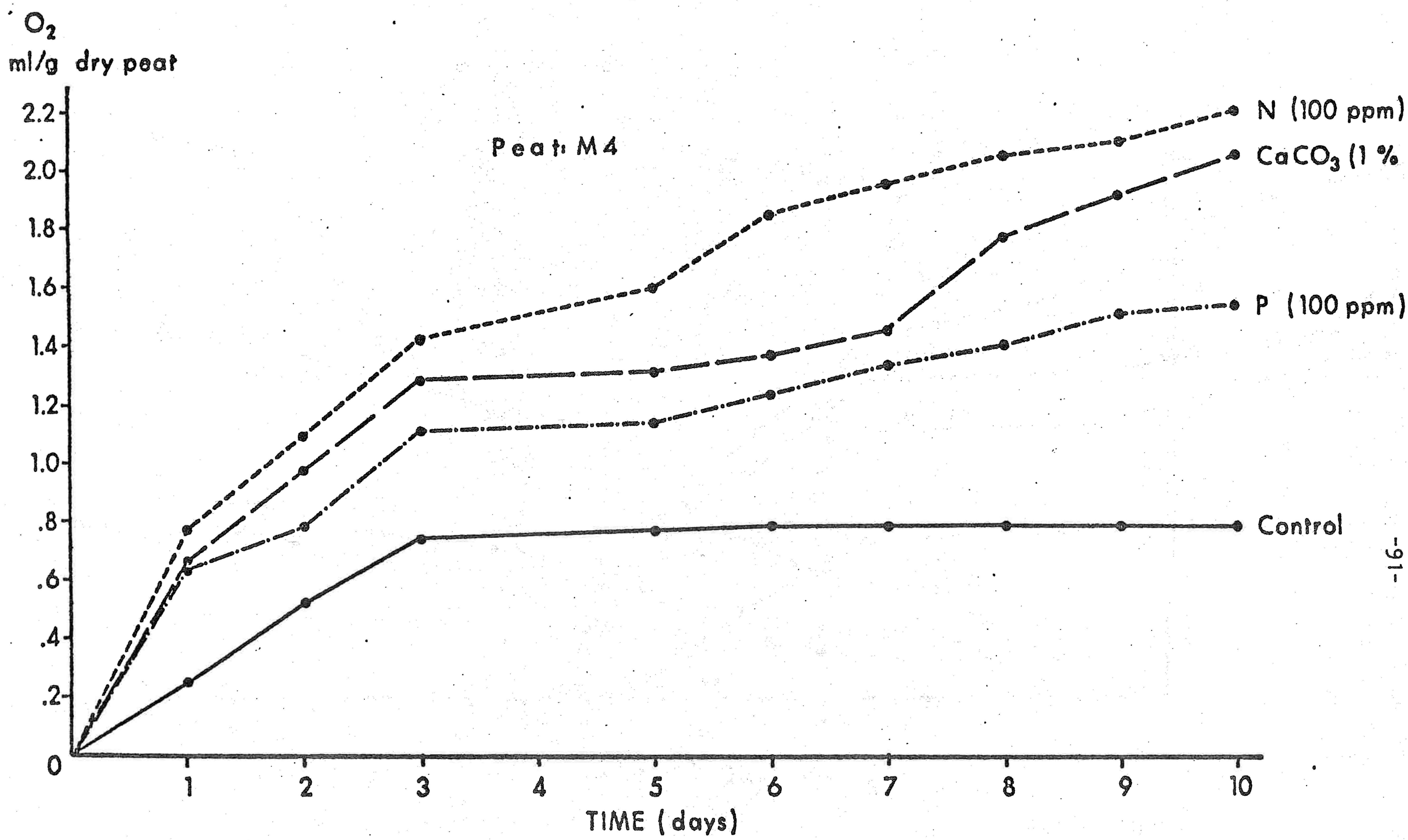

FIGURE 3. Effect of amendments on O_2 uptake by peat sample M4 incubated at 25 $\pm$ 0.5° C. Concentrations of N, $CaCO_3$ and P are based on wet weight of the peat.

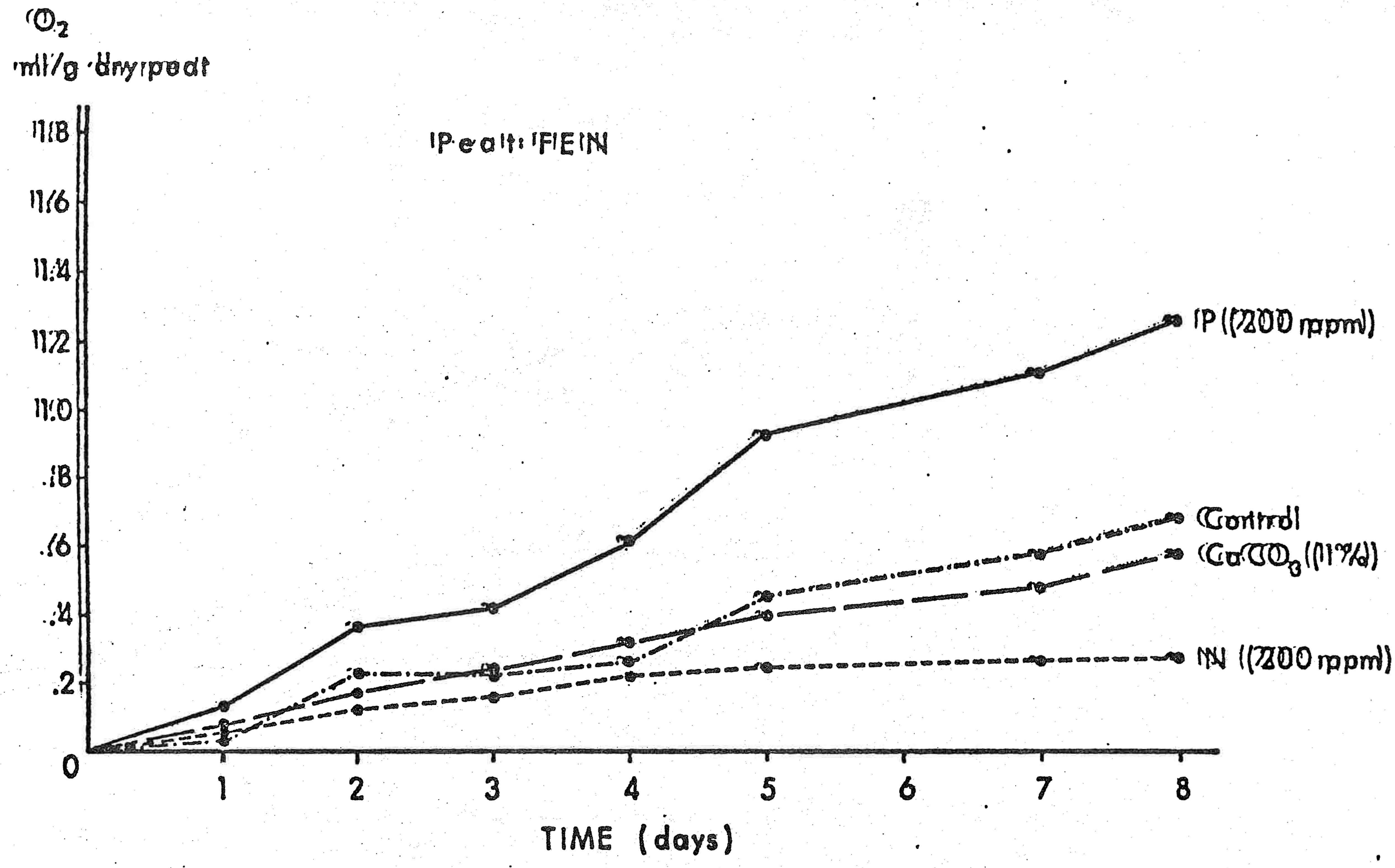

FIGURE 4. Effect of amendments on O_2 uptake by peat sample FEN incubated at $25 \pm 0.5°$ C. Concentrations of N, $CaCO_3$, and P are based on wet weight of the peat.

Under field conditions, peat either stored or applied as a surface amendment undergoes several fluctuations in environmental conditions. Among these are freezing and thawing and wetting and drying. These phenomena affect the physical character of peat directly and also its microbial activity which in turn can alter both the physical and chemical nature of peat. Additions of organic carbon in the form of plant residues provide an extra source of energy. This has been shown in cultivated peatlands to affect the rate of decay of the peat.

An experiment was designed to help elucidate some of the effects of drying in air, freeze drying, freeze-thaw cycles, fertilizer additions and addition of an energy source on the decomposition and physical properties of three peats from the Fort McMurray area. The three peats used were the samples designated F, M and FEN (Table 1). They represented a general increase in degree of decomposition and reduction in fiber content. Care must be exercised in making direct comparisons between the first two and the latter peat since F and M are both moss peats whereas FEN is a fen peat.

The peats were each split into three main treatments. The first portion was kept field-moist and will be referred to as "normal" peat designated by the letter n. The second aliquot was air dried and is designated by the letter a. The third portion designated by the letter f (not to be confused with upper case F) was freeze-dried to represent the type of drying that occurs during winter in exposed peat. Each treatment was replicated three times and incubated at field capacity at $25^{o} \pm 5^{o}C$ and CO_2 production measured daily. Three freeze-thaw cycles were imposed on each treatment starting on day 7. Each cycle lasted one week and consisted of freezing at -10^{o} C for 24 hours followed by thawing and incubation for 6 days. Daily CO_2 production measurements were made. Freezing occurred on days 7, 14 and 21.

No treatment involving no freezing and thawing was used because previous experience indicated that by the end of 6 - 7 days after a disturbance, the rate of respiration was constant and at a very low level.

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

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 at a specific activity of 7.35 Ci/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 and measurements of fungi was made on days 0, 6, 9, 27, 34, and 64. Numbers of cellulose degraders were estimated by the MPN technique of days 0, 27, 34 and 64. Routine measurement of other speficic groups of bacteria were made during the experiment. These results are contained in the section on microbiological studies.

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

Effect of drying on physical properties:

Drying affected most of the physical properties examined (Table 2). Bulk density was increased by air drying peats F and M 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 (S) and Mesic peat (M) and a slight increase in the Fibric peat (F) but not so great as the effect caused by air drying the peat.

Pore volume was changed only slightly if at all due to drying but air capacity was affected more severly. Air capacity decreased by 11% in the fibric peat but increased by 33% and 43% in the mesic and sedge peats respectively. This may slightly improve the utility of mesic and sedge-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 peat M in which a slight (6.3%) reduction occurred. The fiber content of the sedge 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 peat (M) was affected only by the freeze-drying treatments.

Hydraulic conductivity 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 hydraulic conductivity 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 sedge peat. Hydraulic conductivity was reduced to about 48% of its original value in the fibric peat but in the sedge peat hydraulic conductivity was reduced to 18% of its original value. The seriousness of this is even greater than the change would appear because the sedge peat had the lowest original hydraulic conductivity. Air dried sedge peat had a hydraulic conductivity 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 sedge peat and probably also highly humified moss peat may not be advisable for erosion control in areas where probabilities of dessication are high.

Results reported in Table 2 indicate that drying has a generally adverse effect on the utility of peat. This effect is manifested primarily through a reduction in hydraulic conductivity which is reduced substantially by drying. The sedge peat was affected most. The only advantageous effect of drying was observed in an increase in air capacity of the moderately well humifed peat (M) and the sedge peat (FEN). For application to level surfaces as mulch, dried peat may be more desirable here. For applications to sloping land as an initial erosion control medium, undried fibric peat would probably be most desirable.

Effect of microbial activity on physical properties of peat:

Results reported above are generally in agreement with literature data. However, very few if any reports are available describing the effects that microbial activity may have on ameliorating or aggravating problems caused by drying or the role of microbes in altering physical properties of normal peat spead on the soil surface or stored in piles in the field. The data to follow (Table 3) address this question.

Table 2. Effect of air- or freeze-drying on physical properties of three peat samples from the Ft. McMurray area, Alberta

Peat	Treatment	Db g/cc	Pore Volume %	Air Capacity %	Fiber Content Unrubbed %	Fiber Content Rubbed %	Hydraulic Conductivity X 10^{-4} cm/sec
F	Normal	0.052	96.5	38.7	95	85	4.38
	Freeze-dried	0.056	96.3	35.8	95	80	1.28
	Air-dried	0.061	95.9	34.4	95	80	2.10
M	Normal	0.086	94.3	21.1	80	55	3.60
	Freeze-dried	0.079	94.7	27.7	75	50	1.09
	Air-dried	0.090	94.0	28.1	75	55	1.06
FEN	Normal	0.119	92.6	20.7	35	10	2.83
	Freeze-dried	0.107	93.3	25.2	35	10	0.82
	Air-dried	0.116	92.7	29.6	35	10	0.51

Table 3. 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	Db*	Pore Volume	Air Capacity	Fiber Content		Hydraulic Conductivity
					Unrubbed	Rubbed	
F	Normal	+ 17.3%	- 0.62%	- 22.2%	0	0	+ 777%
	Freeze-dried	+ 8.9	- 0.3	- 11.1	- 5.2%	- 12.5%	+ 728
	Air-dried	+ 41	- 1.7	- 24.4	- 10.5	- 6.25	+ 176
M	Normal	+ 17.4	- 1.1	- 1.9	- 6.3	- 9.1	+ 417
	Freeze-dried	+ 8.9	- 0.42	+ 5.8	- 2.6	- 10	+ 678
	Air-dried	+ 4.4	- 0.21	- 13.2	- 13.3	- 18.2	+ 434
FEN	Normal	+ 21.8	- 1.7	- 17.4	0	0	+ 154
	Freeze-dried	--	--	---	0	0	+ 372
	Air-dried	+ 6.0	- 0.43	- 22.0	0	0	+ 459

*All values reported as % change over corresponding original value from Table 2.

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 due to drying itself. The drying appears to have arrested the rate of increase in bulk density caused by microbial activity such that at the end of the 61 day incubation period, the bulk density was higher in the normal peat than in the dried peat. The only exception to this was the air-dried fibric peat. Thus, although drying increased bulk density, and the dried peats therefore started their incubation at a higher bulk density, and bulk density increased during incubation, the dried peats had a lower bulk density at the end of the incubation period than did the normal 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 peats M and FEN (Table 2), subsequent incubation reduced it again. The overall net effect for peats M and FEN was that air capacities of the incubated dried peats were greater than the initial air capacities prior to drying and much greater than in undried normal peat after incubation. Generally drying appeared to have a greater effect on air capacity than did incubation in the M and FEN peats but the reverse was true for the fibric peat. If 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 rate of loss of air capacity. One must keep in mind, however, that air capacity can only be increased at the expense of water capacity. Practises which are beneficial with respect to air capacity will be detrimental with respect to water capacity.

The effect of microbial acitivity 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 (F and M) 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 conductivity than the corresponding normal peat prior to incubation. In fact, after incubation, hydraulic conductivity of the normal sedge peat was greater than in the normal fibric peat prior to incubation. It would appear that the undesirable hydraulic conductivity levels of sedge 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 hydraulic conductivity is contrary to what might be expected when comparing results of examination of unaltered peats of various stages of decomposition. Generally as decomposition increases, hydraulic conductivity decreases. Microbial activity within these peats, however, when exposed to freeze-thaw cycles, nutrients and extra energy can increase hydraulic conductivity. Under virgin conditions in the field, no extra nutrients are present and the soil environment is substantially different from that present when peat is spread on the soil surface. Further work to outline the causes of beneficial effects of the treatments imposed is needed.

Effect of drying on microbial activity:

Initially, activities of cellulose degrading enzymes were higher in the fen peat sample than in the two moss peats (Table 4). The fibric peat sample had the lowest activity. Since the substrate (cellulose) is not limiting, the factors controlling the enzymatic activity of the fibric peat must be environmental. The higher activity level in the neutral, high-N fen peat further supports this hypothesis.

Drying affected microbial activities in all three peats as measured both by enzymatic activity and CO_2 production (Table 5, Fig. 5). Activities of enzymes degrading cellulose were substantially reduced in the fen and mesic moss 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. Freeze-drying was generally intermediate in effect between normal and air-dried peat. 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 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. Shield <u>et al</u>.(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 come from decomposition of fungi and bacteria killed during drying. Freeze-drying would be expected to have an intermediate effect because it kills fewer cells.

Effect of freeze/thaw cycles, nutrients and glucose on microbial activity:

The treatments imposed affected the rates of CO_2 production (changed the slope of the accumulative production line) in all three peats (Fig. 6). 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, peat sample M (control) had respired 28.9 mg CO_2 per g dry peat whereas the respective values for the fen sample and sample F 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 (Fig. 7). 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 totaled in 21 days approximately the same as in 7 days after rewetting.

Addition of nutrients and lime altered the relative rates of CO_2 production (Fig. 8). Whereas the previous (physical) treatments 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 neutal, relatively nutrient-rich fen sample. Thus during 21 days following

Table 4. Initial enzymatic activities in three peat samples from Ft. McMurray

Peat	Cellulose C_1*	Carboxymethyl** Cellulose C_x	G-glucosidase†
F	0.332	0.580	0.131
M	0.341	0.764	0.162
FEN	0.574	0.694	0.575

* mg reducing sugar/g dry peat present 5 days after adding substrate (cellulose powder).

** mg reducing sugar/g dry peat present 24 hrs. after adding substrate (carboxymethyl cellulose).

† mg saligenin present 3 hr. after adding substrate (Salicin).

Table 5. Effect of drying on enzymatic activity of three peats from Ft. McMurray

Peat	Treatment	Cellulose (C_1)*	Carboxymethyl Cellulose (C_x)	G-glucosidase
Fibric (F)	Normal	0.332	0.580	0.131
	Freeze-dried	0.413	0.335	0.160
	Air-dried	0.383	0.583	0.150
Mesic (M)	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

*For units see Table 4.

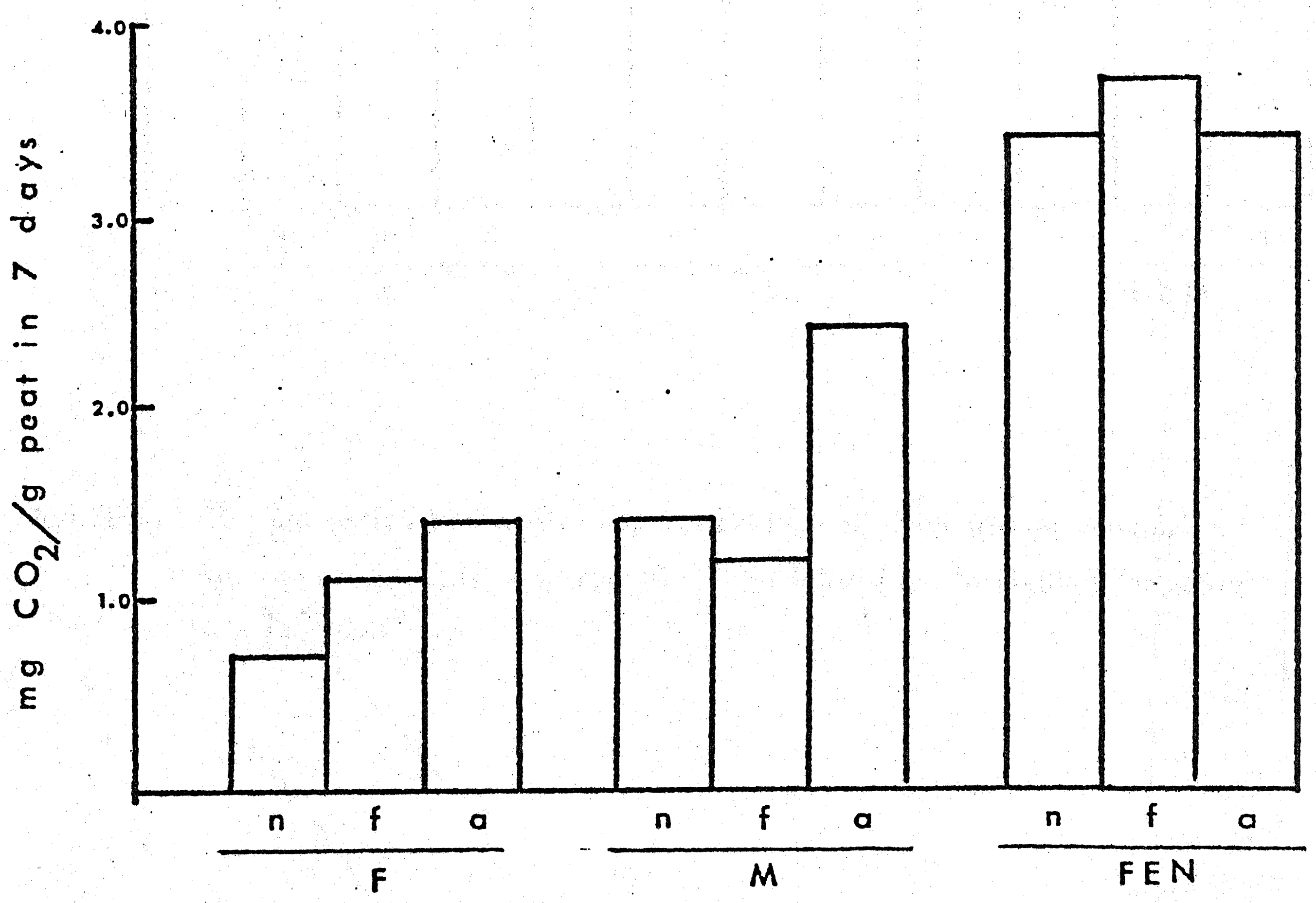

FIGURE 5. CO_2 production from peats F, M and FEN remoistened after air-drying (a), freeze-drying (f) as compared to the control (n). Incubation temperature was 25 $\pm$ 0.5° C.

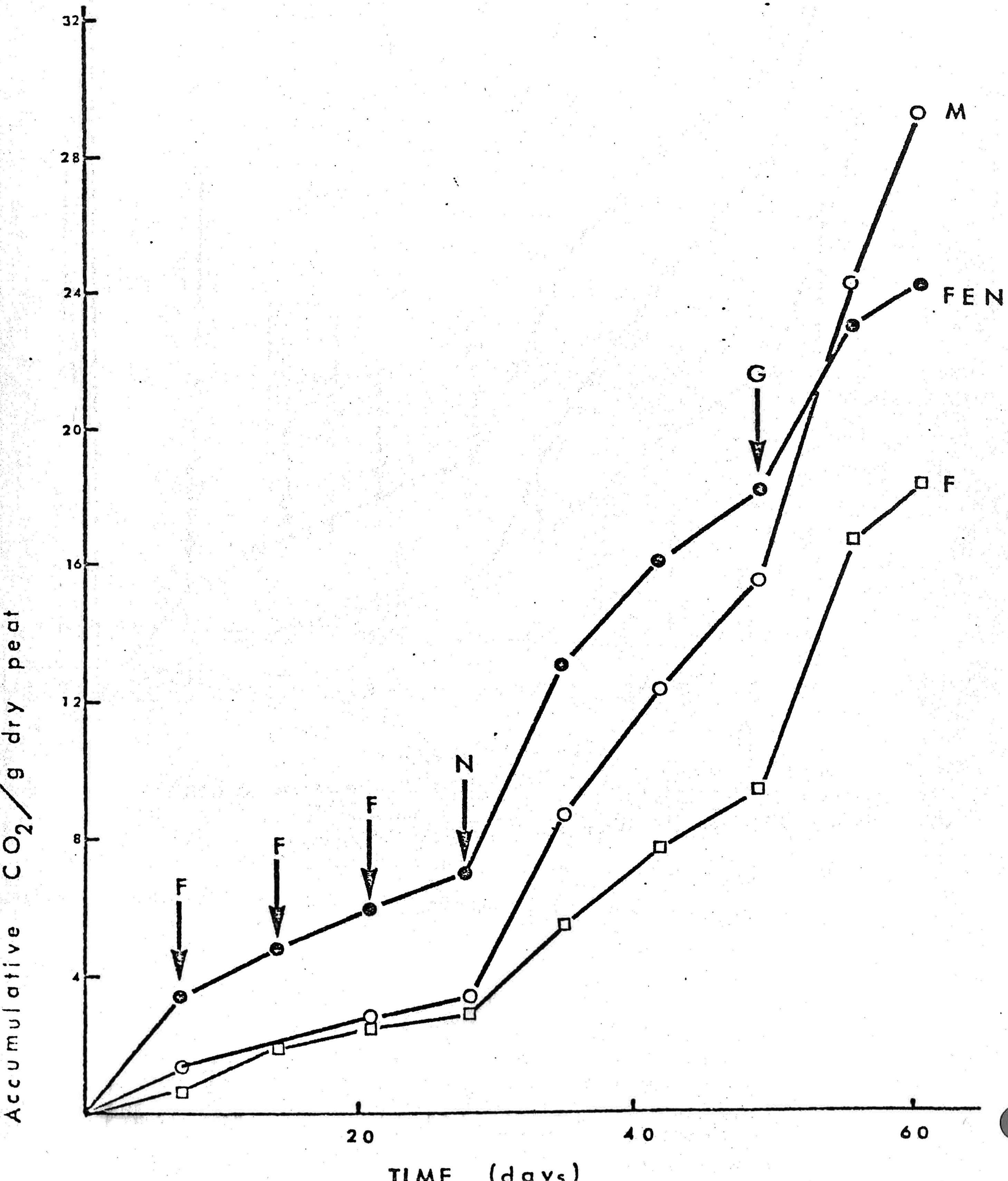

FIGURE 6. Accumulative CO_2 production from control (undried) portions of peats F, M and FEN during 61 days incubation at 25 ± 0.5^{o} C. Freezing events are [illegible] addition of nutrients by N and addition of glucose by G.

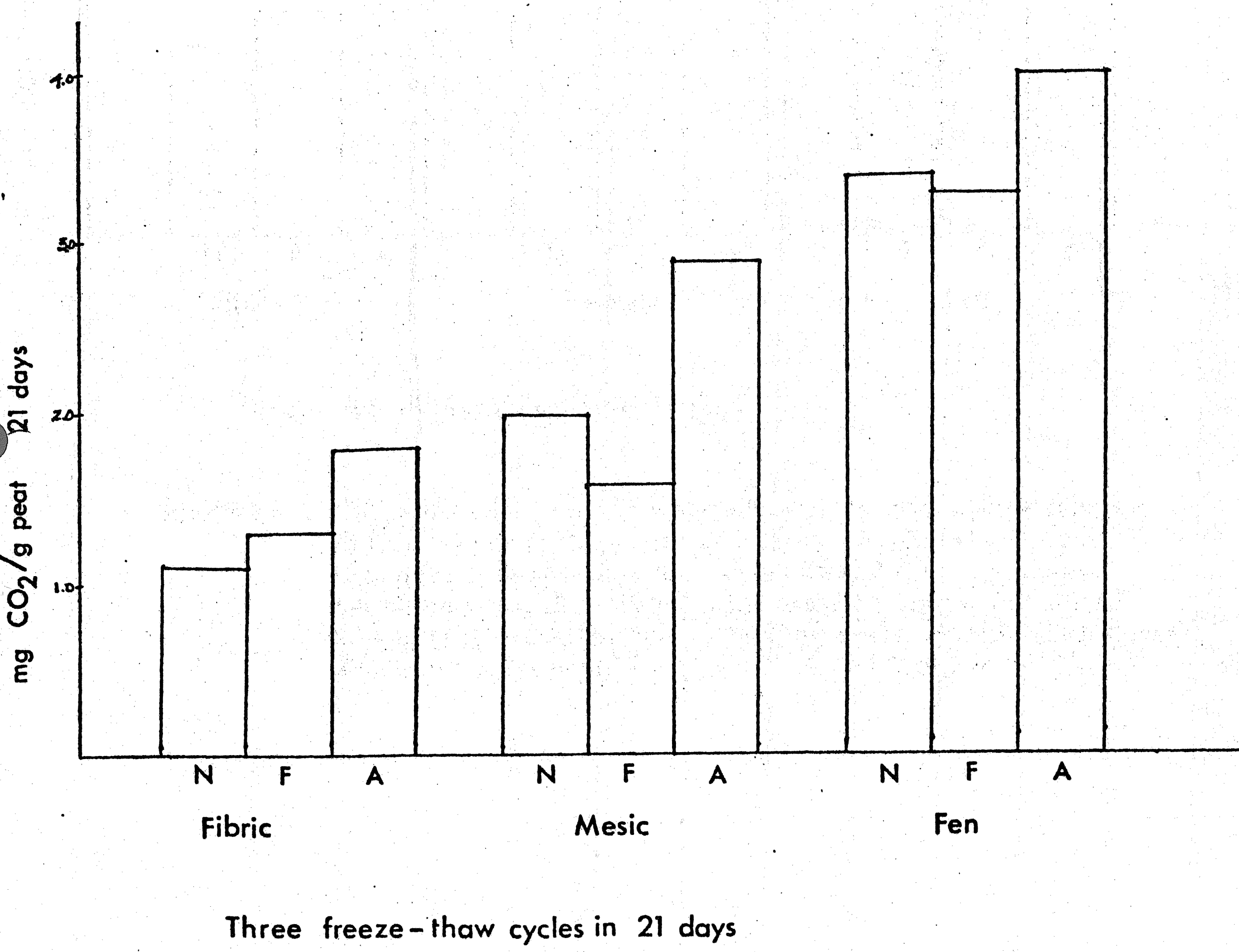

FIGURE 7. CO_2 production during 3 freeze-thaw cycles from peats F (Fibric), M (Mesic) and FEN remoistened after air-drying (A) and freeze-drying (F) as compared to the undried control (N). Incubation temperature was 25 $\pm$ 0.5 C. The samples were incubated for 7 days after drying before the freeze-thaw cycles started. Each freeze-thaw cycle consisted of 1 day at -10° C and 6 days at 25° C.

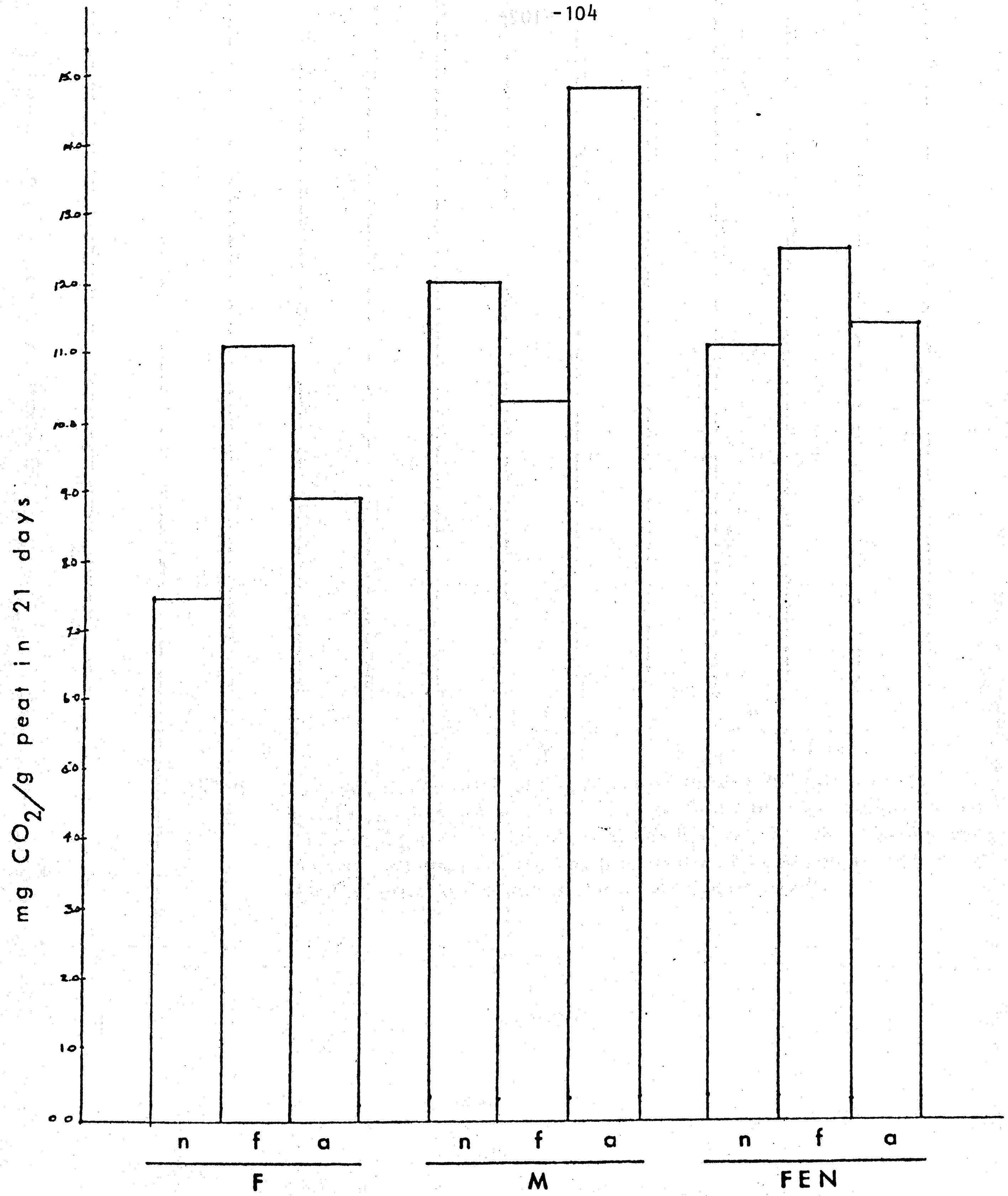

FIGURE 8. CO_2 production after adding N, P and lime at 200 ppm each (wet wt. basis) to peats F, M and FEN. The N, P and lime were added on day 29 following three freeze-thaw cycles from day 7 – 28. Samples were air-dried (a) and remoistened, freeze-dried (f) and remoistened or not dried (n) prior to the start of the incubation on day 0.

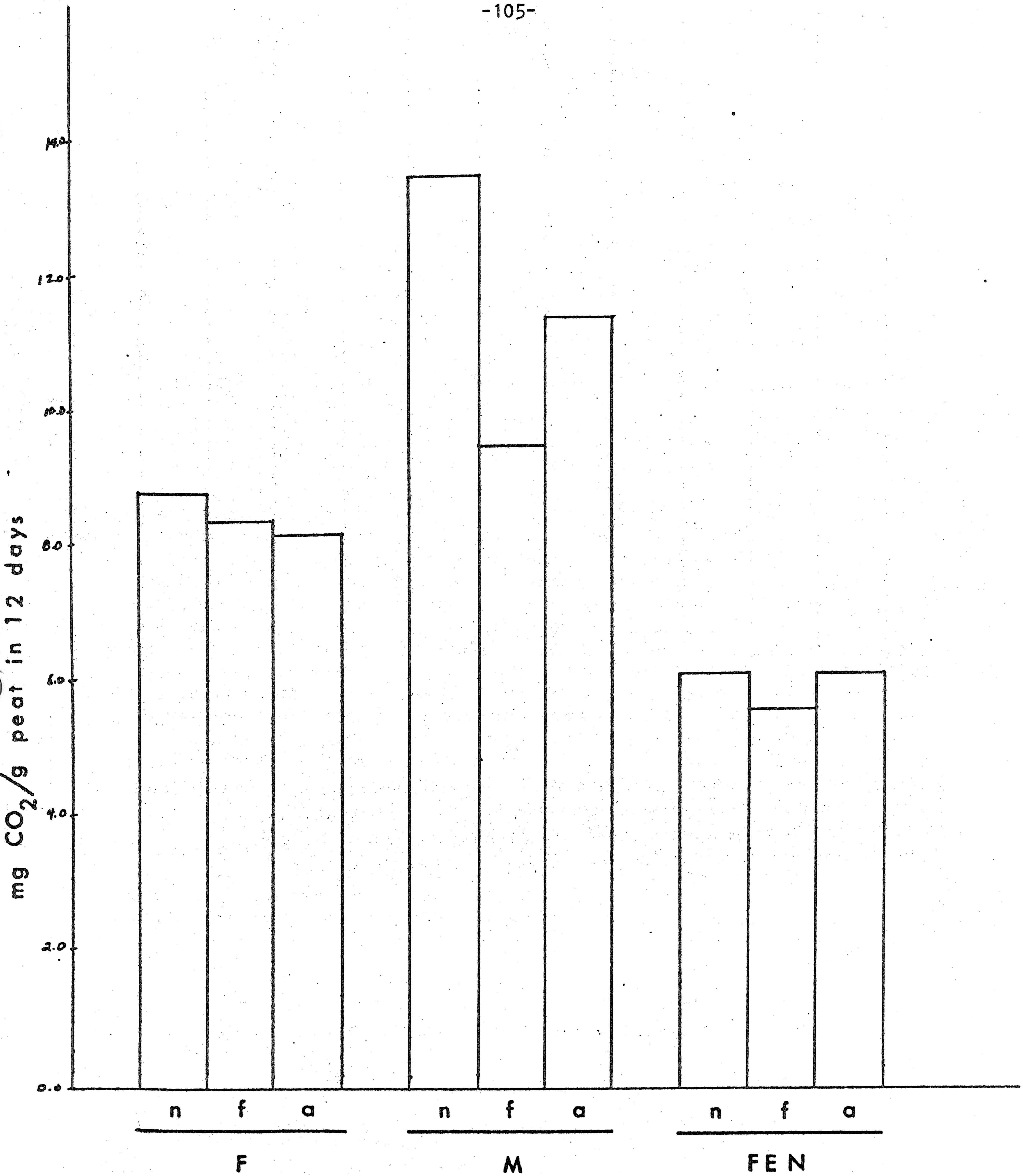

FIGURE 9. CO_2 production from peats F, M and FEN, remoistened after air-drying (a) freeze-drying (f) and control (n) to which 200 ppm glucose-C (wet wt. basis) had been added. The C was added on day 49 following nutrient additions and 3 freeze-thaw cycles. Incubation temperature was 25 $\pm$ 0.5 °C.

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 production 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 (Fig. 9). 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 (a readily available energy source) 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 hypothsis 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 61 days of this incubation experiment. 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.

Treatments which affect the physical environment of peat appear to affect all peats similarly, thus maintaining differences initially existing between them. Chemical conditions, however, would appear to have a greater control over biodynamics of disturbed peats and therefore altering chemical conditions tends to mask differences in biological activity between peats. Thus, in the long run, with management of the chemical environment of peat, one would expect physical properties of most peats applied to soil and used for reclamation purposes to approach a common point. How long this would take remains to be seen. What that ultimate point is, will depend upon many additional factors not included in the present study. Conversely, it would appear that management practises which do not affect the chemical environment of peat would likely help maintain the initial differences in physical properties between peats.

"Priming" effect of added C:

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 (Fig. 10). Thus, not only did the added glucose

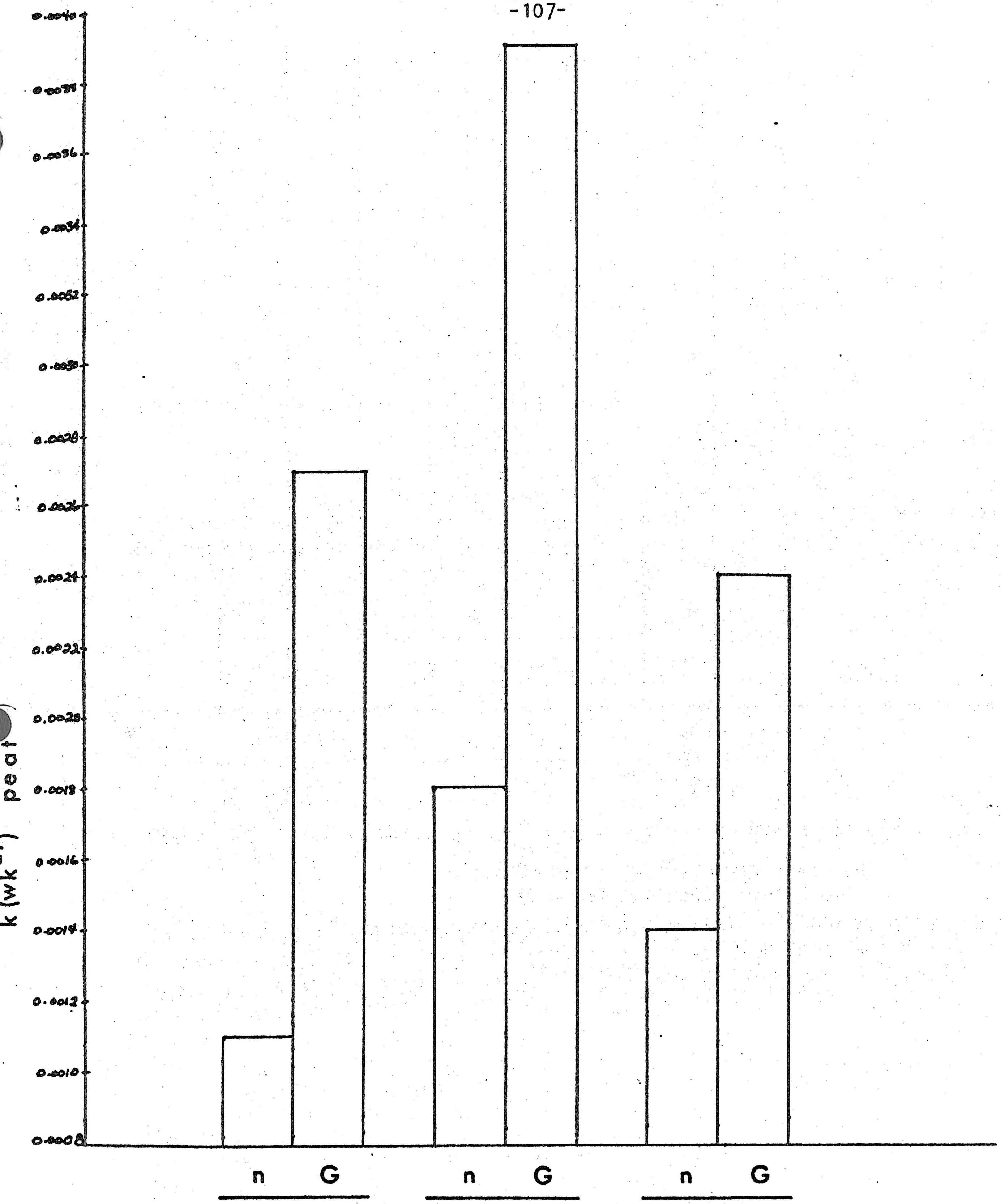

FIGURE 10. Effect of added glucose on the rate of carbon loss, defined as $k = \frac{1}{dt} \ln(\frac{Co}{C_o -}$

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. 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 25 ± 0.5° C increase microbial activity as a result of its direct comsumption, it also increased the rate of consumption of peat-C to about twice the rate prior to adding glucose. The rate of loss (k) of glucose-C from the peat varied from 1.08 wk^{-1} for peat M to 0.63 wk^{-1} for peat F. The fen peat was intermediate between the two of 0.94 wk^{-1}. The ratio of k for glucose to k for peat-C with glucose present provides an estimate of the relative availabilities of the C in the various peats. Glucose-C was consumed 277 times fater 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 is 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 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.

An increase in rate of decomposition of peat-C caused by glucose addition would be expected to cause an increase in the rate of cellulose decomposition. This may have occurred, but the activity of enzymes degrading cellulose was generally lower at the end of the incubation period than at the start (Table 6). The reduction occurred for all enzymes in all three treatments of the fen peat sample. The more mesic peat M exhibited an increase in cellulose activity in all three treatments and in the carboxymethyl cellulse activity in the dried treatments. No consistent trend was evident in the fibric moss sample (F).

These results indicate two things. First, cellulose activity generally increases when microbial populations increase in peat. We did not find this consistently in the present experiment with cellulose activity measured after 61 days incubation. It is probably that the decline in enzyme activity over the 61 days resulted from a decline in substrate in the fen peat which was originally low in fiber. In experiments reported in the literature, incubation times have been short. The early increase in activity accompanying short incubation times has obviously not persisted for the 61 days of this incubation, if it in fact occurred at all. These data indicate that activity of enzymes degrading cellulose does not necessarily remain high over the long term, even when microbial activity is high. This has important implications for the stability of peat applied in the field. Secondly, coupled with this is the large priming effect observed prior to termination of the experiment. The extra carbon being respired would not appear to be coming from the cellulose in the peat but from humified material or from turnover of microbial metabolites. Glucose inhibits use of cellulose by many cellulose-degrading microorganisms. Thus it would also be expected to reduce cellulose activities. Hence, treatments which cause priming of the soil organic matter need not necessarily increase rate of decomposition of all organic components and not all added organic materials would be expected to have the same priming effect.

Table 6. Change in enzymatic activity of peat during 61 days incubation exposed to three freeze/thaw cycles, added nutrients, lime and glucose

Peat	Treatment	Cellulose (C_1)	Carboxymethyl Cellulose (C_x)	G-glucosidase
F	Normal	--	- 87%	+ 25%
	Freeze-dried	+ 7.7%	+ 53%	- 16%
	Air-dried	- 86%	- 1.3%	- 37%
M	Normal	+ 22%	- 74%	- 1.2%
	Freeze-dried	+ 78%	+ 94%	- 5.0%
	Air-dried	+ 820%	+ 89%	- 26%
FEN	Normal	- 68%	- 97%	- 30%
	Freeze-dried	- 59%	- 48%	- 35%
	Air-dried	- 27%	- 26%	- 35%

Conclusions

Results of the present investigation indicate that drying increases peat bulk density and reduces its fiber content and hydraulic conductivity. Incubation for 61 days in the lab also affected these properties. Generally incubation increased bulk density. The increase was less where samples had previously been dried. Fiber content declined as a result of incubation but in all cases, hydraulic conductivity increased after 61 days incubation. The incubation caused a complete reversal of the detrimental effect of drying on peat hydraulic conductivity.

Biological activity was generally lowest in the fibric moss and highest in the fen peat. Physical alteration of the peat which could cause lethal injury to soil microbes increased the rate of peat decay. However, the effect of physical manipulations was similar in all peats and differences between peats in rate of biological activity were not altered by physical treatments. Changes in the chemical environment of the peat, however, altered the relative positions of the peats used. Generally, adding nutrients and increasing the pH caused a greater increase in respiration rate of the inactive fibric peat than in the more active fen peat. Difference between peats were thus maintained by physical treatments, whereas chemical treatments masked them.

Addition of glucose doubled the rate of peat decomposition. The peat components undergoing increased attack were postulated to be microbial metabolites and humified material, not cellulose. The relative rates of biological oxidation of glucose and peat-C in the various peats appears to be a useful technique to consider in assessing the alteration of peat-C in peat-mineral mixes.

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VE 6

LONG TERM PREDICTION OF VEGETATION PERFORMANCE FOR DIKE MANAGEMENT

INTRODUCTION

L.C. Bliss

In the initial planning stage, this project was conceived as an integrated study to determine the response of natural and artificial plant communities on steep-sided sand dikes to dry and nutrient-poor environmental conditions. The objectives are: 1) to determine responses of pioneer and climax species to drought stress conditions from field and growth chamber-greenhouse studies; and 2) by modelling the data, on soil water dynamics, micro and mesometeorology, tree water relations, lichen physiology, and the role of wood plant mycorrhizae, to be able to predict the development and stability of several plant communities types on a sand dike system.

Although originally planned as a part of this integrated study, the soil nutrient research is not being done as a part of this project. In turn, dike hydrology was not initiated although we strongly urge its inclusion. To date we have concentrated on a Jack pine-lichen woodland, the stable natural plant community on sand soil of the region. This last summer, research on primary succession on open sand and the ecophysiology of a key successional species has been initiated. We expect to begin micrometeorological and physiological studies on established vegetation plots on the GCOS dike in 1977. This is a very essential and integral part of our research program.

The Richardson Fire Tower site (subdivisions 15 and 16, Sect. 30. Twp. 102, R6 W4 and subdivisions 1 and 2, Sect. 31, Twp. 102, R6 W4) was chosen because of its: 1) accessibility; 2) representativeness in terms of pine-lichen woodland; and 3) its representativeness in terms of slope (2.3:1 rise, 19^{o} slope, and 20^{o} S of W aspect). The sand hill has a vertical rise of 72 m from the drainage at the base to the top of the hill.

The forest is an open Jack pine stand with an average density of $61 \pm 2.7/100m^2$, mean tree height 7.4 ± 0.003 m and dbh 6.5 ± 0.001 cm in the 50 continguous plots of the main study area. In plot #47 where the major meteorological tower is located tree density is $76/100m^2$, height 6.5 m and dbh 5.5 cm. Trees were defined as 2m high and/or 2 cm dbh. Ocular estimates of the tree canopy average 29% (10 to 40%) with 35% cover in plot #47. In the intensive study area herbs and dwarf shrubs average 23%, mosses 16% and lichens 38% cover.

This location is being used by other researchers as a control site for precipitation chemistry, SO_2 windfall, photosynthesis of branches, meteorological network station and soil microbial studies.

Research details to be presented by my colleagues will cover the dynamics of soil-plant-atmosphere water and thermal regimes within this plant community. The combined field and laboratory data are being modelled to better predict plant responses to the extreme year of environmental conditions, a year that may not occur during this period of study, yet a year or series of years that could devastate any revegetation plan and management scheme that did not take such predictions into account.

Data from the various components of this study will be made available whenever possible to other researchers within the program. A key objective of these seminars is to learn what data are available and how the various studies interrelate.

SOIL PHYSICS

D.H. Whitfield and A. MacLean

Introduction

The soil physics component of VE 6.1 is dedicated to gathering field data on seasonal water balance and temperature variation on the hillside plots, and to lab determination of soil hydraulic and thermal characteristics for modelling purposes. Field installations were initiated in October, 1975, and so some temperature and neutron probe data are now available for a full year. Intensive field work, including final instrument installation, began in early April, 1976.

This report will ignore the soil temperature data and concentrate on water balance.

Field Installations

At present, the field installation are as follows:

Top Site

Neutron probe access tubes	: 3 down to 6 m
Tensiometers	: 3 sets (20, 50, 100, 200 cm)
Thermocouples	: 1, 2, 5, 10, 20, 50, 100, 150, 200, 300, 450, 600 cm

Middle Site

Neutron probe access tubes	: 3 down to 6 m	
Tensiometers	: 4 @ 10 cm	
	5 @ 20 cm	
	4 @ 30 cm	
	3 @ 50 cm	
	3 @ 100 cm	
	3 @ 200 cm	
	3 @ 300 cm	
Thermocouples	: 5 @ 1 cm	1 @ 200 cm
	5 @ 2 cm	1 @ 300 cm
	5 @ 5 cm	1 @ 450 cm
	5 @ 10 cm	1 @ 600 cm
	5 @ 20 cm	
	5 @ 50 cm	
	5 @ 100 cm	
	5 @ 200 cm	
	5 @ 450 cm	
	5 @ 600 cm	

Bottom Site

Neutron probe access tubes	: 3 down to 6m
Tensiometers	: 3 sets as at top site
Thermocouples	: as at top site
Water table access tube	: 1

Gulley

Water table access tube	: 1

Soil Characteristics

The soil parent material, although it is all sand, with a very low content of fine particles, varies from place to place. Lenses of relatively fine and relatively coarse sand are interwoven. There are a few rocks, from 5 cm across to 50. These seem to be too few to much affect water movement.

We have one set each of measurements of hydraulic conductivity and volumetric water content as functions of water potential. These are plotted in Fig. 1. Measurements currently under way on a large number of samples will tell us how representative these are.

Both sets of data are rather striking; the soil exhibits a broad plateau in water content at nearly constant potential and then an abrupt change in potential to levels physiologically very stressful to plants over a very minute change in water content. The hydraulic conductivity is very high at saturation and drops precipitously to exceedingly small values below 5% water content. From these data we can readily identify a field capacity to which the soil will drain under gravitation at about 4.5 to 5% water content. As -100 bars would seem to occur at about 4%, we see that, in the upper meter of soil, only 5 - 10 mm of water are available between field capacity and a physiological limit. As the sample analyzed to produce these data may be somewhat atypical, this is a tentative conclusion.

The high conductivity at saturation perhaps provides an explanation of the long-term persistence of the Richardson hill: It is so permeable as to be very slowly eroded. During a rapid snowmelt in early April, there was no apparent movement of water on the soil surface; all of it penetrated into the frozen soil.

Field Measurements

Here we will present data from gravemetric sampling, tensiometers, psychrometers and the neutron probe. Again, temperature data are ignored. Also, we consider only the middle site on the hill, as it is of greatest interest to the modellers.

Data from the tensiometers (down to -30 cm) appear in Fig. 2. Each point is an average from up to 5 instruments. We have concluded that these data cannnot be trusted when they indicate potential below -100 mb. It appears that below that the hydraulic conductivity is so small that water does not move away from the tensiometer cups in time for them to equilibrate with the surrounding soil. Thus we take readings -100 mb as being anything from that to tens of bars.

Also on Fig. 2 are our few psychrometer results, which confirm the above judgement of the tensiometer data.

Though May and early June the water potentials were consistently below -100 mb. During the rest of the summer there were alternating dry (ca. July 10, Aug. 10, early Sept.) and wet periods (ca. July 1, 20, Aug. 15).

We combined neutron probe data with surface gravimetric measurements where they were available, to produce the results shown in Figs. 3 and 4. The former shows gross seasonal changes, indicating a seasonal amplitude corresponding to about 35 mm of water from -2 to -6 m. Perhaps this is close to the amount of throughflow at -6 m. Note that the water contents are all very small. Neutron probes are usually used in much wetter soils. In our case, the response volume of the probe is very large, which makes vertical integration difficult.

Fig. 4 combines various results. On the right margin the total water in the soil column on March 9, 1976, plus the estimated snowpack at the start of melt are indicated. The dots indicated neutron probe results, integrated to -6 m, and using gravimetric surface measurements where they are available. Earlier season data are not shown, as they are far too high to be believed. It

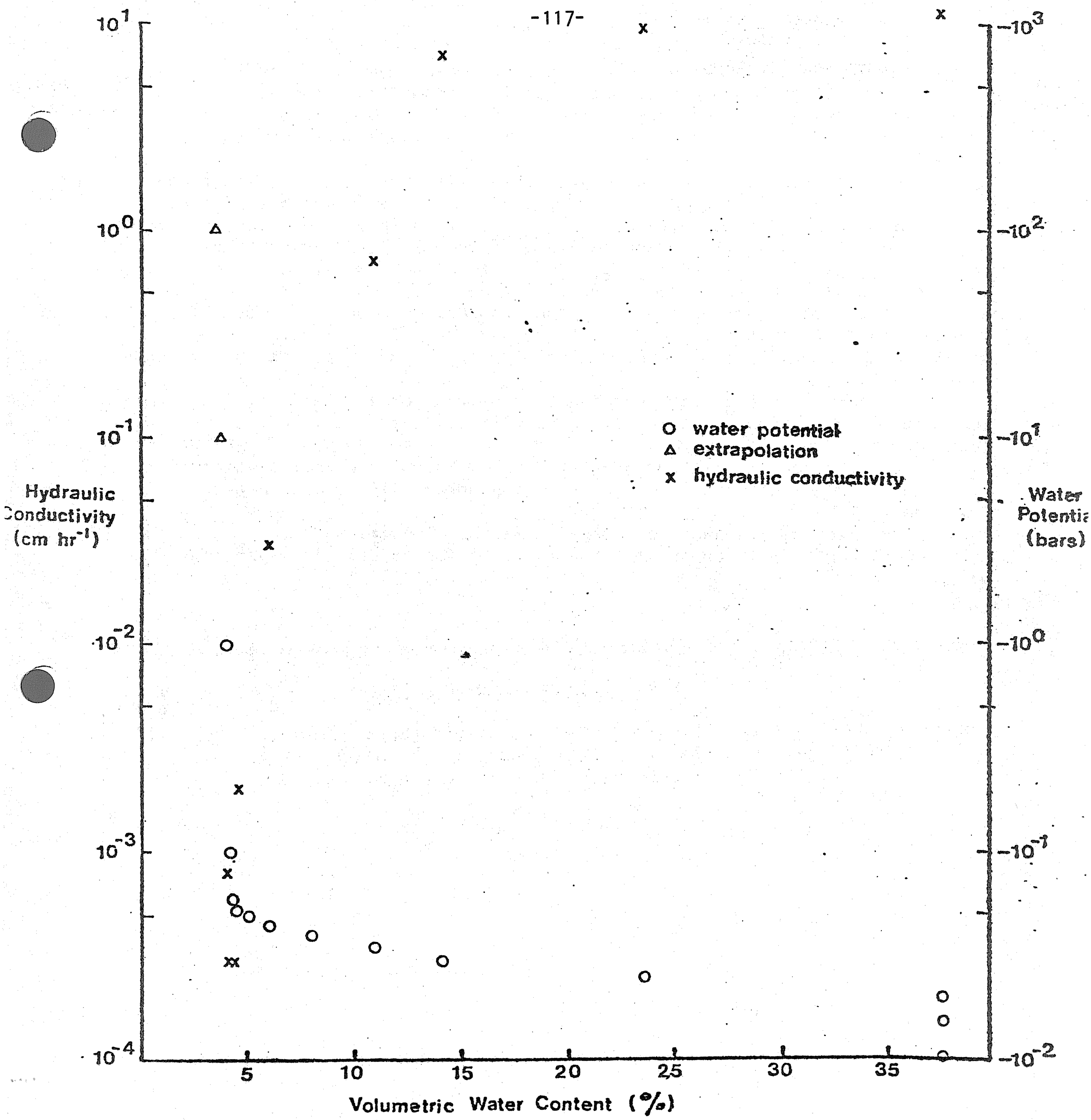


Fig. 1. Hydraulic conductivity and water potential as functions of volumetric water content for a single sample of soil from the Richardson hillside. Also indicated are extrapolations used in the model.

seems that just after snowmelt, when the soil surface was wet and deeper levels were dry, the neutron probe gave false results because readings at, say, -50 or -100 cm were largely responses to water in the top 20 or 30 cm. The two circled points seem to be spuriously low. The remaining data are very noisy, but useable.

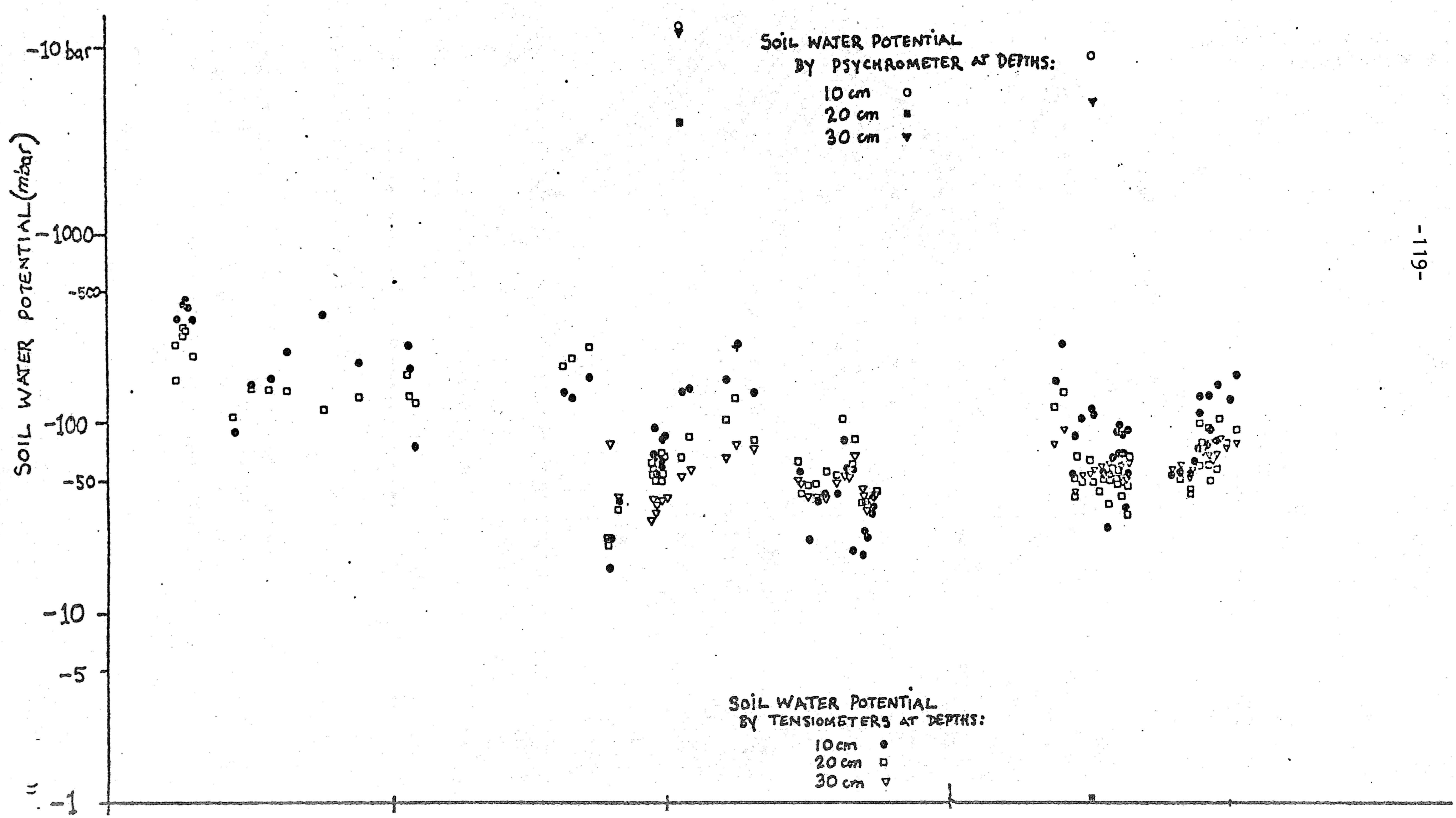
Also plotted on this figure are cummulative precipitation (courtesy of Claude Labine) and calculated cummulative loss. The former has had subtracted from it estimated interceptions by the trees (see meteorology section of this report) and by lichen and needle duff (see lichenology section). The latter is precipitation plus net decrease in total soil moisture. The absolute position of this line in in doubt because of our problems with the early April neutron probe data, but the general slope from May on should be good. The drops in loss are impossible and due to noisy data. This cummulative loss should be the sum of surface evaporation, transpiration by plants and throughflow.

We hope to analyze our water data from the other two hillside sites soon and all of the temperature data. We will calculate cummulative losses from each site and compare them.

It is apparent that our greatest gap in knowlege concerns water content in the upper meter of soil, and next year's program will be designed to fill this gap.

We offer many thanks to George Davis, who took many of the field measurements and did the bulk of the data reduction calculations and figure preparation.

Fig. 2. Soil water potential as measured by tensiometers at the middle site. Each point represents the average of readings from up to 5 instruments. Values below -1000 mb are unreliable. Also indicated are psychrometric measurements.



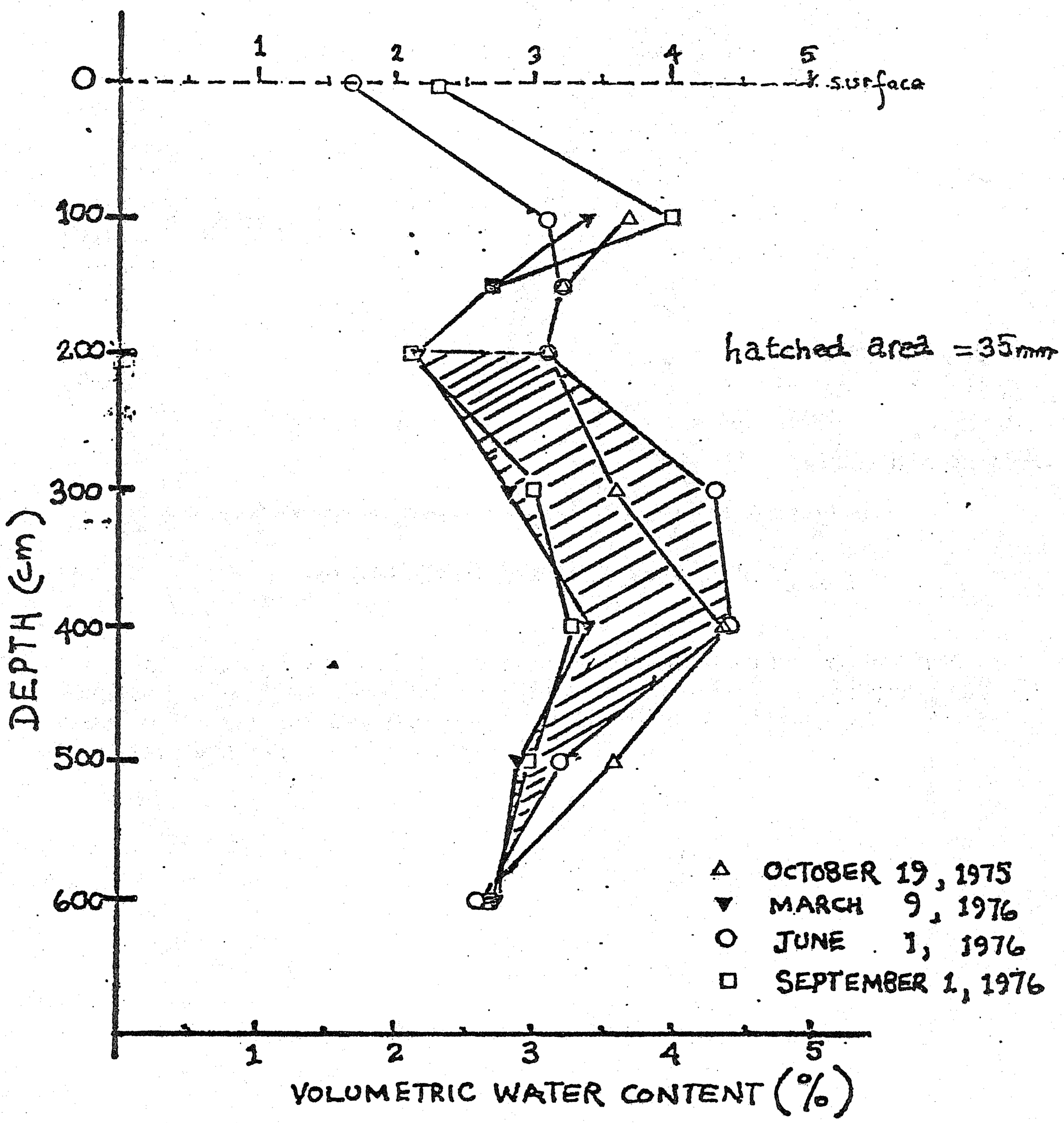


Fig. 3. Seasonal changes in soil water content as determined by gravimetric sampling (surface) and neutron probe (other points). The hatched area indicates the maximum observed seasonal amplitude of 35 mm of water between 2 and 6 meters.

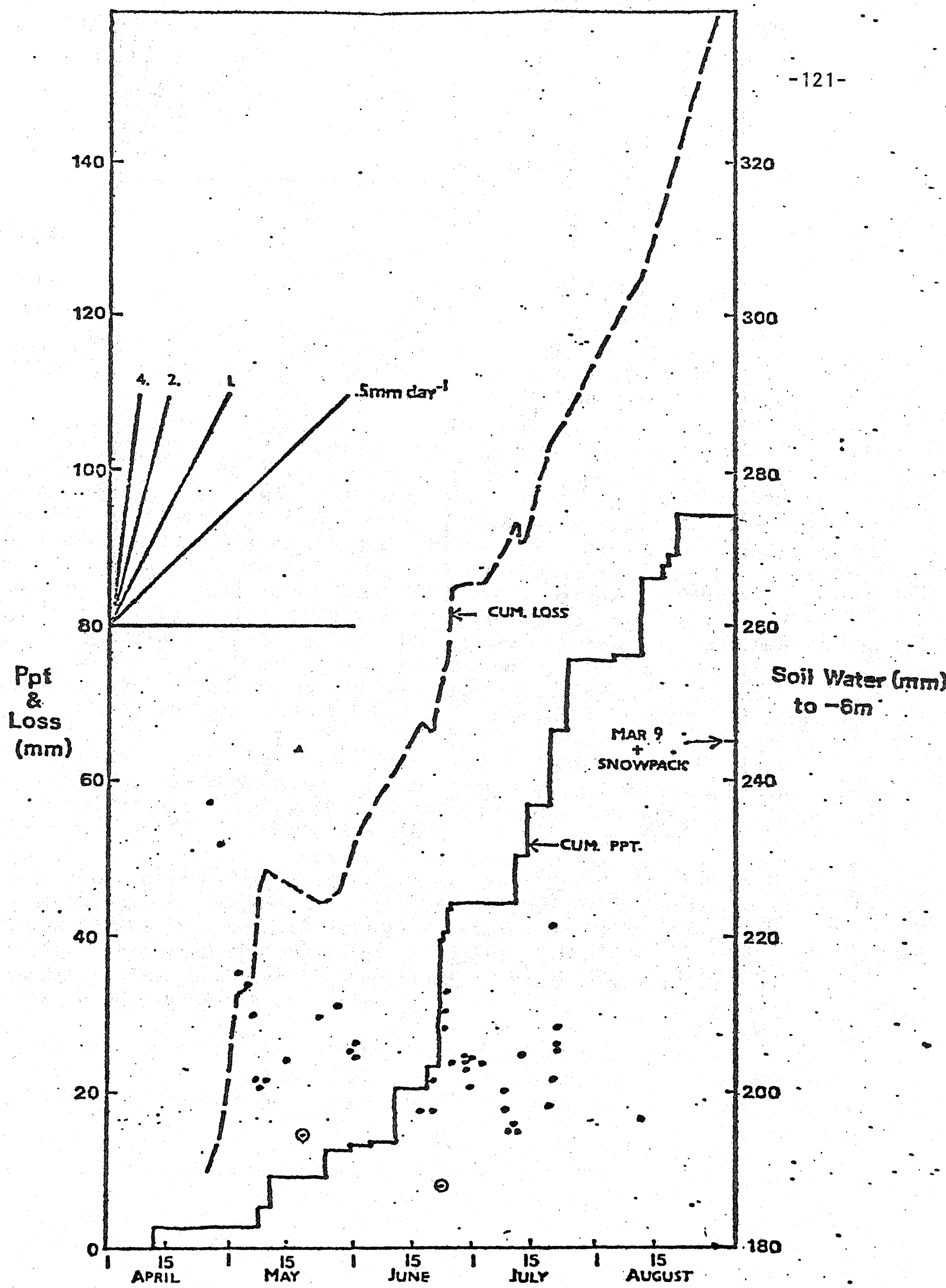


Fig. 4. Seasonal soil water content, integrated from the surface to 6 meters depth (dots), cummulative non-intercepted precipitation (solid line), and calculated cummulative loss (dashed line) over the season. At the left centre are indicated the slopes corresponding to various loss rates. Also shown is the estimated total amount of water in the soil and snowpack before snowmelt.

MICROMETEOROLOGY AND MICROCLIMATOLOGY OF VEGETATION CANOPY

C. Labine

Since joining the project in May of this year we have been involved mostly with the field portion of the project. This consisted of completing the installation of the sensors and data loggers we were to use for the 1976-77 field season.

We have essentially three levels of data acquisition either because of sensor requirments or because of the different data needed by the various researchers of the project. Table I lists the three systems, their frequency of sampling and the sensors used. The long term continuous data are provided by battery-powered Campbell Data Acquisition System. These data will provide the driving variables for the model and describe the mean microclimatic regime for our site. The Fluke system (AC powered with generator) is used during the "intensive runs". These are either continuous 24 hr time periods or several successive days of measurements during the light portion of the day i.e., from just before sunrise to after sunset. During these runs we also operate our manual data acquisition. The two automatic data acquisition systems produce a printed copy in the field and also feed into punch paper type machines. These tape machines make possible the collection and processing of a vast amount of information.

Apart from these data we have also been involved with the gathering of extra parameters which are necessary to describe the environment. One of these was the installation of a multi-level track system to measure radiation in the forest canopy. Short-wave, long wave and photosynthetically active radiation were measured both above the canopy as a reference point and on a trolley travelling within the canopy at four levels. This information is of vital importance to the radiation portion of the overall model.

Another special project was to measure precipitation within the canopy in order to determine how much of the incoming precipitation is intercepted and also what amount comes down as stem flow. An extensive network of rain gauges was established in order to obtain a good measure of the incoming water on the slope.

We are at present in winter mode of field operations. The Campbell data system will be operational throughout the winter months. We will be making periodical visits to the site for instrument maintenance and snow course measurements.

As a preliminary introduction to our data we wish to show how our site fits into the general climatic trends and also how this past field season compares with other years. From Fig. 1, one observes that Richardson is warmer than Ft. McMurray especially in the first part of the growing season, namely May and June. In July and August, however, the temperatures come together. Fig. 2 shows the same trend for the 1976 field season. Richardson, (our site) is 2 to 3 C warmer than Ft. McMurray or Mildred Lake. Here again this is true early in the season and the differences are not as great later on. Fig. 3 gives us a better understanding of this trend. By comparing the screen data from the fire tower site with our own screens, one in the middle of the hill, and the other at the bottom of the slope. The mid-screen values are again warmer at the start of the season but deviate less from the other sites as we approach July and August. It is obvious that with the high insolation in May and June, the hill side, because of it's southwest exposure warms up much more than the top of the hill which is also very well ventilated.

Turning our attention to precipitation we find that Richardson is a slightly drier site than Ft. McMurray (Fig. 4) in agreement with the general trend as one goes north from Ft. McMurray. For the 1976 field season we find that Richardson was either near normal or slightly above normal when compared with long term records. (Table 2). This applies from May through July, August was drier than normal.

In conclusion, one could say that our site for the 1976 field season was warmer (1-2%) than normal in the early part of the season but near normal as we progressed into July and August. The precipitation pattern was near normal or higher than normal.

Since 1976 was a normal year climatically one has to consider this in light of the entire project. The ideal would be to measure the environment and monitor plant responses during a dry and hot year, in order to judge how well the plants do in such extremes. We cannot hope to have such conditions unless we plan to continue this work over a long time span. In more realistic terms, however, this can be achieved through the working model by inputing extreme conditions that have been recorded in past climatic data. For example, in the last thirty years, the extreme maximum temperatures have been on the average 16°C higher than the mean maximum temperatures (Fig 5). The precipitation data from Ft. McMurray can show similar extremes (Table 3).

We are now proceeding with the data analysis and are preparing for the next field season. We are intending to duplicate to a certain degree, the long term continuous data acquisition on the dike and to reduce our activity at Richardson. It is planned to have the Fluke system shared between the two sites.

Table 1. Instruments used for the three levels of data acquisition at Richardson.

Level of Acquisition	Parameters Measured	Frequency of Sampling
1) Manual	*Dew Point temperature at .5, 2, 4, 5 m	every 15 minutes during intensive runs
	*Wind Speed at .25, .5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0 m	every 14 minutes during intensive runs
2) Continuous Campbell CR-5 Digital Recorder	Global Radiation (280-2850nm) Red Radiation (695-2850nm) Infrared Radiation (3500-50,000nm) Global Diffuse All Wave incoming 300-6000nm All Wave outgoing 300-6000nm Air Temperature-8m, near surface Wet Bulb Temperature-8m, near surface Soil Heat flux Wind Speed and Direction 8m	Integrated values over 30 minute period printed every 30 minutes
3) Short term intensive	Same parameters from the Campbell System (except soil heat flux and wind speed and direction) Air Temperature at .25, .5, 1, 2, 3, 4, 5, 6 m Relative Humidity at .05 m Leaf Temperatures Lichen Thalli Temperatures Soil Temperatures .01, .02, .04, .08, .125, .25, 2.0, 6.0 m *Three wind components (U,V,W) at 8 m	every 3 minutes during intensive runs

*Sensors on loan from Meteorology Department, University of Alberta

Table 2. Total precipitation for:
Richardson, Richardson L.O. and Ft. McMurray (mm).

Station	May	June	July	Aug.
Ft. McMurray (1941-1970)	33.0	61.6	73.7	64.0
Richardson L.O. (1941-1970)	24.9	56.6	57.4	73.4
Richardson (our site) (1976)	22.3	71.9	67.7	33.3

Table 3. Precipitation data for Dt. McMurray (mm).
Data from Canadian Climatic Normals.

	Total ppt	May	June	July	Aug.	Sept.
1908-1944 Mean	370.8	37.3	58.9	78.8	53.8	47.0
1941-1970 Mean	435.4	33.0	61.5	73.7	64.0	53.1
Max ppt	647.5	98.0	137.2	204.0	109.0	132.6
Min ppt	276.6	5.1	19.3	5.6	10.2	5.6
Examples of low ppt years						
1938	336.6	34.0	43.9	64.3	52.8	15.2
1940	276.6	49.5	48.0	5.6	30.2	31.5

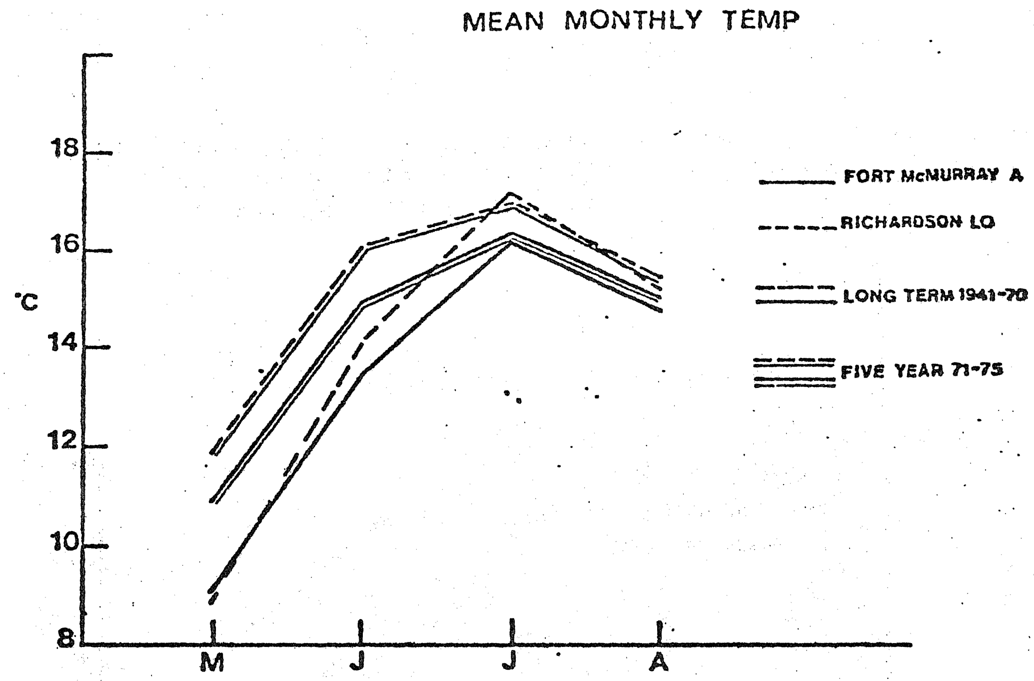


Figure I. Mean monthly temperatures for Fort McMurray Airport and Richardson Lookout. Long term and recent five year means are shown.

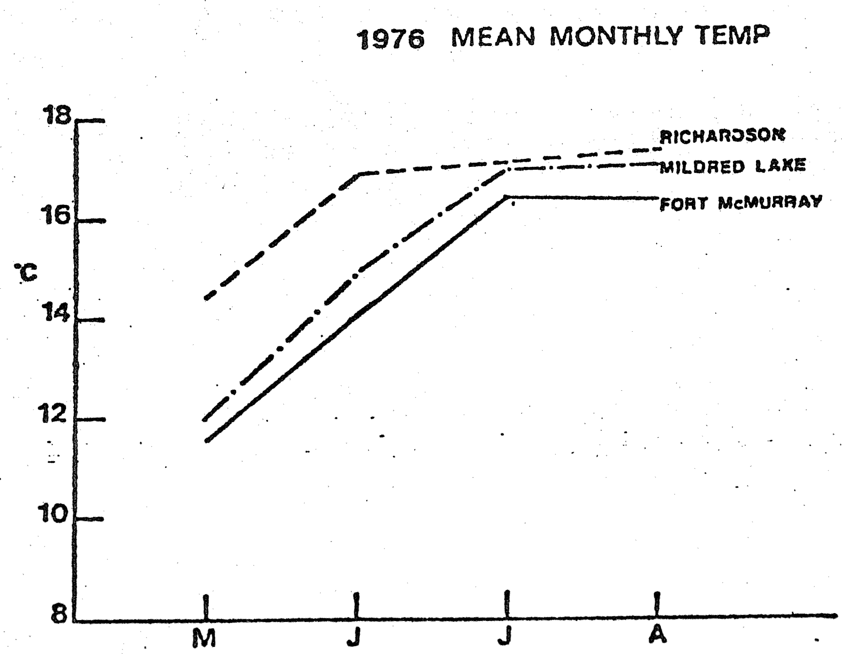


Figure 2. Mean monthly temperatures for 1976 (May to August) for Richardson (our site), Mildred Lake and Fort McMurray Airport.

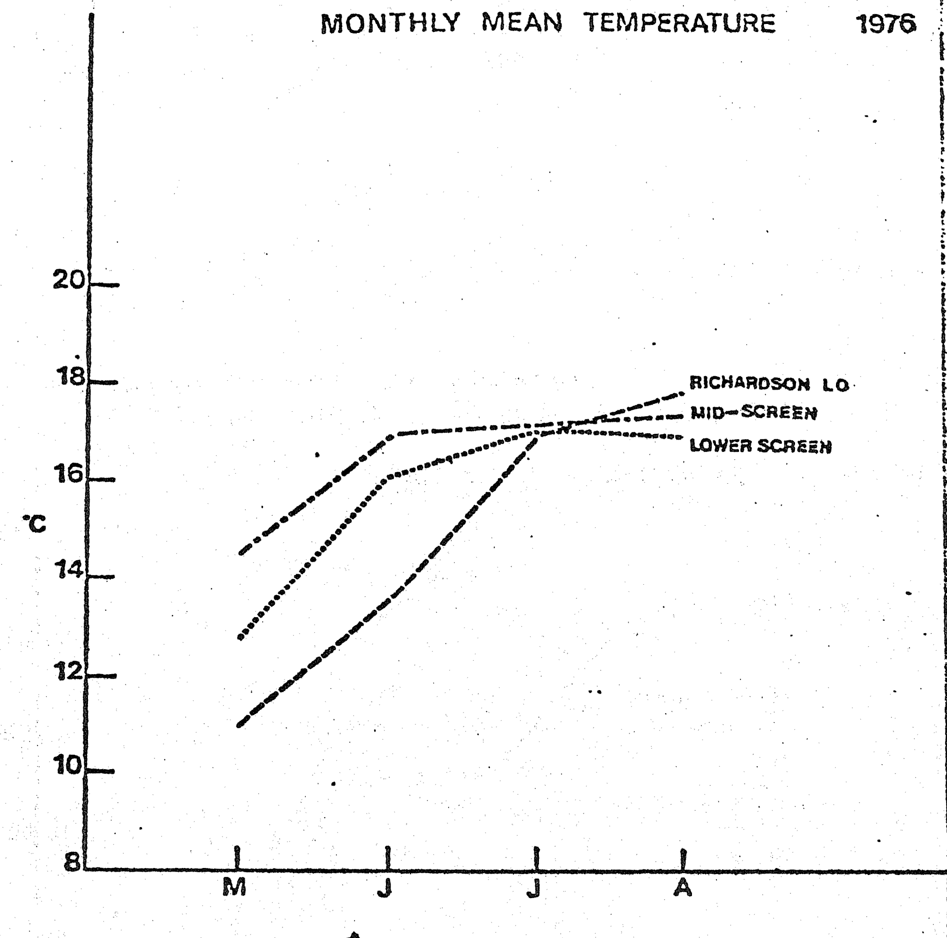
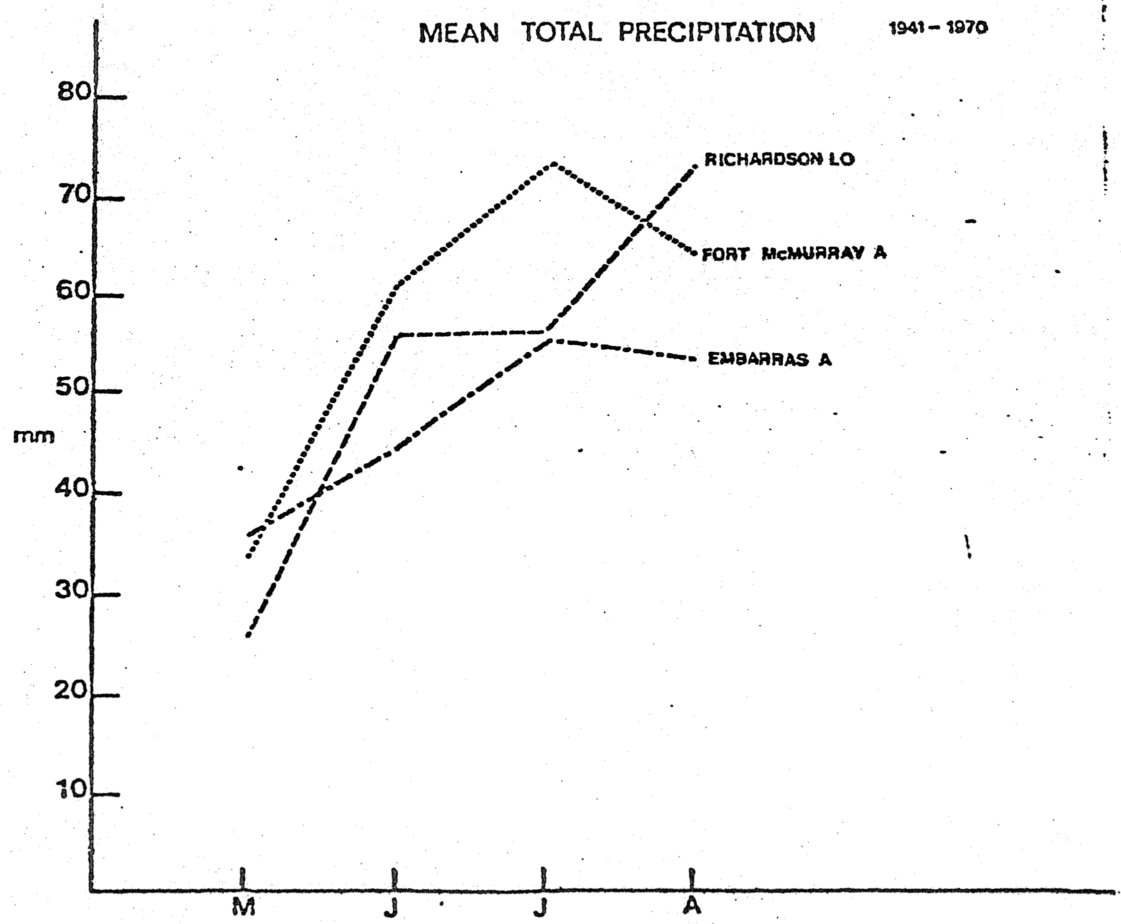


Figure 3. Mean monthly temperatures from Richardson Lookout and our own two Stevenson screens.



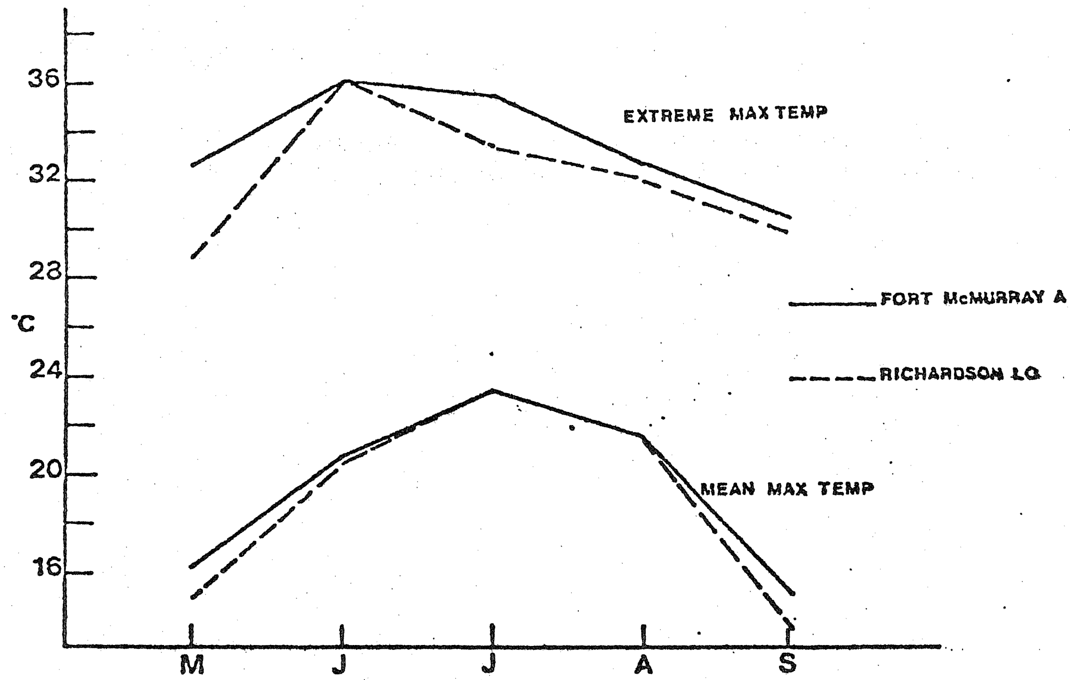


Figure 5. Mean maximum and extreme maximum temperatures for Fort McMurray and Richardson Lookout.(I94I-I970)

PLANT PHYSIOLOGY

J.M. Mayo, J.E. Harter, S. Nelson

Introduction

The plant ecophysiological research on the Jack pine forest at Richardson Fire Tower is designed to understand the physiology of plants growing on stable sand slopes and to supply the necessary parameters for development of a soil-plant-atmosphere model of heat and water fluxes. This model will help characterize the behavior of natural vegetation on stablized sand and allow the prediction of vegetation performance for dike management. The present study also constitutes a base line for extention into and comparison with communities influenced by pollutants such as SO_2. A basic assumption in this study is that water is a major controlling factor in the long-term stability of vegetation on sand. Plant ecophysiological research has thus initially concentrated on the water relations of the major shrub and tree species with the emphasis on Jack pine, Pinus banksiana. Mineral nutrition is also recognized as an important limiting factor on sand, and will need to be incorporated into models of the system.

The major areas of research are listed below. Much of this work is either ongoing or the data only partially analyzed and the conclusions therefore tentative. This report will discuss only the portion of the completed field research presented at the October 1976 AOSERP workshop, and will conclude with future research objectives.

Major Areas of Research

1. Seasonal and diurnal plant-water relations of the major shrub and tree species at the Richardson Fire Tower study site, with a concentration on Jack pine.
2. Laboratory studies to determine sub-lethal and lethal water stress levels for Jack pine.
3. Determination of the canopy structure or architecture of mature Jack pine trees to aid in assessing the effect of interception of environmental parameters by plant parts at various points within the canopy.

Methods and Materials

Field studies at the Richardson Fire Tower were initiated in late fall, 1975, and continue to date. The approach has been to examine plant responses intensively over periods of one to several days at biologically significant times of the year: mid-winter, pre-thaw, snow melt, needle flush, mid summer, etc. This allows a comparison of diurnal and seasonal changes in the plants water status and aids in understanding the development and significance of internal water deficits.

Water potential and its components are used to evaluate water deficits in Jack pine. Water potential is a measure of the free energy status of water and is usually expressed in negative pressure units of bars or atmospheres (1 bar = 0.987 atm.). Water moves through the soil-plant-atmosphere system along a gradient of decreasing (more negative) water potentials. The components of plant water potential can be written as:

$$\Psi = \Psi_p + \Psi_\pi + \Psi_m$$

where Ψ = plant water potential; p = turgor; r = matric potential; and π = osmotic potential. More negative plant water potentials indicate increasing internal water deficits. This is controlled by the level of soil water potential, the atmospheric demand due to radiation, vapour pressure, and temperature, the the plant's ability to exercise control over transpiration by stomatal closure. Increasing internal water deficits imply increasing stress although plant species vary as to the degree that normal physiological processes are impaired or stressed by a given level of water deficit.

Plant water potentials were measured directly with thermocouple psychrometers (Mayo 1974) or estimated from xylem pressure potentials (xylem tensions) determined with a Scholander pressure chamber (Ritchie and Hinckley 1975). Psychrometry allows a measurement of both water potential and component potentials and thus gives a more complete assessment of a plant's water status than water potential or xylem tension alone. Psychrometry, however, is difficult under field conditions so the bulk of the field measurements were necessarily made with the pressure chamber. Tissue water content has also been measured and is useful for comparison with the older literature on trees and is necessary for the modelling component.

Transpiration rates of needled branches were measured using a dew point hygrometer (EG & G model 880). The technique involves the measurement of the increase in absolute humidity of an air stream passing over a transpiring branch enclosed in a plexiglass cuvette (Slavik 1974). Transpiration rate may be used to calculate the diffusive resistance to water vapour of the needles. Transpiration resistance is the sum of the resistance situated in the needles and in the boudary layer of air at the plants surface:

$$R_t = R_l + R_a$$

where R_t = transpiration resistance; R_l = leaf resistance; and R_a = boundary layer resistance. Adequate ventilation in the curvette reduces the boundary layer resistance to a small value so that R_t approximates R_l and reflects the degree of stomatal control over transpiration. A portable ventilated diffusion porometer (Gresham et. al.1975) has also been built and field tested and will be used to increase the stomatal resistance measurement capabilities.

Results

Seasonal trend in xylem tension.

The seasonal progression of xylem tensions of Jack pine at midslope on the study hill at Richardson Fire Tower is indicated in Figure 1. Values remained high (-3 to -10 atm.) throughout the winter with little diurnal change between dawn and midday readings. It was originally thought that the trees might experience severe water stress in winter due to their apparent ability to rapidly break dormancy and assume a positive net assimilation (Bliss 1975), and because of data from a Whitecourt, Alberta study indicating lower xylem tensions during the winter for pine and spruce (Legge et. al.1976). Severe winter water stress did not occur perhaps due to high soil moisture levels going into winter.

The magnitude of the diurnal variation increased suddenly after the spring thaw period. Mean summer (May to September) maximum (midday) and minimum (dawn) xylem tensions varied between -4 to -7 atm. and -11 to -14 atm., respectively. The absolute maximum and minimum values measured at this site were -3.4 and -16.2 atm. A similar range is reported for *Pinus banksiana* X *P. contorta* hybrids at Whitecourt (Legge et al. 1976). However, trees at this latter site tended to experience more negative xylem tensions during both summer and winter.

Figure 1 also indicates that a general decrease in xylem tensions (and increase in water deficits) occurred during the summer. These water deficits did not appear to be stressful since high dawn values were always attained. Precipitation during this period was average to slightly above average and soil moisture remained high (see Soils Section). The model of heat and water fluxes will help to predict the water deficits that would occur during years with reduced precipitation and soil moisture.

Diurnal trends in xylem tension, transpiration, and leaf resistance:

Figures 2 and 3 illustrate the diurnal progression of xylem tensions, transpiration, and leaf resistance of Jack pine during the intensive study periods of April 3-4 and June 29-30, 1976. The April study was conducted during the snow release period. Soil temperatures to 50 cm depth remained within 1°C of freezing while pine needle temperatures were often elevated to 10 - 15° C. Midday transpiration rates were less than 0.1μg cm^{-2}sec^{-1} with corresponding leaf resistances of approximately 100 sec cm^{-1}. These values indicate that the stomata were fully closed. Xylem tensions remained nearly constant, varying between -6.5 and -8.0 atm. over the 30 hour period, and providing additional evidence that the plants water status did not vary significantly. The spring thaw period with the combination of cold soils and elevated leaf temperatures has been suggested as being potentially stressful for Jack pine. These measurements indicate that the trees remained dormant during this period and avoided the development of large water deficits.

The uniformity of the plant responses in April contrast sharply with the large diurnal changes in xylem tension, transpiration, and leaf resistance that occurred in late June. The June study was conducted during a period with high radiation levels, high air and needle temperatures, and high evaporative conditions. Xylem tensions showed a diurnal range of over 10 atm. from high dawn values near -5 atm. to low midday values near -15 atm. (disregarding one anamalous value near -18 atm.). This change in xylem tensions of 10 atm. is a large diurnal fluctuation and reflects the intensity of atmospheric evaporative demands. Rapid recovery occurred within two hours of sunset, indicating that soil moisture was not limiting. Water deficits to -15 atm. would be devastating to many temperate region agronomic species, and this probably represents a sub-lethal stress for Jack pine. The significance of this level of water deficit will be determined by laboratory studies.

Transpiration rates varied from low night levels less than 0.1μg cm^{-2} sec $^{-1}$ to high midday levels near 1.4μg cm^{-2}sec^{-1}. Transpiration rates closely paralleled xylem tensions, particularly on June 30, when transpiration increased concomitantly with decreasing xylem tension. The low leaf resistance values of 10 to 15 cm^{-1} measured during midday represent fully open stomata. The high night values greater than 100 sec cm^{-1} represent closed stomata and are similar to the lowest values obtained during the April run.

Partial midday stomatal closure is evident between 1400 and 2000 hours on June 29. Transpiration decreased several times (and leaf resistance increased) even though radiation levels remained high and the stomata were not light limited. This response may simply be due to the extreme evaporative conditions at the time, although the level of water deficit as indicated by xylem tensions had previously been greater and the stomata remained open. This suggests that the midday closure may have been due to other factors such as an increase in intercellular CO_2 concentrations as a result of high temperatures and not simply due to water stress.

Transpiration and leaf resistance are plotted against xylem tensions (Fig.4) and radiation (Fig 5) for the June 29-30 study period to help clarify the factors influencing water loss from Jack pine. The midday closure values of June 29 are plotted on the graphs but have been excluded from the curves.

Figure 4 shows there is a nearly linear increase in transpiration with a decrease in xylem tension over the range of -5 to -18 atm. This indicates that the stomata remain open, transpiration is not limited, and the pine trees are not appreciably water stressed at xylem tensions (water deficits) down to -18 atm. Maximum transpiration rates occurred in midday when xylem tensions were lowest. Figure 5 indicates that the stomata were responding largely to radiation. High radiation levels result in elevated needle and air temperatures and create high evaporative damands. This results in increased water loss and thus increased water deficits in the trees. The failure of Jack pine to close stomata and limit transpiration at high water deficits is in complete contrast to that reported for *Pinus contorta* seedlings by Dykstra (1974). He showed a steady increase in stomatal resistance as tree water potential decreased from -3 to -15 bars. Curves similar to Figure 4 and 5 have been obtained from the other summer intensive study periods at Richardson Fire Tower so the relationship appears valid. The ability of Jack pine to maintain open stomata and CO_2 flux for photosynthesis at increasing water deficits may be an adaptation to a xeric environment. Laboratory studies in stress physiology will need to be conducted to determine at what point water becomes limiting.

Conclusions

Appreciable water stress did not occur in Jack pine trees at the Richardson Fire Tower study site during the winter, spring thaw, and summer periods of 1975-76. This may be the result of favorable environmental conditions (eg. soil moisture) throughout this time, or simply the ability of Jack pine to tolerate water deficits. Future work at Richardson and in the laboratory will be oriented towards putting limits on this tolerance. Plant responses (not necessarily Jack pine) and environmental parameters must also be monitored on the GCOS dike. This will serve as input into the model to aid in the prediction of vegetation performance, especially during environmental conditions more extreme than may be encountered in these study years.

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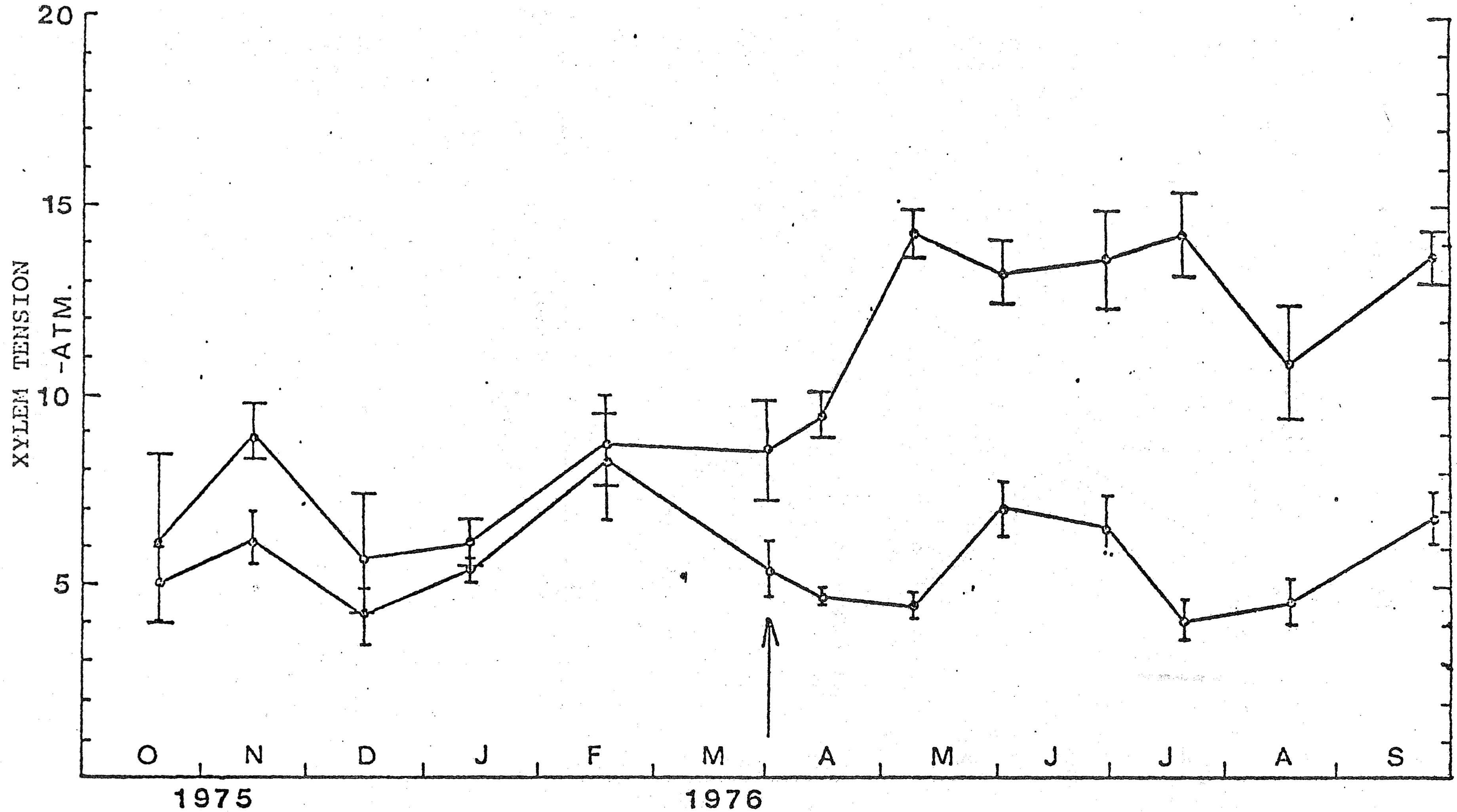

Figure 1. Seasonal courses of maximum (dawn) and minimum (midday) xylem tensions of *Pinus banksiana* at midslope on the study hill at Richardson Fire Tower during 1975-76. Vertical bars represent 95% confidence intervals and the vertical arrow indicates snow release.

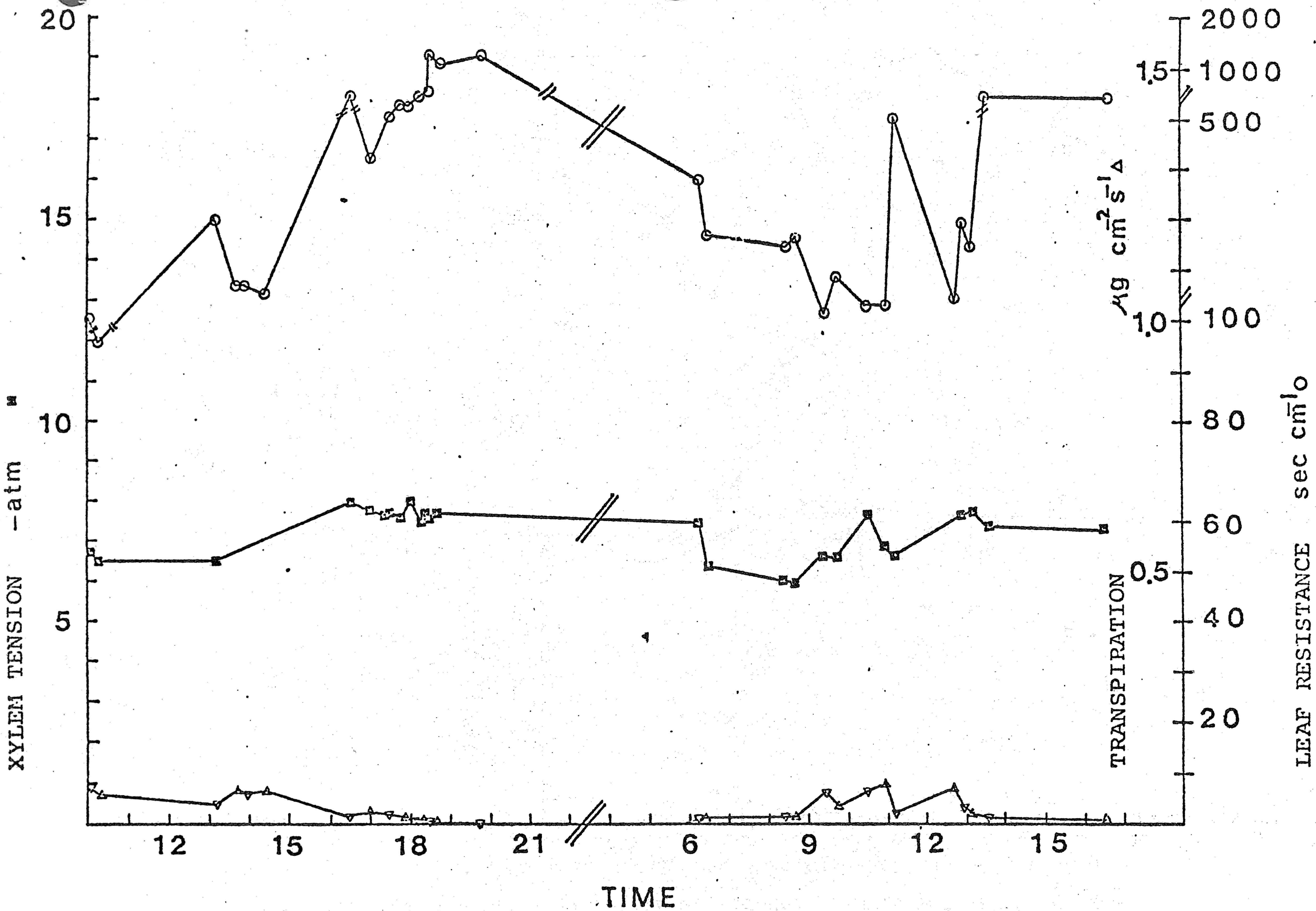

Figure 2. Diurnal courses of xylem tensions, transpiration, and leaf resistance of Pinus banksiana at midslope on the study hill at Richardson Fire Tower on April 3-4, 1976.

■ XYLEM TENSION

▽ TRANSPIRATION

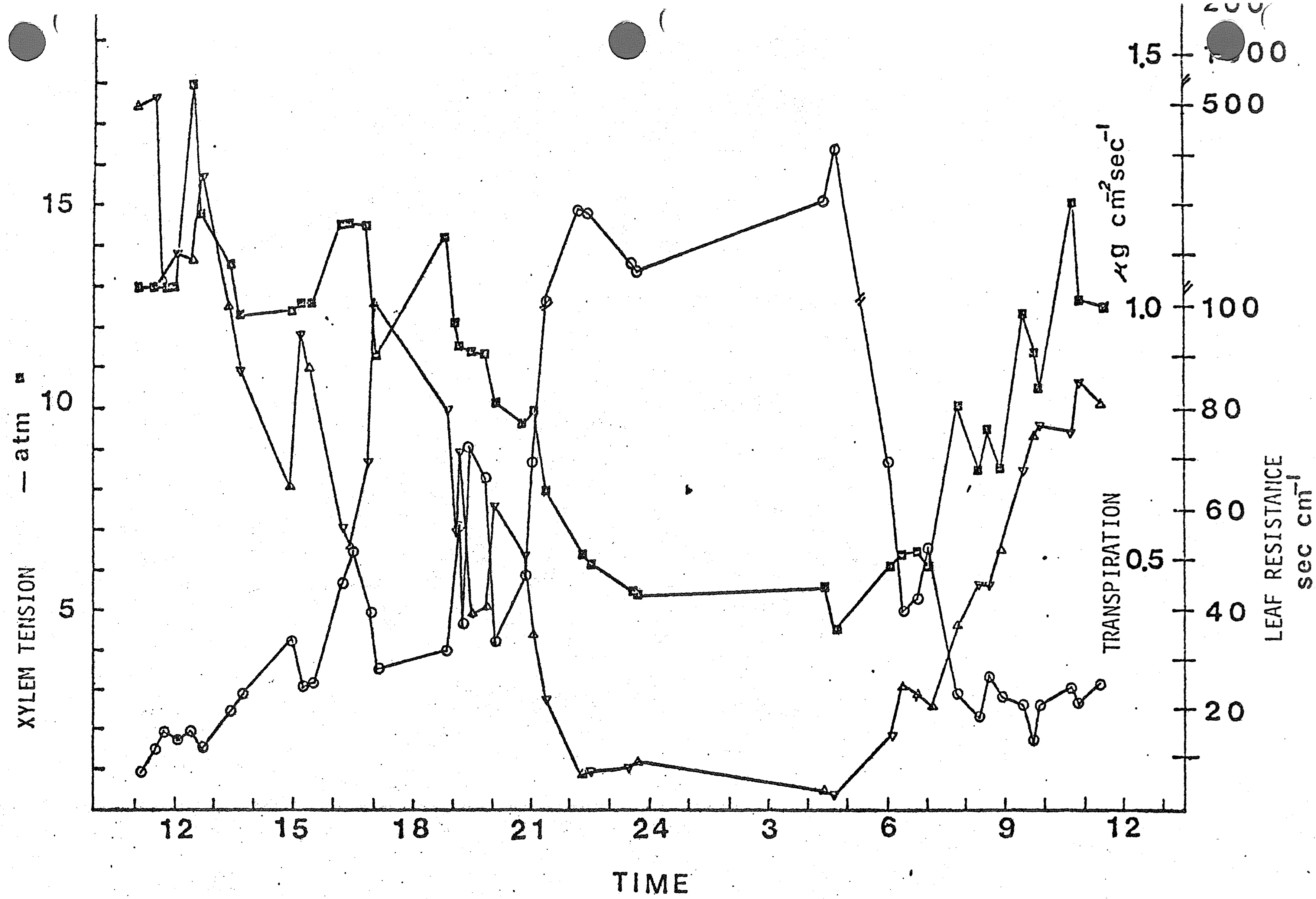

Figure 3. Diurnal courses of xylem tensions, transpiration, and leaf resistance of <u>Pinus banksiana</u> at midslope on the study hill at Richardson Fire Tower on June 29-30, 1976.

▣ XYLEM TENSION
▽ TRANSPIRATION
○ LEAF RESISTANCE

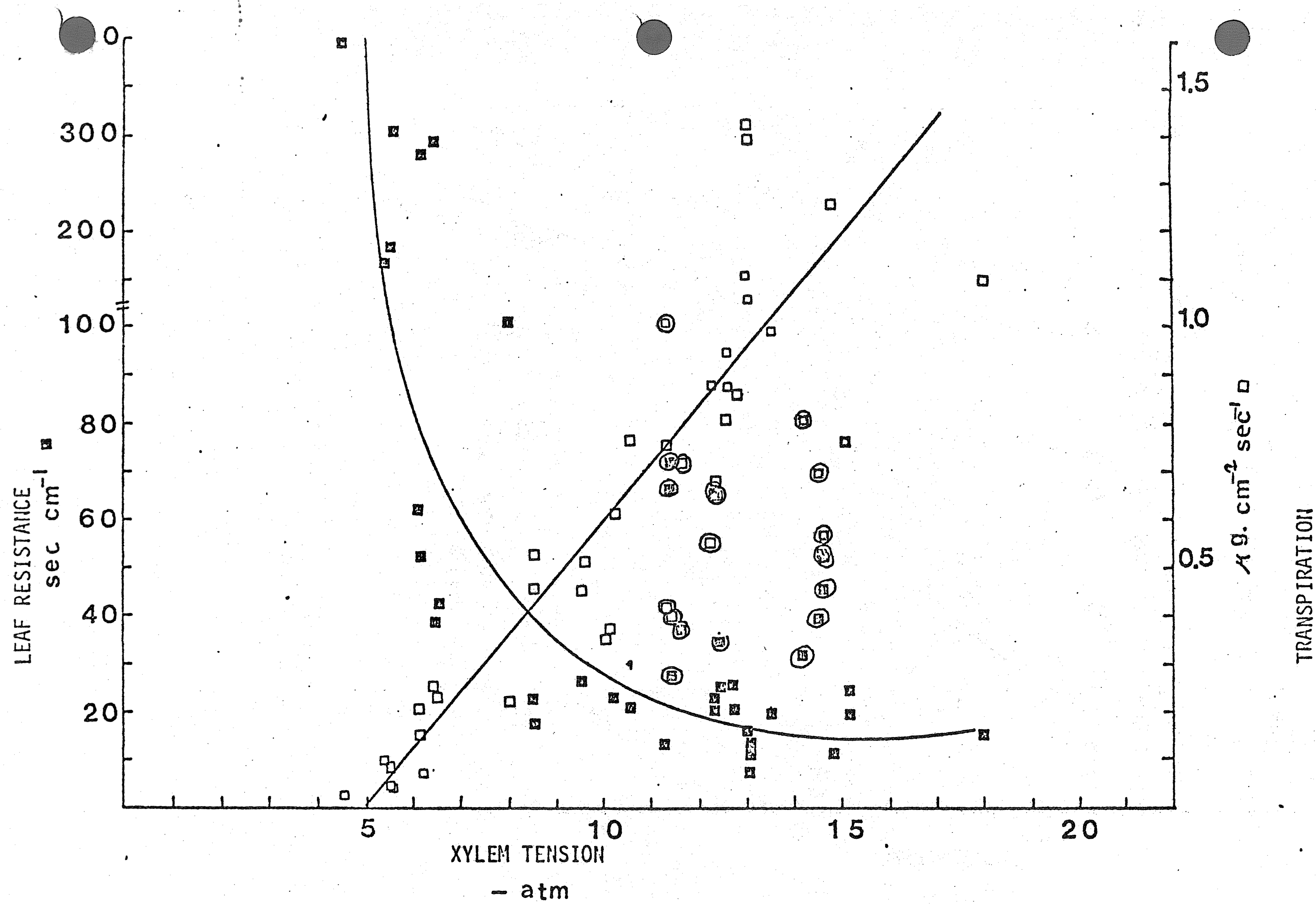

Figure 4. Transpiration and leaf resistance of Pinus banksiana versus xylem tensions for the period June 29-30, 1976, at Richardson Fire Tower. Circled values represent probable midday stomatal closure and are excluded from the curves.

□ TRANSPIRATION
⊠ LEAF RESISTANCE

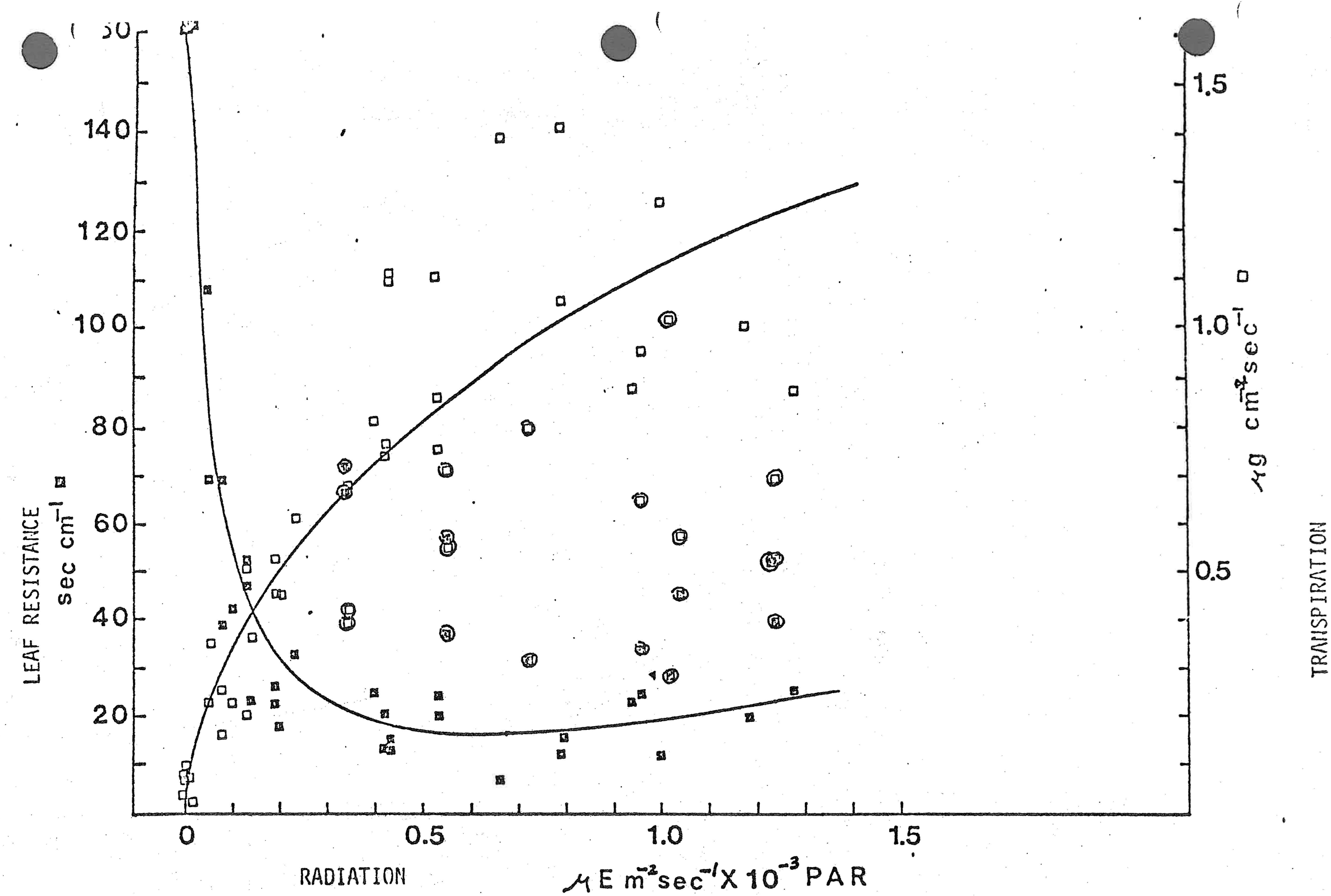

Figure 5. Transpiration and leaf resistance of Pinus banksiana versus radiation for the period June 29-30, 1976, at Richardson Fire Tower. Circled values represent probable midday stomatal closure and are excluded from the curves.

□ TRANSPIRATION

▣ LEAF RESISTANCE

INVESTIGATIONS ON THE ROLE OF LICHENS IN THE JACK PINE - LICHEN FOREST ECOSYSTEM

D.C. Lindsay

In both mature and developmental plant communities on sands throughout North America lichens provide the major ground cover. Any plant community allowed to develop naturally on the sands of the tailings dike mat therefore can be assumed to have a considerable lichen component during at least one phase. Previous work on lichens in communities developed on sands soils has shown that they have an important role in water relations, believed to be the major factor in the establishment and maintenance of stable plant communities on the tailings dike.

Studies were thus begun in mid-November 1975 on the ecology and ecophysiology of the major component of the lichen ground layer in jack pine forest, Cladina mitis (Sandst.) Hale & Culb., to determine its exact role within the forest ecosystem. Data arising from this study would then be used in the construction of a lichen water relations and energy budget submodel. This submodel would then be incorporated into the major model of prediction of plant responses to climatic variable on the tailings dike.

1. Water relations

The most important role Cladina mitis appears to play in the forest ecosystem is its function as a mechanical barrier to water and energy exchange between the soil and the atmosphere. Recently Rouse and Kershaw (1971) have shown that Cladina species act as an extremely efficient mulch in black spruce forest on coarse sands in Ontario. This would appear to be surprising since lichens lack morphological and anatomical structure to regulate water loss or uptake, reacting passively to environmental fluctuations. Experiments were carried out to investigate the water relations of Cladina mitis.

A. Evaporation:

This was investigated both in the field and laboratory. Laboratory studies involved studies of evaporation under controlled conditions in a wind tunnel. The wind tunnel is illustrated diagrammatically in Fig. 1. It was 200 x 35 x 35 cm, fitted with a plexiglass observation window in the top side, access hatch in the side and aperture for the lichen core to rest on a Mettler top pan balance in the base. Wind speed through the tunnel could be varied by adjusting the voltage to the fan. Air flow was smoothed by use of tubular baffles 25 x 4 cm in the anterior section of the tunnel. Flow at all windspeeds was checked by suspending cotton thread at various heights in the tunnel and found to be laminar except for 2 cm directly above the lichen carpet. Radiation load could be varied by shielding the plexiglass window and by placing floodlights at various height above it. In this manner radiation loads of up to 3.2 watts m^2min^{-1} were obtained, equivalent to a sunny mid-summer afternoon at Richardson Fire Tower. A Cladina mitis carpet covered the floor of the tunnel, with a central core of lichen supported on a Mettler top pan balance. The tunnel was instrumented for relative humidity, temperature of the lichen and the air. Evaporation rate was determined by weighing the lichen core at regular intervals. At the beginning of each drying run the lichen carpet was saturated with excess distilled water and allowed to drain.

Drying runs were carried out at four wind speeds, 0.50, 0.75, 1.00 and 1.25 m sec^{-1} and at two radiation loads, darkness and 3.2 watts $m^2 min^{-1}$. From the following formula, derived by Dr. D.W.A. Whitfield, it is possible to calculate total resistance of the lichen carpet to water loss:

$$r_t + 1.138 r_b = \frac{2a(e_T - e_A)}{E(T_T^A + T_A^A)}$$

where:

r_t = thallus resistance
r_b = boundary layer resistance
a = 2.17×10^{-4}
e_T = thallus vapour pressure
e_A = air vapour pressure
E = evaporation rate gm cm^2 min^{-1}
T_T^A = thallus temperature ^oA
T_A^A = air temperature ^oA

The results are shown in Fig. 2. Boundary layer resistance decreases with increase in wind speed and is related to its square root. At water contents of between 170% and 140%, thallus resistance becomes the major factor in controlling water loss. Radiation load appears to have little effect on boundary layer resistance.

Field experiments at Richardson Fire Tower involving measuring water loss from lichen carpet placed in mesh sod pots. Adjacent lichen carpet was instrumented as in the wind tunnel, wind speed being measured by hot-wire anemometer. Resistances in the field were found to be very similar to the values obtained in the wind tunnel experiments.

B. Precipitation retention and infiltration:

Experiments carried out to determine the quantities of rainfall lichen carpet and needle duff absorb before penetration to the underlying soil. Previous workers, e.g. Jack, 1935; Moul and Buell, 1955, has shown that species of Cladonia can absorb up to 4.5 time their own weight of water or 5.6 mm of rainfall before any infiltration to the underlying soil would occur. The experimental apparatus is illustrated diagrammatically in Fig. 3. Lichen carpet or needle duff was placed in a mesh-bottomed aluminium tray 40 x 25 cm. A funnel 16 cm diameter was placed centrally under the tray to avoid edge effects. In the laboratory rainfall was simulated by use of a watering can rose to spray droplets whose fall was randomised by an oscillator fan blowing at 2 m sec^{-1}. The rainfall rate used was 20 mm $hour^{-1}$. It was found that the lichen carpet absorbed 1.82 mm of rainfall before any penetration occurred, showers of 0.7 - 1.5 mm failing to pass through the carpet. Needle duff retained 1.25 mm of rainfall. On a unit depth basis the two types of ground leyer absorbed the same quantities of rainfall, the lichen layer (mean depth 4.5 cm) retaining 0.41 mm rainfall per centimetre and the needle duff (mean depth 3.0 cm) retaining 0.42 mm rainfall per centimetre.

Little data are available from Richardson Fire Tower since most of the field work was carried out under dry conditions. The apparatus was set up in an open area of forest and infiltration from showers recorded and compared with results from an adjacent rain gauge. It was found that the lichen carpet retained the first 1.89 mm of rainfall, very close to the laboratory values.

Sand under the ground layer, despite receiving less water from rainfall than bare sand, retains its moisture longer and is often wetter than bare sand (Porter and Woollett, 1929). Soil samples collected beneath lichen carpet, needle duff and bare sand at Richardson Fire Tower indicate that the ground cover is very effective as a barrier to water transport between atmosphere and soil:

Table 1. Water content (% weight) of soil following precipitation at Richardson Fire Tower, October 1976. (means from six sites)

Sample depth	Bare sand	Lichen carpet	Needle duff
ground layer	-	224.1	187.7
soil surface	14.9	9.8	10.3
soil -10 cm	6.9	6.9	5.5

Field studies next year will include work designed to show that soil under the ground layer retains its moisture longer than bare sand during dry periods.

2. Energy relations

Studies have been carried out on the geometrical structure of the lichen canopy and its attentuation of radiation with depth. Data are illustrated in Fig. 4. The greatest surface area occurs just below the tips of the podetia where internodes are elongating rapidly. The penetration of PAR (Fig. 5) shows that much of the radiation is absorbed in the upper part of the lichen layer with a negligeable quantity reaching the underlying soil surface.

3. Lichen water relations submodel

A submodel has been designed by Dr. D.W.A. Whitfield which predicts resistances, water content, thallus temperature and other variables with input of air and thallus temperatures, relative humidity and wind speed. The submodel has been tested by using data from wind tunnel drying runs and intensive runs at Richardson Fire Tower. There is close agreement between observation and prediction regarding the wind tunnel data and less close agreement between intensive run data and submodel predictions, probably because of greater experimental errors in the field.

4. Long term studies

In May 1976 three 100 m^2 plots at Richardson Fire Tower, near top of hill, middle hill and base of hill, were scraped bare of vegetation. Each plot was then divided into two equal halves, the uppermost 3-4 cm of soil then being removed from one half to expose mineral soil. Each of these halves was then divided into eight equal subplots, 4 being left undisturbed and the other 4 being seeded with a mixture of fragments of *Cladina mitis*, *Peltigera malacea* and *Stereocaulon tomentosum* at the rate of 10 gm m^2. A 2 m wide bare zone was established around each 100 m^2 plot to prevent lichen fragments being transported onto the subplots. So far no growth of lichens has been observed in the subplots, which through the action of wind blowing fragments must all be regarded as having been seeded.

From observations in the Richardson Fire Tower area, the first cryptogamic colonizers of bare sands under or near tree cover appear to be *Cladina mitis* and the mosses *Polytrichum piliferum* and *P. juniperinum*. The two mosses have erect unbranched stems and a complicated subterranean rhizoidal system which bind the sand. These mosses may form turfs of some extent which are rapidly invaded by lichens. Scraping of the plots at Richardson Fire

Tower showed that underneath the lichen layer, a Polytrichum layer could still be discerned. Polytrichum may play an important role in the initial colonization of bare sand, providing a foothold for the faster growing lichens.

Summary

Although the 1976 summer at Richardson Fire Tower has been wetter than normal, the lichen ground layer was dry (average 10 - 30% water content). During a normal or dry summer, the lichen layer would be drier for longer periods of time and pose a great fire hazard.

The properties of the lichen layer may be summarized:

1. It acts as a mechanical barrier to water and energy exchange between the soil and atmosphere.
2. It absorbs nutrients directly from rainfall; these eventually become available to the ecosystem.
3. Several species in the ground layer fix atmospheric nitrogen.
4. Antibiotic effects of lichen acids and other exudates inhibits germination in grasses and other vascular plants.
5. It tends to prevent the establishment of seedlings through the heaving processes incurred in the wetting/drying cycle.
6. It absorbs the kinetic energy of raindrops and prevents erosion.

Future research will determine more accurately the nature of these properties and whether these features are suitable for plants involved in the recolonization, stabilization and long term management of sand dikes.

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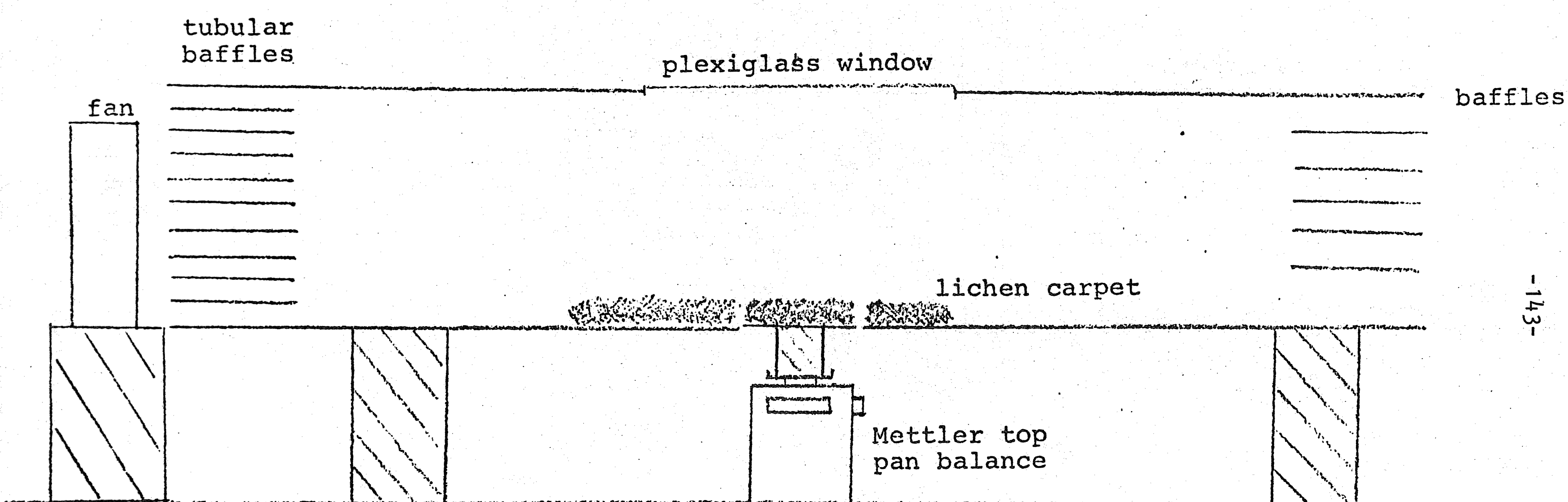

Fig. 1. Diagram of wind tunnel apparatus used to determine resistance to water loss.

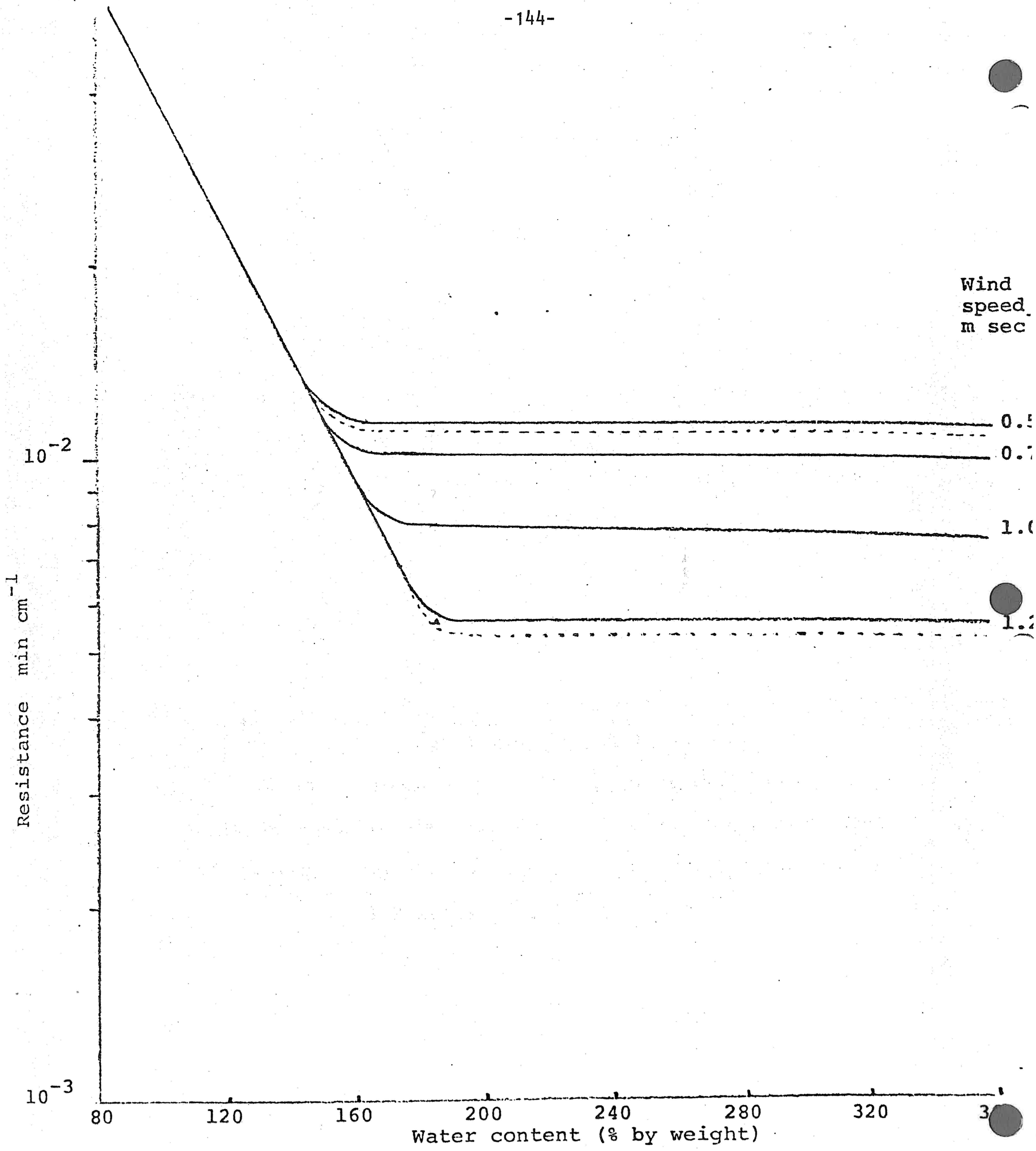

Fig. 2. Total resistance to water loss of Cladina mitis at various wind speeds, water contents and radiation loads.

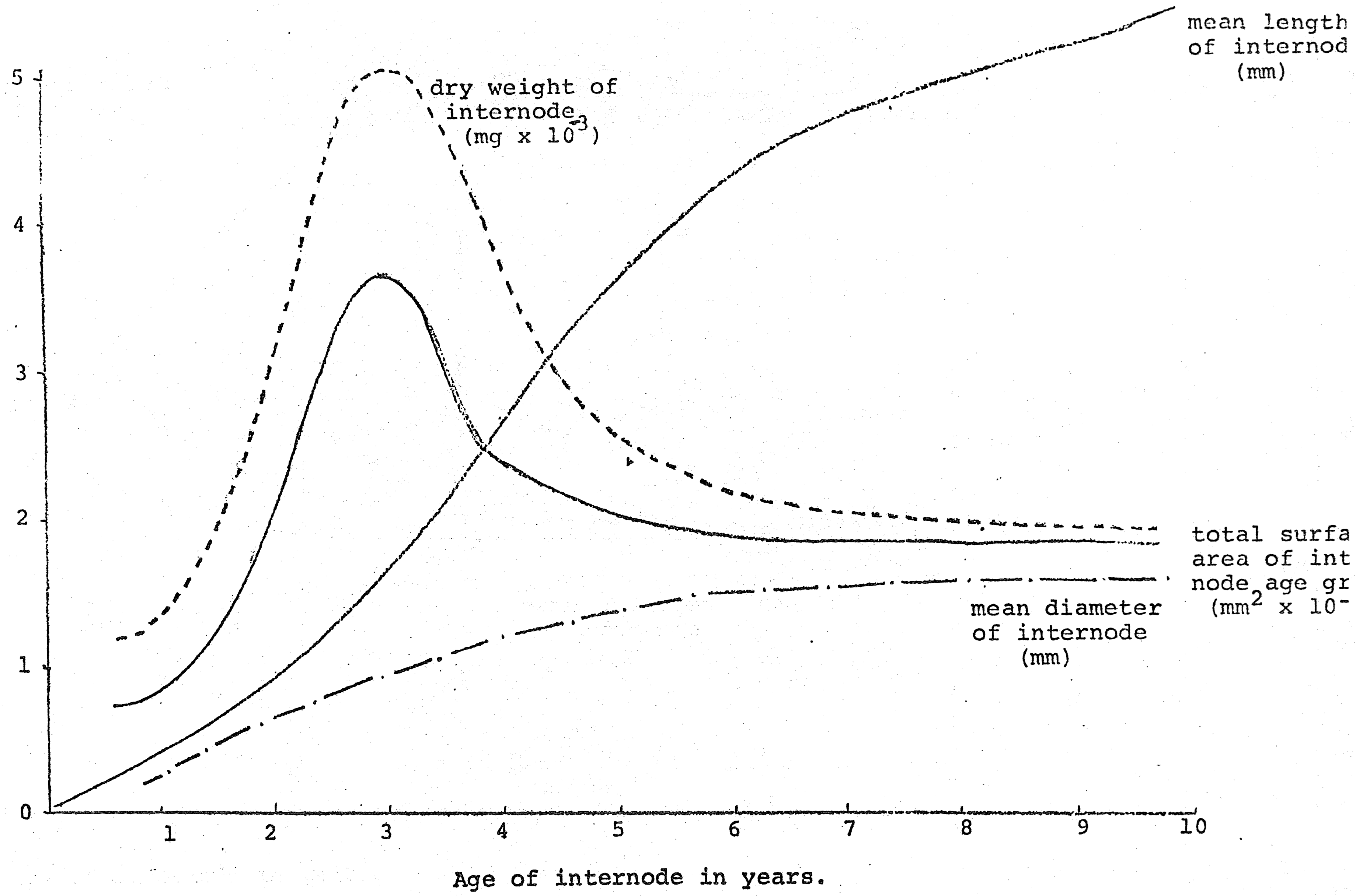

Fig. 4. Surface area and dry weights of internode age groups.

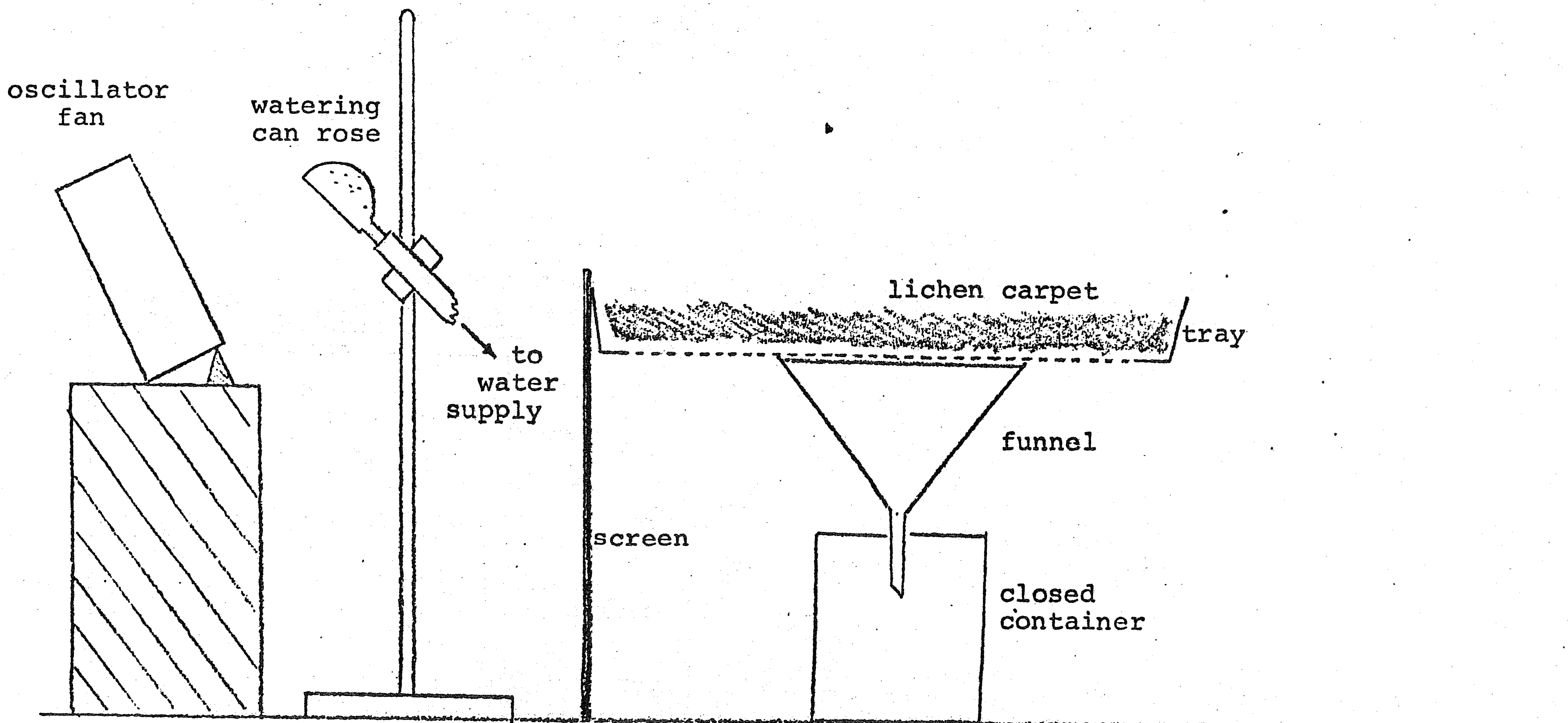

Fig. 3. Rainfall interception apparatus.

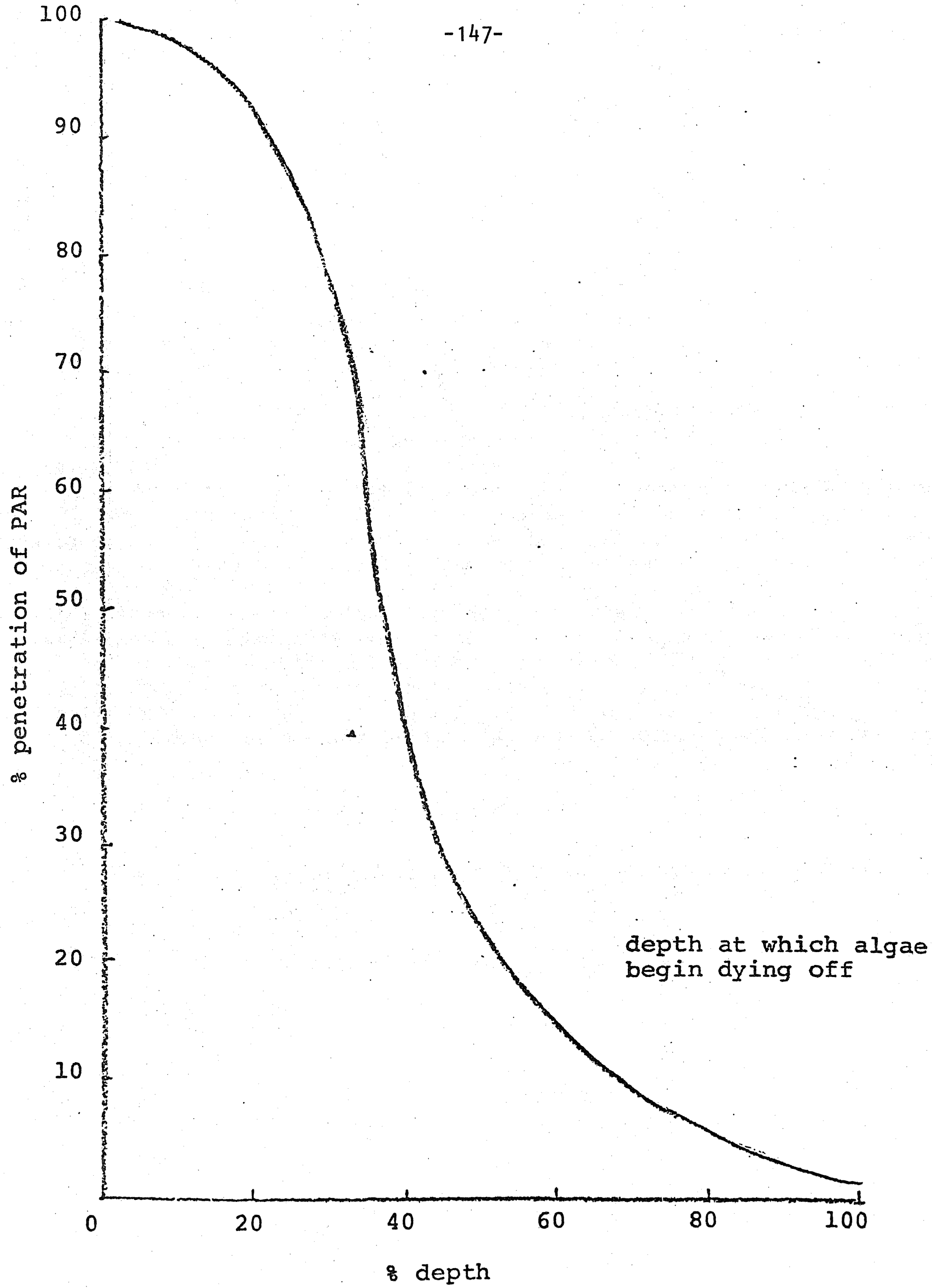

Fig. 5. Penetration of PAR in *Cladina mitis* carpet.

SUCCESSIONAL ROLE OF *HUDSONIA TOMENTOSA*

S. Nelson

Pinus banksiana - lichen woodland is the dominant vegetation type on xeric sandy soils within the Vegetation Committee Study Area. A major pioneer species found after disturbance in this area is *Hudsonia tomentosa* Nutt. Disturbed sites - characterized by open, moving sand, xeric conditions and nutrient poor status - in which *Hudsonia* is commonly found are burns, roadsides, blowouts and sand dunes.

This past summer (1976), field observations were made at a burn located at the Richardson Fire Tower Runway and at a blow out approximately 25 km north of this runway. Results are preliminary, however a few observations which will be further studied are as follows: *Hudsonia* prefers drier open sand exposures, can withstand blowing in and out of sand, produces abundant flowers most of which develop mature seeds, and invades open sand by vegetative and seedling growth.

Research planned for next summer will include the above mentioned sites as well as a large sand dune, south of Lake Athabasca, approximately 105 miles north-eastof Ft. McMurray. The intention of the study is to examine *Hudsonia's* role in natural succession based on an ecophysiological approach, and will provide insight into the physiological characteristics required by species involved in natural stabilization of disturbed sites in the area.

MYCORRRHIZAE IN JACK PINE STANDS AT THE RICHARDSON FIRE TOWER SITE

R.M. Danielson

Mycorrhizae have repeatedly been shown to be necessary for normal growth of higher plants. Recent developments in mycorrhizal research on severely disturbed soils have demonstrated that specific combinations of fungi and hosts significantly influence survival and growth of tree seedling. These results indicate that mycorrhizal associates can be successfully manipulated and that they should be a factor in management decisions, especially in impoverished or severe environments. It was with the knowledge that mycorrhizae are an essential component of soil-plant systems and with the conviction that mycorrhizae are manageable that we have designed our research program.

Studies have been limited to three plant species, Pinus banksiana, Artostaphylos uva-ursi, which are dominants at the site and Hudsonia tomentosa, a pioneer on sandy soils. Jack pine and Hudsonia both form ectomycorrhizae while bearberry forms ectendomycorrhizae. Our objectives have been to define the mycorrhizal relationships of these plants and to select and test species of fungi which might be useful in a revegetation program.

Collections of fruiting bodies of presumptive mycorrhizal symbionts have been made periodically throughout the growing season. Based on these collections it is known that 40 to 50 fungi are associated with pine and bearberry. Comparisons of mycorrhizae morphology indicate that many species of fungi form mycorrhizal with both bearberry and pine. Pure culture synthesis techniques are being used to confirm associations between specific fungi and these plants.

The ecological distribution of the mycorrhizal fungi has been studied by making observations of sporocarps in mature pine stands, disturbed soils along roadsides and on an area burned in 1971. The burned area is naturally being recolonized by pine and bearberry. In terms of the presence or absence of sporocarps (but not necessarily vegetative growth) certain species are restricted to either mature stands or disturbed areas. For example, Elaphomyces spp., Cantharellus cibarius, Chroogromphus rutilis, Suillus spp, hydnums and other species were found only in mature stands. Species found on physically disturbed or burned areas included Astraeus hygrometricus, Scleroderma meridionale, Laccaria laccata and Rhizopogon rubescens.

In order to determine the distribution of fungi by an independent method, random samples of mycorrhizae were collected from the Richardon Fire Tower Slope and the burn area. The mycorrhizae were surface sterilized and plated on a selective medium. The isolates from the two areas were compared and matched, if possible, with isolates obtained from sporocarps. Preliminary results of this experiment largely confirm the observations made on sporocarps. A large number of species were isolated from each area, no single species was dominant and the populations occurring on the two areas were distinct.

At this point our work indicates that (1) there is considerable species diversity both in mature pine stands and in disturbed soils, (2) no dominant species has been detected, (3) different species of fungi are associated with pine at different stages of forest growth. The implications of these observations are that certain mycorrhizal fungi may be better adapted to conditions on disturbed soils than others and that inoculation of planting stock with selected fungi may be beneficial.

MODELLING

A. Mehlenbacher and D. Whitfield

Introduction

The purpose of the modelling effort is to predict the amount of water lost from the system and the effect that this has on the plants. Modelling the soil plant atmosphere hydraulic system on a slope has never been done before, and it presents great complexity. We have solved the problem of predicting radiation profiles, although this has not been incorporated into the overall model as yet. The problem of predicting temperature and humidity profiles might be unsolvable, and the solution, if it exists, would be very complex. Therefore, we will be treating the temperature and huidity profiles empirically. The energy and water balance of the plants are not affected by the slope. At the moment, energy balance is well understood, and probably nothing can be done to improve this part of the model. Water balance, on the other hand, it poorly understood (Gardner _et al_., 1975). Therefore, we have not decided on a final form for this as yet.

A simplified flow diagram of the model is shown in Figure 1.

Radiation

Atmospheric radiation is partitioned into shortwave (SW) and longwave (LW) radiation. Shortwave radiation is divided further into direct and diffuse PAR and direct and diffuse NIR. From three measurements at the top of the hill the four types of shortwave radiation are calculated using formulae derived from data of Szeicz (1974). The actual amount of diffuse radiation intercepted by the slope comes from the sky and from reflection off the forest on the plain below (Fig. 2). The actual amount of direct radiation intercepted by the slope is a complex function of the latitude and longitude of the site, the slope and aspect of the hillside, and the year, day, and time (Gloyne, 1965). The amount of radiation penetrating through to different levels in the forest is an exponential function of leaf area, sun angle, estimated degree of clumping, and effective area factors for the interception of direct or diffuse radiation. Preliminary values for these effective areas have been determined for needle clumps from Richardson Fire Tower by summer assistant P. McCourt. The fraction of needle clumps that is in direct sun at any level equals the fraction of direct sun penetrating to that level. Thus we are able to treat the energy balances of sunlit and shaded leaves separately.

The amount of longwave radiation into a level is a function of the measured LW of the sky, the view factor to the sky, and the longwave radiation produced by a blackbody at measured air temperature.

Air in the canopy

The air temperature at any level in the canopy is an average of T_{8m} and the value resulting from a line drawn from T_{8m} to $T_{.05m}$, when $T_{.05} > T_{8m}$. When $T_{.05m} < T_{8m}$, the air temperature at every level is T_{8m}. Humidity at every level is Q_{8m}. Windspeed is exponentially attenuated into the canopy. (Fig. 3)

Water relations

The model of water relations considers four compartments: soil, sapwood, needle clumps, and air (Fig. 4).

Input of water to the system is by perolation of precipitation through the canopy to the soil surface and down through the soil layers. The top layer fills to field capacity, whereupon it overflows to one lower, and so on.

Water is lost from the system by transpiration through the needle clumps. This is a function of the needle-air humidity gradient and the needle clump resistance. The humidity of the needles is a function of the needle temperature, and needle temperature is determined as a solution of the energy balance equation for the needle clumps. The longwave and shortwave radiation that is absorbed by a needle clump is balanced by the emission of longwave radiation and by the turbulent transfer of sensible and latent heat away from the needle clump. The energy balance equation for sunlit leaves is (symbols are defined in the appendix):

$$NIR_{sl,\ abs} + PAR_{sl,\ abs} + LW_{abs} = \sigma(T_{n,sl} + 273)^4 + \rho Cp\frac{(T_{n,\ sl} - T)}{r_b} + \rho Lt\frac{(Q_{n,\ sl} - Q)}{r_b + r_n}$$

The transfer of sensible heat away from a needle clump is resisted by the boundary layer resistance of the needle clump (r_b). r_b is an empirical function of windspeed which was determined by Gates _et al_. (1965) for ponderosa pine needle clumps (Fig. 5). The transfer of latent heat away from a needle clump is resisted by r_b and the needle clump resistance (r_n). r_n is an empirical function of the intersity of photosynthetically active radiation and vapour pressure deficit which has been determined from measurements of J. Mayo and C. Labine (Fig. 6).

The transfer of water between compartments is directly proportional to the water potential difference between them and inversely proportional to the resistance. The water contents of the soil, sapwood, and needle clump compartments change in the following way:

$$\frac{dC_{s,i}}{dt} = Inf - \frac{\Psi_{s,i} - \Psi_t}{r_{r,i}}$$

$$\frac{dC_t}{dt} = \left(\sum_i \frac{\Psi_{s,i} - \Psi_t}{r_{r,i}}\right) - \frac{\Psi_t - \Psi_n}{r_t}$$

$$\frac{dC_n}{dt} = \frac{\Psi_t - \Psi_n}{r_t} - \left(E_{sl} - E_{sh}\right)$$

A value for $r_{r,i}$ has been tentatively determined by D. Thompson, a graduate student of J.M. Mayo. r_t is unknown, and so we chose a value slightly less than the smallest $r_{r,i}$. $\Psi_{s,i}$ is an empirical function of $C_{s,i}$ (see soils physics section). Ψ_n is an empirical function of C_n determined by J. Mayo and S. Nelson (Fig. 7). The same functional relationship is temporarily being used for Ψ_t as a function of C_t.

Results

The present version of the model has been tested by simulation of an intensive run (June 29-30) and the month of May (May 6-June 2).

The results for the June 29-30 are shown in Figures 8 and 9. Figure 8 shows that the model follows the diurnal trends in temperature, humidity, and transpiration. However, low predicted air temperatures in the canopy cause low needle temperatures which cause low predicted transpiration rates. Obviously, we hope to improve the model for air temperature, although as indicated in the introduction, a complete solution is impossible. We will try a mechanistic determination of the soil heat flux and use it in an empirical expression for air temperature.

Figure 9 shows that the model also follows the diurnal trend in needle clump water potential. This can be improved by the proposed improvement in the temperature model and by further work on the water relations.

The results for the May simulation are shown in Figure 10. The general trend in predicted water loss follows the general trend of the calculations from the soil water balance quite closely.

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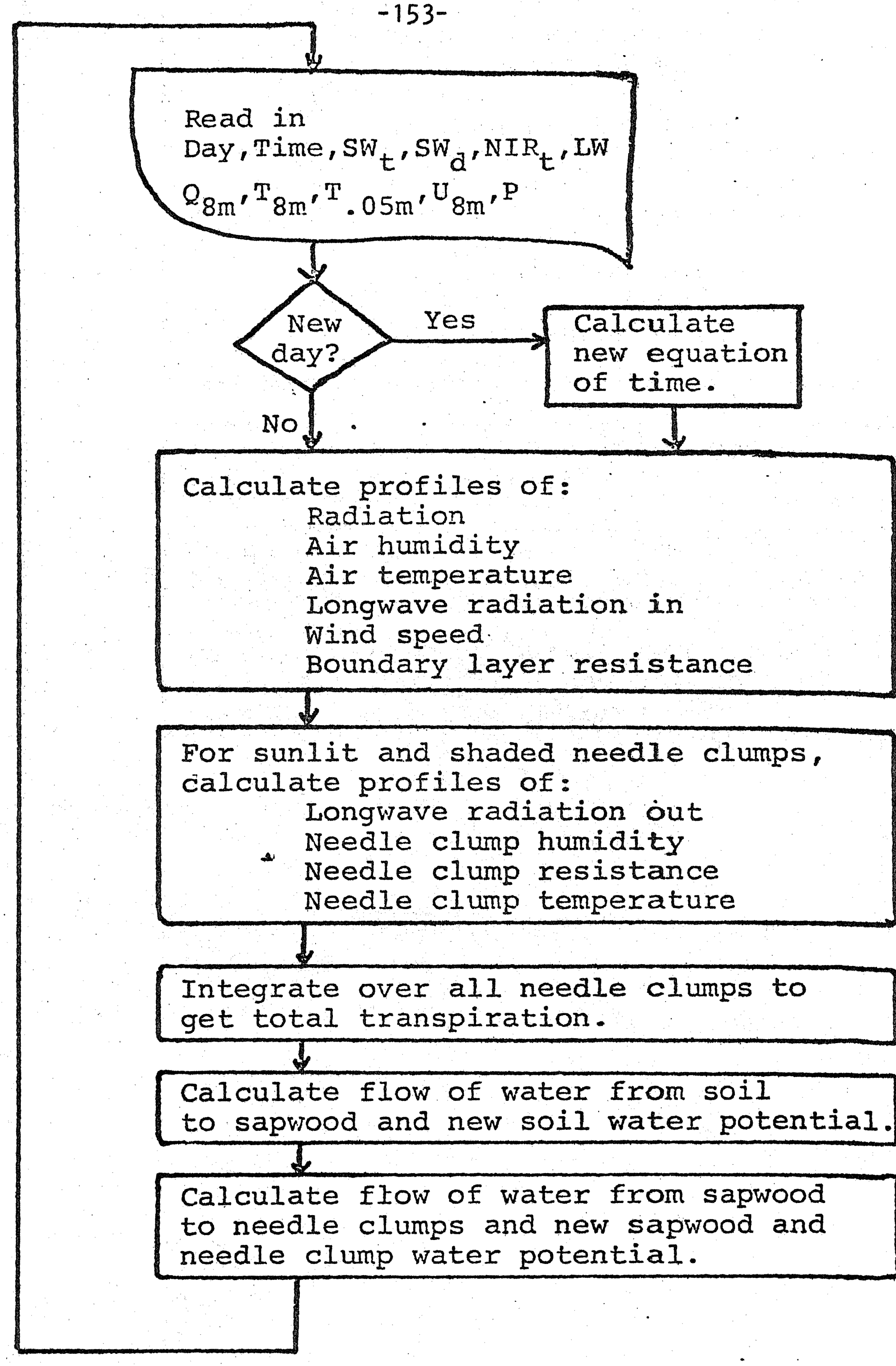

Figure 1. Simplified flow diagram of the model.

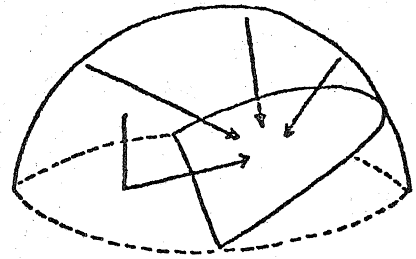

Figure 2. Sources of diffuse radiation.

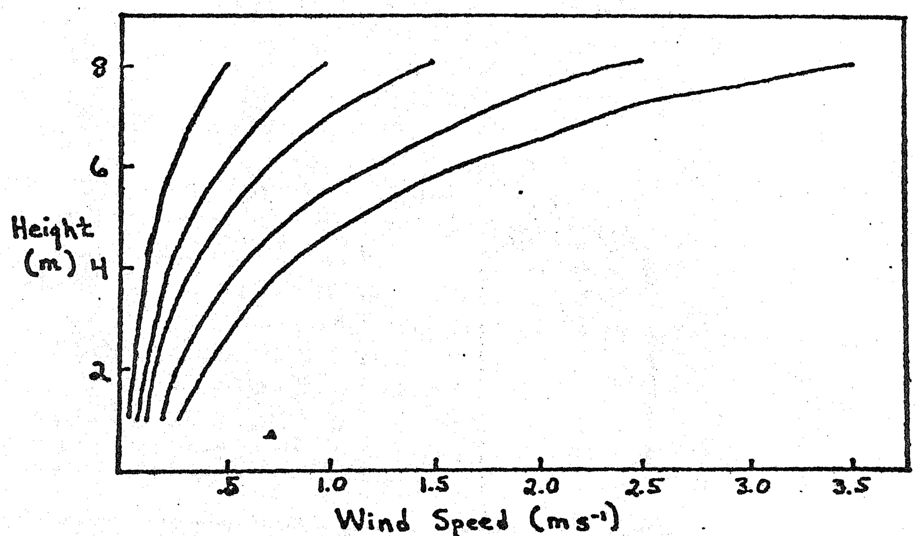

Figure 3. Attenuation of wind speed in the canopy.

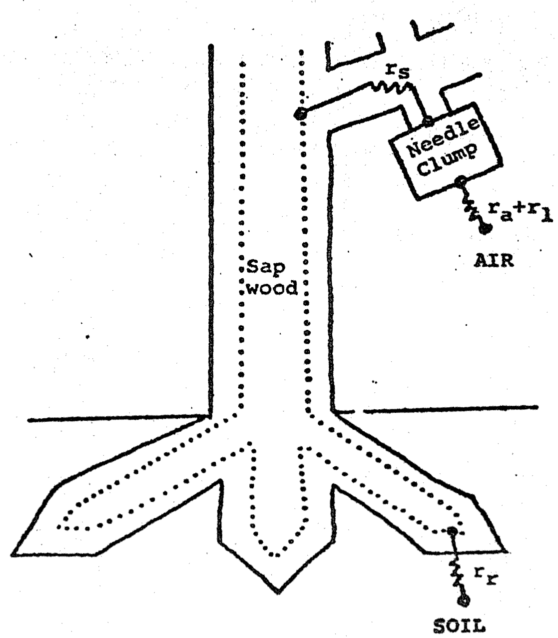

Figure 4. Schematic diagram of water relations model.

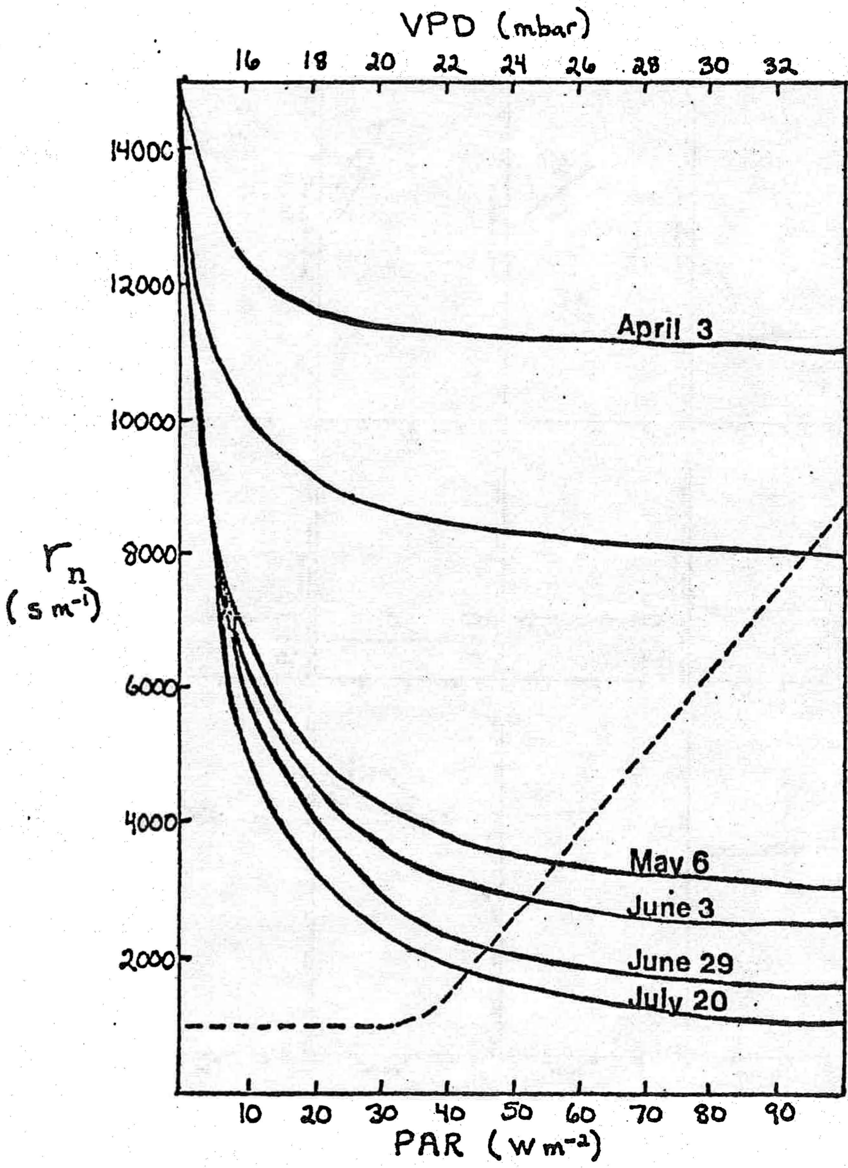

Figure 6. Needle clump resistance as a function of PAR (solid lines) and as a function of VPD (dash line).

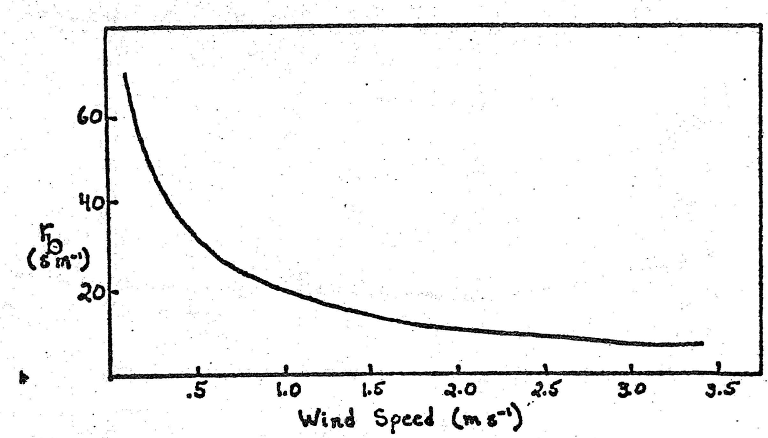

Figure 5. Boundary layer resistance of a needle clump as a function of wind speed.

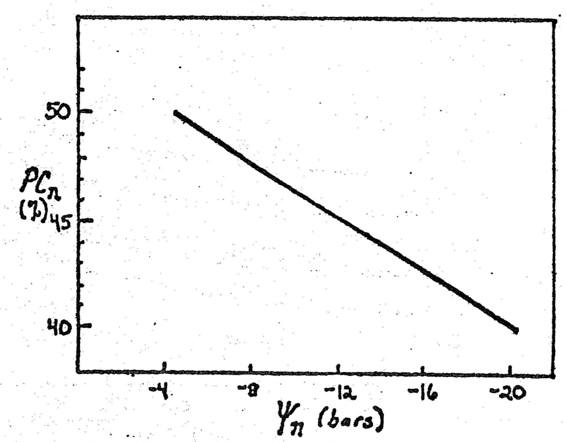

Figure 7. Needle clump water potenctial as a function of percent water content.

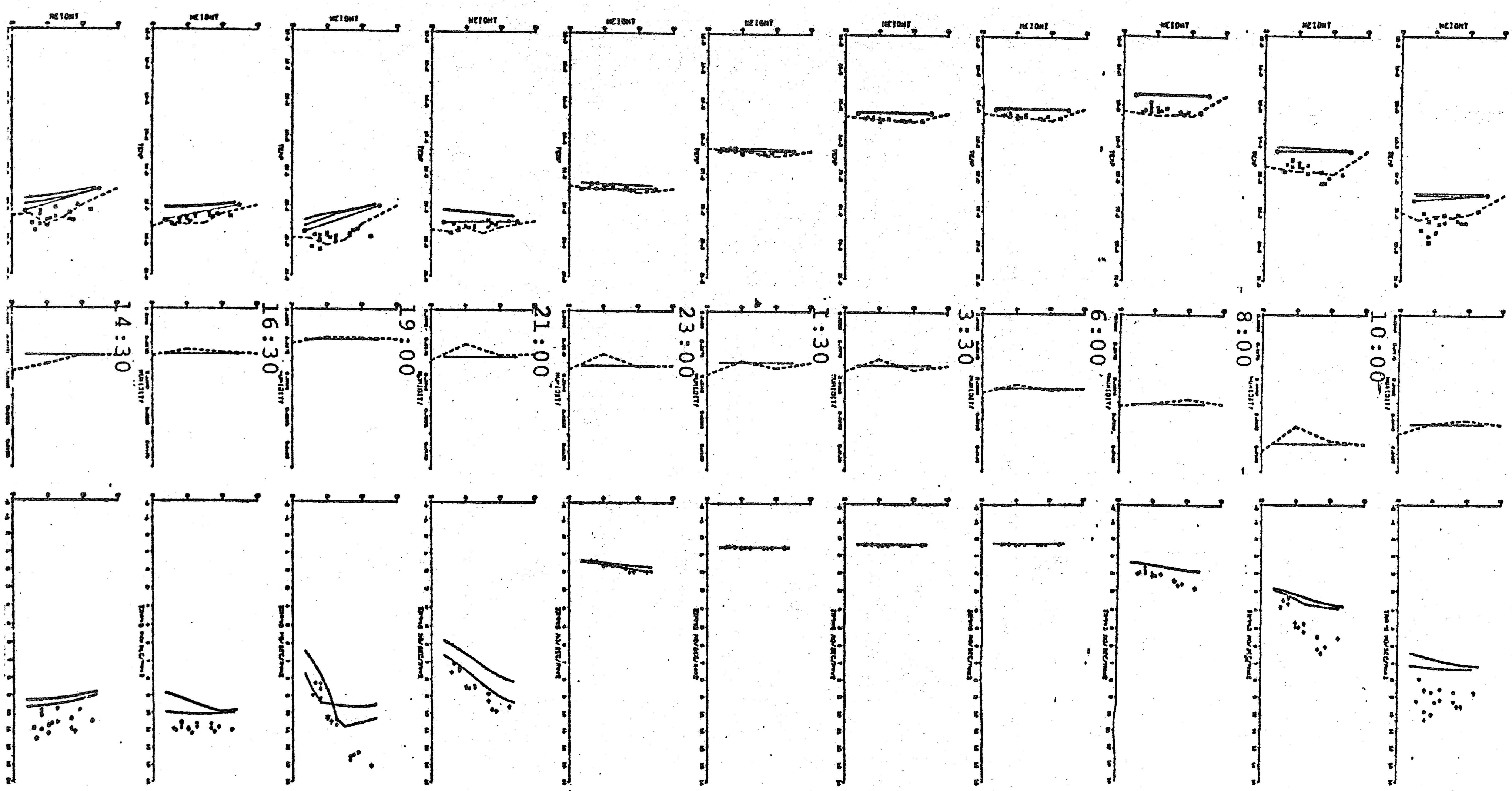

Figure 8. Measurements and model predictions of air temperature and humidity, needle clump temperature, and transpiration rate. Air temperature and humidity profiles: measurements-dash line; predictions-solid line with circles. Needle temperature and transpiration rate profiles: measurements-dots; predictions-solid lines (sunlit and sh[illegible]d). June 29-30.

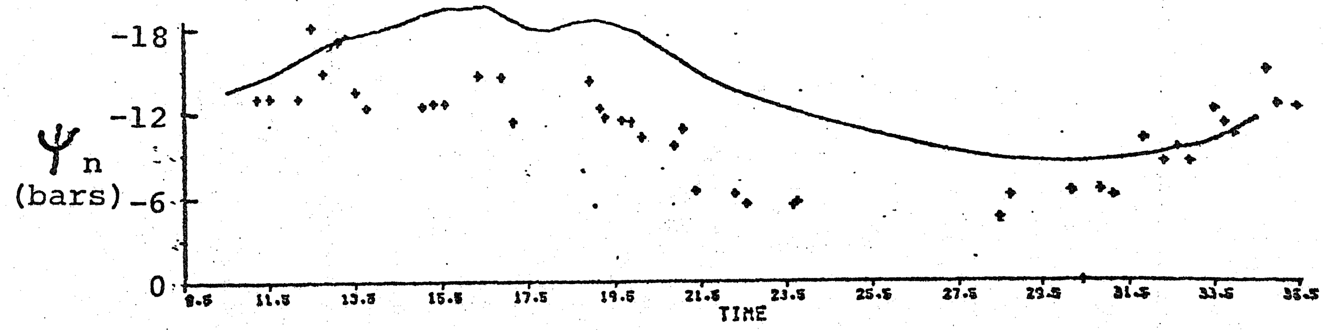

Figure 9. Diurnal needle clump water potential.
Measurements-pluses; predictions-solid line.
June 29-30.

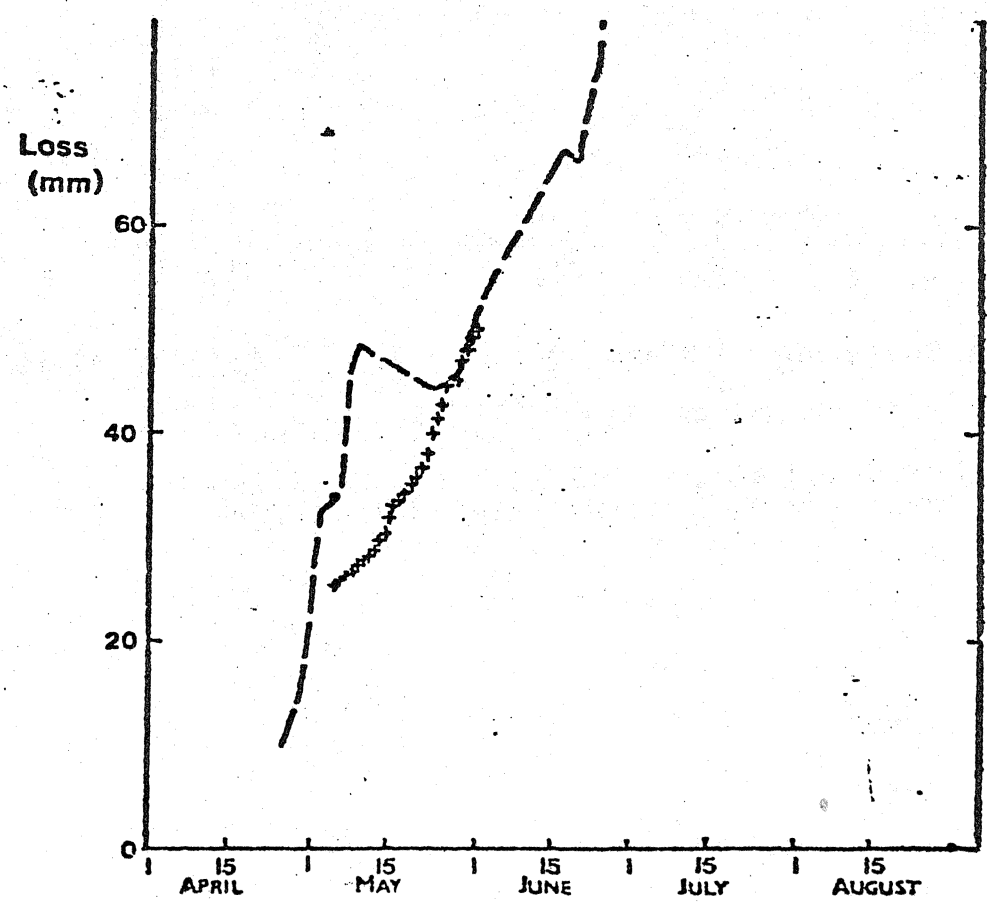

Figure 10. Total loss of water due to transpiration during May.
Predictions-pluses;
Calculations from soil water balance-dash line (see soil physics portion of this report).

Appendix

Symbols

C	Water content
Cp	Specific heat of air
E	Transpiration
Inf	Infiltration of precipitation
Lt	Latent heat of vaporization
LW	Longwave radiation
NIR	Near infrared radiation
PAR	Photosynthetically active radiation
Q	Specific humidity
r	Resistance
SW	Shortwave radiation
T	Temperature
U	Wind speed
VPD	Vapour pressure deficit
σ	Stefan's constant
ρ	Air density
Ψ	Water potential

Subscripts

abs	Absorbed
n	Needle clump
r	Root
s	Soil
t	Sapwood
i	Level i

VE 7.1

RECLAMATION FOR AFFORESTATION BY SUITABLE NATIVE AND INTRODUCED TREE AND SHRUB SPECIES

THE IMPORTANT ROLE OF TREES AND SHRUBS IN THE LAND RECLAMATION PROCESS

J.E. Selner

The history of mined land reclamation is more than 50 years old both in Europe and North America. Reclamation for forestry commenced at the beginning of these early reclamation trials. Professional circles were very sceptical of such attempts at that time, opposing these activities and maintaining that it was impossible to sustain re-growth on disturbed lands. They predicted that afforestation on disturbed lands cannot develop a green forest and the result will more likely be an artificial steppe.

Fortunately the authors of these gloomy predictions were wrong. More than a half century of experience proved that afforestation is possible on drastically disturbed lands and must be considered as the major and most effective technique in the land reclamation process.

Land and especially mined land reclamation is a hard-to-define complicated process where sterile, dead, and very often unsuitable overburden and wate materials are transformed into living and productive soils with the resulting definite soil profile.

The two important steps determine the rapidity and success of this process:

1) Weathering of minerals.
2) Organic matter suply.

Weathering of minerals can be regulated partly through mining management, especially through selective mining of overburden or controlled placement of overburden where better and faster-weathering materials are deposited on the surface as a planting medium.

Organic matter supply depends on the effectiveness of reclamation and on vegetation species properly selected for this purpose.

Not all planted trees and shrubs are able to provide this function. Some trees are sensitive to the hostile environment of drastically disturbed lands and are unable to accept these new conditions for their survival. However, some species are perfectly able to accept these new conditions and fulfill all functions which we are expecting for the reclamation process. These functions and purposes expected from trees can be summarized for the first step of reclamation as follows:

A. Amelioration properties

The most valuable trees and shrubs for reclamation are those which have properties to enrich and improve the poor and sterile overburden and waste materials, such are aerial nitrogen fixation and organic matter supply.

An example of such pioneer trees are Euroasian black alder, *Alnus glutinosa*, or grey alder, *Alnus incana*. These species and especially the first one provide, besides nitrogen fixation, the great volume of falling leaves which are easily and quickly decomposed. In central Europe, there are examples of these species transforming sterile tertiary overburden clays into productive forestry soils with 3 definite horizons in less than 40 years. These pioneer species can improve hostile conditions of overburden materials in a relatively short time. More sensitive commerical and evergreen species can be planted easily under their protection.

The possibility of introducing these Euroasian alders is still open to research and to find proper winter-hardy ecotypes for Canadian conditions. Many native and introduced pioneer species such as poplars, aspens, willows, alders, birches and native shrubs, can be utilized successfully for their amelioration properties in the land reclamation process.

B. Slope stabilization and erosion-control properties

There is no way that steep slopes which are not essentially stable can be managed through afforestation alone. However, on stable slopes, the stability can be controlled or improved by properly established vegetation. Trees, as the highest grade organisms of all plants have the highest ability to perform this function, mainly because their root system is the strongest and penetrates into relatively deep layers.

Successfully established forest cover can improve slope stability and provide the best possible erosion-control. However, we have to understand that the most critical period for the erosion development on slopes of abandoned mines or spoil piles usually arises shortly after afforestation, before trees are fully established and ready to provide this function.

The length of this critical period depends on the length of the growing period, which is conditioned by local climate, and from the different growth rate of different species.

For this purpose we have to select trees which are able to develop a strong and deep root system and can grow rapidly. This situation is much easier if these trees can be reproduced vegetatively. Large cuttings of poplars and willows can provide tremendous help is properly planted. This technique has been practised, especially in combination with planted bare-root stock and established grass-legume mixtures, in European mountain areas for centuries.

An opinion that grasses are the best in erosion control is false. We have many examples of serious secondary erosion, developed on successfully established grasslands.

C. Aesthetic and recreation purposes

Trees and shrubs are able to mask scars on the environment, especially those developed by industrial activities. The increasing demand of modern society for more recreation areas opens new horizons for planning and development of reclamation. Abandoned mining areas can be reclaimed for recreational purposes. Old abandoned open pits can be reclaimed for artifical lakes and together with planting of trees can create picturesque roadways, hiking trails, bird watching areas, boating, fishing and camping opportunities.

Such examples exist in Ohio, where the Ohio Power Company planted more than 34 million trees on more than 30,000 acres and created 320 lakes and ponds which the Ohio division of Wildlife has stocked with fish, and also in the Rhineland, Germany, where the operating mining company has developed valuable recreational areas at Bruehl-Liblar, near Cologne where today there is no reminder of the former open pits.

D. Research and study purposes

Reclamation of drastically disturbed lands is a young professional field where not all facts about the climate, soils, relief, vegetation, geologic materials, microorganisms and other factors are fully known. These factors create an inseparable dialectic complex which through its integral properties influences positively or negatively our reclamation activities.

There are many examples of trees planted on disturbed land having survived successfully for a certain period of time and after this being damaged or destroyed by fungi, small mammal, insects, climate, or other enemies.

Genetic properties of planted trees are insufficiently known to be utilized fully in reclamation.

Some professionals, including foresters, speculate that local native species must naturally be the best for reclamation purposes. This is incorrect. We cannot expect that native trees which were developed not during centuries but during thousands of years for quite different environmental conditions, will also be suitable almost overnight for environments which were fundamentally altered by mining activities.

We have to find and develop new trees for these completely new conditions.

Sometimes, the introduced trees are better suited to these new conditions than the local native species. Introduced trees are sometimes enemy-free. Natural enemies are not present from the original area.

Douglas-fir which was introduced to Europe a long time ago has no enemies there among fungi or insects. Gilletela coolley is the only relatively harmless parasitic insect of the douglas fir while native Norway spruce and scotch pine have hundred of insect enemies.

The Alberta Forest Service has been involved in mined land reclamation and afforestation research for some years. More than 600 reclamation research plots were established with more than 60,000 marked trees and shrubs planted and researched both on coal mined land and the Athabasca tar sands. About 40 tree and shrub species, both coniferous and deciduous, are being studied under different conditions.

These studies compare native versus introduced species, coniferous vesus broad-leaved, containers versus bare-root stock, fall planting versus spring planting, rooted cuttings versus non-rooted cuttings and many other techniques of afforestation.

The supply of proper seedlings was the most difficult part of our programs. Reforestation programs in Canada do not normally work with poplars, alders, willows, birches and other "weeds."

The Alberta Agriculture Provincial Tree Nursery has provided us with all possible assistance, however, some specialities important for reclamation studies are not available or are availabe only in limited quantities.

In 1975, we commenced our collaboration with the Tree Nursery Division, Prairie Farm Rehabilitation Administration in Indian Head, Saskatchewan.

In 1976, we have planted for the first time large quantities of excellent strong bare-root stock from this well managed and organized tree nursery. The resulting survival of this material was more than satifactory.

In the United States, the U.S. Forest Service coordinates the Surface Environment and Mining Research Program. Specialties of trees and shrubs are raised for these reclamation studies, mainly in the U.S. Forest Service Tree Nursery at Coeur D'Alene.

The world's energy crisis and increased mining and industrial activities in Canada will require similar programs for specific Canadian conditions. These research activities together with needs for operational afforestation will require millions of seedlings per year in the very near future.

Tree and shrub production and supply for reclamation purposes probably warrents governmental involvement. The governmental involvement in this area could provide high grade quality planting material at reasonable cost to industry, but in any case must take the responsibility for the proper origin, disease and insect resistance, quality and other ecological requirements.

Planting of trees on drastically disturbed lands is a very important investment for the country and for future generations.*

The following is the accompaniment to the slide presentation:

1. Before I present a brief report about the AFS involvement in oil sands reclamation, I would like to show several slides from the lignite strip mining in the Cologne area, Germany, which is a very similar operation to our oil sands.
   This is the world's largest power plant, Frimmersdorf. The capacity was 2,600 Megawatts in 1967.
2. These bucket wheel excavators are similar to those which GCOS is using at the present. This is Fortuna-Garsdorf, the largest open cast of the world with an output of 150 million tons of lignite per year. Very high productivity of this operation can be seen in an output of 81.5 tons per man per shift.
3. This is the highest possible grade of mining management, which we call "selective mining of the overburden" or "controlled placement of the overburden." This first stage of reclamation and its future success begins here. Materials which are not suitable for reclamation must be separated from those which are suitable. The capacity of these speaders is 131,000 cu yd per day with a 328 ft boom.
4. A spreader is dumping the second best materials which will create a subsoil in this case. The surface layer of very fertile loess soil is being hydrotransportaed onto the overburden surface. Hydrotransportation of soil in the form of a slurry (1:1 ratio) revolutionized reclamation and reduced the cost by more than 80%.
5. This is one of the many reclamation research farms established on a previously back-filled open pit where the top soil was hydrotransported.
6. Reclaimed land must be highly productive to return the cost of reclamation. Reclamation afforestation can be seen in front of this picture.
7. Reclamation for afforestation is planned for more than 4,500 trees per acre (compare this with the Alberta standard of 600-800 trees per acre). This former open pit is now a very famous recreation area.

* The preceeding was from a paper written for the Great Plains Agricultural Council's Forestry Committee Annual Meeting Proceedings.

8. The AFS involvement in Land Reclamation Research began in 1960.

9. This research also included oil sands where we reclaimed for research purposes 11 acres of tailings dike and waste .... and planted 7,500 trees and shrubs one year before the Alberta Oil Sands Environmental Research Program was established.

10. The tailings dike consisted of barren, very erodable sand.

11. The first rain showed residual tar oil in the surface of the alkaline tailings dike.

12. Overburden material deposited in waste dumps showed salinity problems.

13. Under these unfavorable conditions we commenced our project in May, 1974.

14. Pure sulphur was applied to reduce the unfavorable alkalinity.

15. Then we seeded more than 30 species of grasses and legumes.

16. And finally hydroseeded mulches and chemicals.

17. Various soil improving materials and fertilizers were tested.

18. Together with different chemicals.

19. Simultaneously we started our afforestation program.

20. Broad leaved versus coniferous species, bare-root stock versus containers, were tested.

21. Several different planting media including pure sand, sand mixed with muskeg and sand mixed with other ingredients have been included in the large trials.

22. Each planted tree was marked for evaluation purposes.

23. Specific attention was given to trees having amelioration properties.

24. Such as alders, birches, poplars and willows.

25. Or aspen developed from seeds kept under low temperatures and chemical treatment.

26. Native species including wildlings were a part of this project.

27. Germination of seeded grasses and legumes and the sprouting of planted trees started within 3-4 weeks.

28. White spruce performed well. We planted white spruce despite a warning form GCOS which had very poor results with planted spruce.

29. Different pines performed very well.

30. Where moisture and fertilizer have been accumulated, growth in planted holes was best.

31. All available legumes were tested for their soil improving properties. This is the perennial lupin which developed flowers within several weeks.

32. Commercial species of grasses and legumes used in our program were much faster to develop than the native species used by Dr. Herman Vaartnou. The boundary between our test sites illustrates the difference.

33. Professor Schichtel from the Research Institute and University in Innsbruck, Austria is one of the world's leading reclamation experts specializing in desert conditions. He came to visit our program in 1974.

34. Sharp-leaf willow, Salix acutifolia, was the best of all tested willows.

35. Native balsam poplar, Populus balsamifera, was tested as bare root stock, rooted cuttings and non-rooted cuttings.

36. Oats was the best annual nurse crop in our mixtures.

37. Unfortunately, some of the established plots were damaged by erosion. This is the result of the first heavy rain.

38. We have constructed some primitive dams,

39. Which controlled erosion very successfully.

40. The first dam is missing, it was removed by the company bulldozer doing maintenance work, however, the sediment filling the gully behind the dam is clearly visible.

41. Native species, especially those having the ability to be propagated vegetatively, were utilized in our program. Cuttings for research purposes were prepared from carefully selected trees.

42. Cuttings of balsam poplar.

43. Several ecotypes of the balsam poplar from different parts of Alberta were tested.

44. Reproduction in containers in the greenhouses.

45. Our four most important ecotypes were planted on irrigated nursery fields also for some genetic work.

46. One year-old rooted cuttings are able to develop a strong root system. However, this method is relatively slow, requires greenhouses, nurseries, irrigation, containers, planting media, fertilizers, labor, transportation, and planning. Better techniques of vegetative reproduction which are simpler and less expensive are needed.

47. We are testing the following: Cuttings are collected much stronger, older and larger.

48. And then directly planted in the ground. This angle gives the best results.

49. The tops of planted cuttings are cut off to reduce evapotranspiration and to develop a callus.

50. Cuttings usually sprout within 4-6 weeks. Large cuttings have adequate energy to develop strong and healthy leaves.

51. This is a starting root system developed a few weeks after planting.

52. We are testing different methods of storage of cuttings in connection with their survival.

53. We are also successfully testing cuttings prepared during the vegetation period.

54. Tar sands are very hostile materials for vegetation growth. They are lacking in all basic nutrients. Different fertilizers including the slow-release type and the timing of their applications were tested.

55. Proper fertilizers properly applied are vitally important in oil sands reclamation.

56. Until organic matter is added or developed through amelioration plants in tar sands, these materials must be intensively fertilized.

57. A boundary between fertilized and non-fertilized plots. Plants are chlorotic and starving without fertilizers.

58. In 1975 our program was included into the AOSER Program. Evaluation of nearly 50,000 trees is a very difficult but very necessary procedure.

59. Tolerance, intolerance and root competition of various species of vegetation with the planted trees is being studied on our plots.

60. Rodent populations, in our case <u>Microtus pennsylvanicus</u> and <u>Peromyscus maniculatus</u>, can damage planted trees.

61. Dr. Radvanyi from the Canadian Wildlife Service is working on our reclaimed sites. He trapped and tagged more than 1,000 mice on this site.

62. And killed more than 3,000 animals through this control which is his invention.

63. Control is done with poisoned grains.

64. We are collaborating with many researchers involved in reclamation research. The U.S. Forest Service is involved in the propagation of native species of shrubs and trees,

65. As a part of the SEAM Program. We visited their research last summer.

66. Twelve different techniques of seed preparation are tested in the SEAM Program.

67. Together with newly developed containers.

68. And new techniques of planting.

69. We have considerable communication with leading American reclamation researchers.

70. During the last two years we have visited many operations in Kentucky, West Virginia, Ohio and the Intermountain States,

71. And visited many research sites.

72. The U.S. Forest Service is the leading government agency involved in reclamation research in the U.S.A.
Dr. Grant Davis, the Associate Manager for research was our guest last month. He visited reclamation programs in Alberta and British Columbia and spent one day here at Ft. McMurray.

73. Collection of seeds from suitable native and introduced trees in an important part of our activities.

74. This is European black alder (<u>Alnus glutinosa</u>) which has properties to improve sterile sands.

75. There is no way to solve all problems related to the difficult and complicated oil sands reclamation within two or three years. In certain aspects we were successful.

76. However, this is not the end. This is the beginning.

77. Results obtained through our VE 7.1 Program will help in future management of the important tar sands operation.

VE 7.2, 7.3, 7.4

REVEGETATION FIELD TRIALS OF SHRUB AND GRASS SPECIES AND SEED PRODUCTION TECHNOLOGY

GOALS AND OBJECTIVES

VE 7.2 Goal: To provide preliminary information about the adaptability of selected ecotypes of native species and introduced landrazes to certain environmental conditions and soil types.
Objectives: To select ecotypes and landrazes for revegetation of disturbed areas in Alberta.

VE 7.3 Goal: To provide the information necessary to recommend plant communities for revegetation of disturbed area.
Objectives: To study, select and evaluate proposed species and plant communities for the overall and site-specific environments to be revegetated.

VE 7.4 Goal: To provide the information necessary for seed production and the handling of native grass, legumes and shrubs.
Objectives:
a) To study the effect of environmental factors of the quantity and quality of seed produced in various locations and environments.
b) To study the factors affecting the seed germination and dormancy of native species.

GROWTH CHAMBER AND GREEN HOUSE STUDIES - SPRING 1976

Legumes

These experiments were a continuation of the work done on the testing of legumes on various soil types as written up in "Revegetation Research. A Progress Report on Work Accomplished in 1975", April 15, 1976.

A total of 18 additional species or ecotypes of native legumes were tested after the completion of the 1975 report, and are listed here in Table 1.

Table 1. Plant species used in this study and their common names.

Botany Collection No.	Scientific Name	Common Name
376	Astragalus americanus	American Milk Vetch
377	A. canadensis	Canadian Milk Vetch
380	A. eucosmus	Milk Vetch
389	A. sp.	Milk Vetch
396	A. sp	Milk Vetch
408	Hedysarum alpinum	American Hedysarum
409	H. alpinum	American Hedysarum
413	H. mackenzii	Mackenzie's Hedysarum
419	H. sp.	Hedysarum
423	H. sulphurescens	Yellow Hedysarum
437	Lupinus sp.	Lupine
438	L. sp.	Lupine
442	Oxytropis campestris	Late Yellow Locoweed
445	O. splendens	Showy Locoweed
446	o. splendens	Showy Locoweed
447	O. splendens	Showy Locoweed
452	Thermopsis rhombifolia	Golden Bean
631	Vicia americana	American Vetch

These were tested on varying soil types in different experiments. The procedures are identical to those stated in the 1975 report. The soils used were sand (Devon), clay (Ellerslie), coal (Round Hill), peat (Peers),clay (Dixonville), tailing sand and tar sand (Ft. McMurray), tailing sand (Yellowknife), and greenhouse potting soil. Each species was tested on each soil with and without added fertilizer. The fertilizer was 14-14-14 slow release fertilizer applied at 112 kg/ha of actual N-P-K.

The results obtained were similar to those recorded in 1975. There was no growth produced on the clay from Ellerslie because of the inhibitory herbicide residue. Sand from Devon supports the best growth of the tested soils, except for the greenhouse potting soil Biomass can be doubled by the addition of fertilizer. Peat from Peers was the next best soil but produced only about half as much biomass as the sand and only about two-thirds as much when fertilized. Peat responded well to fertilizer and tripled the biomass production. Coal from Round Hill and tailing sand from Ft. McMurray areas produced about the same biomass. These soils had the greatest response to fertilizer. Biomass increased four times over the unfertilized tailing sand and about three times on the coal by the addition of fertilizer. There was very little growth on Yellowknife tailing sand, Dixonville clay, and Ft. McMurray tar sand. The low pH as well as the soil structure with respect to Dixonville clay itself tends to inhibit growth. There seemed to be a wetting problem in the tar sand. Even when the soil was moist, growth was very poor. The results on these three soils confirmed results obtained last year.

A fertilizer experiment was conducted to test increasing rates of 14-14-14 fertilizer on Ft. McMurray tailing sand and coal. In each case there was increased growth of *Hedysarum alpinum* with increased fertilizer application (see Table 2).

Table 2. Effect of fertilizer of *Hedysarum alpinum* grown on coal and tailing sand.

	Height of Hedysarum (cm)	
Treatment	Coal	Tailing Sand
Control	3.2	2.4
112 kg/ha	4.9	3.6
224 kg/ha	5.2	4.6
448 kg/ha	5.5	5.6

Lime and fertilizer treatments were also applied to Yellowknife tailing sand and Dixonville clay. Neither the increases in fertilizer nor the lime treatment had any beneficial effect on the growth of *Hedysarum* on Yellowknife tailing sand. Addition of lime at 6731 kg/ha to Dixonville clay succeeded in raising the pH sufficiently in order to double the height of *Hedysarum*. Addition of fertilizer with lime did not increase top growth and seemed to decrease root growth (see Table 3).

Table 3. Effect of lime and fertilizer on *Hedysarum alpinum* grown on Dixonville clay.

Treament	Height (cm)	Length of Roots (cm)
Control	2.1	2.0
224 kg/ha N+P	2.5	1.9
Lime 6731 kg/ha	3.9	6.7
224 kg/ha N+P plus lime	4.0	3.4

A herbicide experiment was started to test the resistance of seedlings of several native legume species to certain selective herbicides. Ten species representing eight genera of native legumes were planted. One month after seeding most of the species were in the 2 to 3 leaf stage at which time the plants were sprayed with one of 5 treaments or left on a control. The treatments were as follows:

1. Control
2. 2,4-D amine 4 oz/A
3. 2,4-DB 16 oz/A
4. MCPA amine 4 oz/A
5. MCPB 16 oz/A
6. MCPB + MCPA (15:1) 16 oz/A

The herbicides were applied in a 15 gal/A spray solution with an aerosole type sprayer. Each treatment was replicated three times.

Based on visual observation the MCPB treatment appeared to be the least damaging to the various legume species although the Lupinus species was injured at that dosage and Glycyrrhiza and Thermopsis species were injured quite severely by this treatment.

Germination tests were conducted on the legume seed collected in 1975. The Hedysarum species in general had fairly good germination (25-40%). Lupinus species had 40-50% germination. The rest of the following species: Astragalus, Lathyrus, Oxytropis, Thermopsis, and Vicia, had very poor germination (0-12%). Experiments were undertaken to determine a method of improving germination of these latter species. It was discovered that scarification would increase germination up to 40-80%. The method of scarification consisted of placing the seeds between two sheets of sand paper and rubbing the seeds in a circular motion, about 10 revolutions. A coarser grade of sand paper was used for the larger seeds.

Grasses

Plant growth in various soils was tested with or without fertilizer in both growth chambers and greenhouses using the seeds of native or naturalized grass species. Each experiment covered a period of three months. Sand, tailing sand (tar), peat, clay and "greenhouse" soil, collected from Devon, Fort McMurray, Peers, Ellerslie and Edmonton respectively were used for testing. These experiments were more or less identical to the ones described in the 1975 annual report. The details of the methods may be referred back to the 1975 report.

Four experiments were carried out during the spring of 1976. The first test, eight species on five soils, a second one ten species on tailing sand and tar sand having varying amounts of peat and silt added (50%), the third test ten species on four soils, and the fourth test six species on three soils using different amounts of added fertilizer.

The genera of grasses tested were: Alopecurus, Bromus, Festuca, Phleum, Poa, Agropyron, Agrostis, Calamagrostis, Phalaris and Puccinellia. In the first test it was found that the tailing sand with fertilizer tended to have larger biomass and lower top/root ratio than those of the other soils. The largest biomass among the eight species tested was produced by F. rubra: 10.3 grams per pot in 76 days with the lowest top/root ratio being 0.47. In the second experiment, 0.7 grams of fertilizer (14-14-14) was applied to each of the pots 42 days after seeding. The plant growth of the four mixed soils was very poor: none of the ten species could produce any inflorescences in these soil mixtures. Soil pH varied from 6.5 to 7.7. Tailing sand and loam mixtures had the best plant growth out of the four soil types with the highest biomass occuring in 4.74 of the Puccinellia sp. The growth in tarsand mixture was greatly retarded and all species had biomass less than 0.3 grams per pot.

Germination test

The germination test of 178 ecotypes of grasses collected in 1975 was carried out during the winter of 1976. The testing was conducted in a germinator during the winter of 1976. The testing was conducted in a germinator under the following conditions: growing period, 24 days; day length, 15 hours; day temperature, 20°C; night temperature, 12°C; humidity, 99%. The majority of the seeds germinated fairly well, but some needed longer time or did not germinate at all. Those with poor germination percentages (less than 10%) involved Calamagrostis spp., Glyceria spp., Hirochloe sp., Oryzopsis sp., and Stipa spp. All of these species will require further studies to find out the causes of the poor germination.

GROWTH CHAMBER AND GREENHOUSE STUDIES - FALL 1976

Our fall and winter growth chamber experiments were started in late July and approximately 1000 pots have been prepared to study soil amendments and fertility levels using native grasses and legumes. In this experiment we are trying to determine the best way to improve the tailing sand from Ft. McMurray for reclamation by mixing peat or silt in addition to the application of fertilizer. Six species of grasses and six species of legumes are presently being tested on tailing sands having varying amounts of peat and silt added (10%, 25%, 50%). Three fertility levels are also being studied, 0, 1.7, 3.4 grams per pot of 10-30-10 fertilizer (1.7 g = 100-300-100 lbs of N-P-K per acre). Greenhouse soil was used as a control. Each treatment was replicated three times.

Legumes

The first part of the experiment had 3 legume species planted. The Astragalus and Oxytropis species were rapid to germinate, starting after only 4 days and having a large percentage after 10 days. Thermopsis was much slower to germinate, about 12-15 days and did not have a very large percentage of germination even though it was scarified. All species germinated in the unfertilized treatments but were slow in the fertilized treatment. Very few seeds germinated in the 200 lb/A fertilizer treatment. In all cases the plants in the 100 lb/A fertilizer treatement were taller than the control plants. This is due to their response to fertilizer even though the fertilizer slowed germination. The fertilizer seemed to be leached out or down far enough that seeds germinated after 2 weeks. It took a much longer time to reduce the 200/A fertilizer concentration low enough for germination, about 30-40 days. There was also a great reduction in the number of seeds that germinated and plants that survived once they started to grow. Thus these plants were shorter in height than in the 100lb/A fertilizer treatment. Germination of Thermopsis seemed to be the least affected by fertilizer possibly due to their slower rate of germination or their thick seed coat preventing fertilizer salt from entering and killing the developing embryo.

Seeds germinated the fastest on straight tailing sand but did not grow very well except when 100 lb/A fertilizer was added. Where peat was added to the tailing sand, the more peat in the mixture the better the plants grew in the unferilized treatments (see Table 4). With the addition of fertilizer there is either no effect of increasing rates of peat or there was a reduction in height.

When silt was added to the tailing sand the seeds were slower to germinate and did not do well at all in the fertilized treatments. There were no Oxytropis plants in the fertilized treatments (see Table 5). The greater the percentage of silt, the taller the plants.

The second part of this experiment was planted a month later. Because there had been poor germination at the high fertility levels in the first part, it was decided that the fertilizer rates this time would only be half as much as the first time. There was much better germination this time but still the higher rate of 100 lb/A seemed to inhibit germination especially when silt had been added to the tailing sand (see Table 6).

Tailing sand alone had the best germination compared to the soil treatments with silt added. The 50% silt treatment seemed to be the best of all the silt treatments. Seeds were very slow to germinate in these treatments except for Hedysarum.

Table 4. Comparison of the height (cm) of 3 species on Ft. McMurray tailing sand with various amounts of peat added (2 months).

Species	Fertilizer lb/A	Alone	Tailing Sand (Ft. McMurray) +10% Peat	+25% Peat	+50% Peat
Astragalus americanus	0	0.5	1.0	1.5	2.3
	100	0.8	2.5	2.3	2.5
	200	-	-	0.7	1.7
Oxytropis splendens	0	1.3	1.5	2.2	4.0
	100	2.2	3.0	2.0	1.5
	200	2.0	3.0	1.2	1.0
Thermopsis rhombifolia	0	4.5	5.7	6.3	10.5
	100	12.3	16.5	17.0	17.0
	200	16.0	-	20.0	18.0

Table 5. Comparison of the height (cm) of 3 species on Ft. McMurray tailing sand with various amounts of silt added (2 months).

Species	Fertilizer lb/A	Alone	Tailing sand (Ft. McMurray) +25% Silt	+50% Silt
Astraglus americanus	0	0.5	1.7	4.0
	100	0.8	2.5	3.0
	200	-	3.0	2.5
Oxytropis splendens	0	1.3	2.5	3.0
	100	2.2	-	-
	200	2.0	-	-
Thermopis rhombufolia	0	4.5	6.5	9.3
	100	12.3	5.5	16.0
	200	16.0	1.5	4.0

Table 6. Percentage germination of 3 species on tailing sand with various levels of silt.

Species	Fertilzer lb/A	Tailing sand (Ft. McMurray) Alone 11 days	Alone 35 days	10% Silt 11 days	10% Silt 35 days	25% Silt 11 days	25% Silt 35 days	50% Silt 11 days	50% Silt 35 days
Astragalus sp.	0	21	40	7	27	3	25	3	36
	50	15	21	3	9	1	8	3	17
	100	9	16	3	8	0	12	0	5
Hedysarum alpinum	0	35	37	17	28	19	39	29	39
	50	21	24	5	15	4	8	4	20
	100	25	32	4	8	1	4	3	16
Oxytropis sp.	0	17	20	1	5	0	9	3	8
	50	4	11	0	0	0	1	0	0
	100	3	4	1	1	0	0	1	1

In the soil treatments using peat there was very little difference in the germination percentage compared to the tailing sand alone, except for Astragalus on 50% peat (see Table 7). There was generally a reduction in germination percentage with the addition of fertilizer. With the exception of Hedysarum, seeds germinated faster in tailing sand alone and were slower to germinate with increasing amounts of peat up to 25% peat. The seeds in the 50% peat treatment were as fast in germination as in straight tailing sand.

Because of the results of the first experiment, another experiment was designed to test the effect of different levels of fertilizer or germination of native legume seeds. Six levels of fertilizer were applied to Ft. McMurray tailing sand plus 25% peat. Astragalus americanus was used as a test species. Table 8 shows the percentage germination at various times after seeding. There was a slight reduction in germination in pots containing 50 lb/A fertilizer. With 75 lb/A fertilizer, there was about a 50% reduction in comparison to the contol. There was a drastic reduction in germination when 100 lb/A fertilizer was added. In the 75 lb/A and 100 lb/A treatments the emerging cotyledons were yellow. Many of these seedlings did not survive especially in the 100 lb/A treatment where most of them died.

It appears that any more than 50 lb/A of fertilizer applied at seeding time will seriously affect the germination of native legume seed. It may be best to add fertilizer after the seed has germinated in future experiments.

Grasses

An experiment was conducted using six grass species - Festuca saximontana, Poa palustris, Agropyron trachycaulum, Elymus canadensis, Bromus pumpellianus, and Agropyron smithii - in various soil mixtures having varying fertility levels. The first three species were planted on July 30, 1976, and the latter three on August 27, 1976. For the latter three species, 15 or 25 seeds were sown in each pot to determine germination percentage.

The seeds were sown in pots, each containing a different soil mixture with one of three fertility levels. In general, most of the species grew normally in the early stages of growth, but later some tended to show certain growth differences or nutrient deficiency symptoms about one month after seeding. For example, after forty days, Poa palustris sown in tailing sand, and in tailing sand with 10% peat and 3.4 gm of fertilzer, showed symptoms similar to necrosis and growth deteriorated, especially when compared to those plants growing in pots with only 1.4 gm of fertilizer. The plant growth in different soil mixtures of various fertility levels was quite variable. To use another example, Festuca saximontana, in a mixture of tailing sand and 50% peat, without fertilization appeared to grown as well there as in a similar soil mixture with 1.7 gm of fertilizer added.

The germination rates and precentages of various soil mixtures of different fertility levels showed interesting results. In general, the three species tested - Elymus canadensis, Bromus pumpellianus, and Agropyron smithii - had poor germination at higher fertility levels. They also had poor germination when grown in tailing sand mixed with silt (see Table 9).

Table 7. Percentage germination of 3 species on tailing sand with various levels of peat.

		Tailing Sand (Ft. McMurray)							
Species	Fertilzer	Alone		10% Silt		25% Silt		50% Silt	
	lb/A	11 days	35 days	11 days	35 days	11 days	35 days	11 days	35 days
Astraglus	0	21	40	16	48	9	40	13	64
sp.	50	15	21	17	36	19	41	7	37
	100	9	16	9	31	16	33	8	44
Hedysarum	0	35	37	32	39	33	43	31	35
sp.	50	21	24	20	31	15	32	18	24
	100	25	32	12	23	15	31	12	25
Oxytropis	0	17	20	16	23	8	13	15	20
sp.	50	4	11	5	9	4	9	5	11
	100	3	4	5	8	4	5	5	11

Table 8. Effect of different levels of fertilizer on the germination percentage of native legumes.

Treatment	Days after seeding. 4	7	10	12	14	17	19	21	28
Control	0	21	28	33	36	41	43	45	46
10 lb/A	0	31	37	44	47	48	48	49	50
25 lb/A	0	21	29	36	43	46	49	49	49
50 lb/A	0	18	21	24	29	31	31	31	32
75 lb/A	0	9	24	23	25	25	25	25	27
100 lb/A	0	1	7	8	12	12	13	13	13

Table 9. Germination percentages of *E. canadensis*

	Fertilizer (gm)	G. % (24 days)
<u>T. S.</u>		
E. canadensis	0	56
E. canadensis	1.7	36
E. canadensis	3.4	36
<u>T.S. + Peat 10%</u>		
E. canadensis	0	56
E. canadensis	1.7	32
E. canadensis	3.4	28
<u>T.S. + Peat 25%</u>		
E. canadensis	0	40
E. canadensis	1.7	32
E. canadensis	3.4	24
<u>T.S. + Silt 10%</u>		
E. canadensis	0	32
E. canadensis	1.7	24
E. canadensis	3.4	20
<u>T.S. + Silt 25%</u>		
E. canadensis	0	16
E. canadensis	1.7	8
E. canadensis	3.4	0

Seed harvesting

During the summer of 1976, considerable time and effort was devoted to harvesting rows of native grass species that had been sown the previous year at four different sites in Alberta. The harvesting was carried out at four different sites in Alberta. The harvesting was carried out as follows: the ripe heads were severed from the stalks using hard clippers, and were placed into bags and tagged appropriately. Shortly thereafter, the bags were transported to the new Environmental Research Centre warehouse at Vegreville, where their contents were spread out on tarps to dry. "Tedding" (i.e. turning) was carried out when necessary. When dry, the heads were collected from the tarps and stored in jute sacks until threshing; which is taking place this fall and will continue during the winter.

The grass species harvested, at the various sites, were as follows:

SPECIES	SITE			
	Ellerslie	Waskatenau	Peers	High Level
Agropyron smithii	X	X	X	X
Agropyron sp. (various)	X	X	X	
Agropyron subsecundum	X	X	X	
Agropyron trachycaulum	X	X	X	
Agropyron yukonense	X			
Agropyron cristatum	X		X	
Agrostis scabra	X			
Agrostis gigantea	X	X		
Agrostis tenuis	X			
Agrostis sp.				X
Alopecurus ventricosus	X	X		
Alopecurus sp.	X	X		X
Arctagrostis latifolia		X		
Arctagrostis sp.			X	X
Bromus inermis	X	X		
Bromus pumpellianus	X	X	X	X
Calamagrostis canadensis			X	
Deschampsia sp.		X		
Deschampsia caespitosa	X	X		
Elymus cinereus			X	
Elymus gigantea			X	
Elymus canadensis	X			
Elymus innovatus	X			X
Elymus sp.	X		X	
Festuca scabrella	X	X		
Festuca altaica	X	X		
Festuca elatior	X			
Festuca idahoensis	X			
Festuca ovina	X	X		
Festuca rubra	X	X	X	
Festurca saximontana		X	X	
Festuca sp.	X	X	X	
Glyceria sp.	X			
Hierochloe odorata	X			
Hierochloe sp.			X	
Koeleria cristata	X	X	X	
Oryzopsis sp.	X			

SPECIES	SITE: Ellerslie	Waskatenau	Peers	High Level
Phalaris sp.	X			
Phleum pratense	X	X		
Phleum sp.	X	X		
Poa ampla	X	X		
Poa alpina	X	X	X	X
Poa compressa	X			X
Poa palustris	X	X	X	
Poa glaucantha	X	X		
Poa pratensis	X	X		X
Poa sp.	X	X		
Poa macrocalyx	X			
Puccinellia sp.	X			
Schizachne sp.	X			
Spartina gracilis			X	
Stipa spartea	X			

Vegetative propagation

In March of 1976, cuttings from three native shrub species - Arctostaphylos uva-ursi, Vaccinium vitus-ideae, and Ledum groenlandicum - were collected from the Woodbend Research Station near Devon. These were then kept in moist peat moss at 5 C and were transplanted back into plots at the same site in mid-May. The purpose of this experiment was to determine the rooting ability of these species when reproduction is attempted by cuttings. Very few of these cuttings survived over the summer, probably because of hot, dry weather conditions during and for some time after transplanting.

In mid-September, cuttings, complete with roots, from the same three species were gathered, planted in individual "Jiffy pots", and placed outside to overwinter. In addition, seeds of Potentilla fruticosa and Eleagnus commutata were sown. These will be transplanted to individual "Jiffy pots" and will also be placed outside to overwinter. Thus, a number of cuttings and seedlings will be available for research puposes when required in the spring of 1977.

ESTABLISHMENT OF EXPERIMENTAL AREAS

A. Fort McMurray

Two experimental areas have been established in the Fort McMurray region during the summer and early fall of this year. The first of these is a two-hectare area near the town of Fort McMurray. In conjunction with Alberta Agriculture, this area has been cleared and prepared for planting over the summer.

The second area is another two-hectare area immediately adjacent to the AOSERP camp. A total of about 950 cubic yards of four soil types (500 yards of tailing sand, 200 yards of peat, 200 yards of silt, and 50 yards of lean tar sand) has been transported to this area from the GCOS site. These soils will be used in future experiments.

Revegetation Trial Sites

Three revegetation trial sites at GCOS were also established in 1976 after previous ones were washed away. These sites represent the three typical soil types that are produced as a result of the GCOS operation. All three sites are located on the slopes of dikes at GCOS. They are as follows:

1. Tailing Pond (Cell 6)

The dike of the tailings pond was selected as one of the trial sites to represent tailing sand. This 0.5 hectare area was seeded with a Northern gray wooded ground cover mixture. Twelve test species were introduced; two were seeded and ten planted vegetatively in late May, 1976.

2. Waste Dump No 5.

This 1.5 hectare site is located on the dike of Waste Dump No. 5. It represents the tar sand overburden. It was directly seeded for ground cover on June 23, 1976. A seed mixture of nine ecotypes, six grasses and three legumes (total weight of 52,3 kg) was used.

3. Overburden Dike (Cell 11)

The site located on the Overburden dike was chosen to represent lean tar sand. This 0.45 hectare site was seeded for ground cover on June 23, 1976 using a mixture of grasses and legumes of commercial varieties.

B. Woodbend Research Station, Devon, Alberta

In the fall of 1975 thirty-seven species or ecotypes of native legume were seeded at the Woodbend Research Station. The seeds were not scarified. The same species were seeded in an adjacent location in the spring of 1976. These seed were scarified except for the Hedysarum and Lupinus species. Only 5 species planted in the fall had germinated and established plants by the fall of 1976. All except 2 species produced plants from the spring planting. The better establishment from the spring seeding was mainly a consequence of the scarification of the seeds.

Seedlings of four tree species were obtained from the Oliver Tree Nursery and were planted in May 1976 at the Woodbend Research Station. The soil which is mostly sand was quite dry at the time of planting and many of the trees did not survive. The precentage of the trees that still survived as of September of 1976 are as follows:

	No. Planted	% Survived
Lodgepole Pine	508	59
Siberian Larch	472	67
White Spruce	496	69
White Birch	428	18

C. Waskatenau, Alberta

In June, 1976 the Waskatenau plot was rototilled and 15 species were planted in a total of 85 rows. In July another 15 species of grasses (125 rows) were seeded in 5, 10, or 20 row plots. All species were planted in rows 30 meters long and one meter apart.

D. Vegreville, Alberta

In July, 1976 the land designated for Revegetation Research at the Alberta Environment Research Centre at Vegreville was cultivated. During July and August, 5 species of native legumes, 15 species of agricultural varieties of legumes, 102 species of native grasses (56 transplanted by hand) 18 species of agricultural varieties of grasses (3 transplanted by hand) were seeded one row per species in rows 60 meters long and 1 meter apart. In addition to the legumes and grasses 35 rows of shrub species were transplanted by hand. There is now just over 3 acres planted at Vegreville.

E. Peers, Alberta

On June 2 and 3, 1976, 41 new ecotypes of grasses were seeded at the Peers introductory nursery. The seeds germinated very well, except for 3 ecotypes of Calamagrostis, 1 of Agropyron yukonense, 1 of Arctagrostis sp. and 2 ecotypes of Elymus innovatus. At the fall evaluation time most of the rows were reasonably healthy, and can be expected to yield seed next year.

In addition 53 native ecotypes and adapted landraces of legumes were seeded at Peers in July of 1976. Most of the ecotypes germinated, but the plants were small at evaluation time in the fall. Next year's seed production will depend upon how they survive the coming winter. This was the first time we have seeded native legumes for seed increase purposes.

F. Beaverlodge, Alberta

In June of 1976, a seed production test site was established at the Beaverlodge station. Forty-six native ecotypes and naturalized landraces of grasses were seeded in five row blocks for testing seed and forage production in the Peace River area. When evaluated in September 1976, most of the species were established very well. The exceptions were two ectoypes of Agropyron smithii, two ecotypes of Elymus innovatus, one Bromus pumpellianus, one Festuca sp. and one Puccinellia sp.

G. High Level, Alberta

June 17, 1976, the High Level seed production test site was increased by adding 33 new ecotypes, a total of 450 rows, to the most northern test site. At evaluation time, September, 1976, all of the Agropyrons, Poa's, Festuca's, Agrostis and two of the Elymus ecotypes were excellent and we expect reasonable seed production next year. Arctagrostis and Calamagrostis did not germinate very well. Three ecotypes of Elymus innovatus were also weak and not very much as this seed can be expected next year.

H. Dixonville, Alberta

None of the test plants established in June, 1975, survived on the heavy clay, and highly acid soil at Dixonville. An additional planting was done in September, 1976, using a number of different species as well as the application of fertilizer or lime.

Ten species of native grasses and nine species of shrubs, selected for their acid tolerance, were planted in three replications. One replicate was left as a control, another had 7860 kg/ha (3.5 T/A) of lime applied, and the third replicate had 448 kg/ha of 26-13-0 fertilizer applied.