SOIL RESEARCH RELATED TO REVEGETATION OF THE OIL SANDS AREA

SUB-PROJECT VE 4

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PART I. STUDIES OF PHYSICAL PROPERTIES OF SOILS AND MINED MATERIALS IN RELATION TO RECLAMATION

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ABSTRACT

Laboratory and field information is being gathered on soils within the AOSERP study area, so as to improve understanding of relationships between the soil physical conditions and the vegetation. Eleven field sites were instrumented, eight of which are on sand, while two are on the G.C.O.S. dike, and one is on till. The sands drain rapidly until a moisture tension of around 60 mbars is reached, after which moisture movement is very slow. At this tension, the amount of water available to plant growth is large in some sands, including the G.C.O.S. dike tailings sand, but is small in others. The effect of additions of till and peat to tailings sand on its moisture characteristics was investigated in the laboratory. Most information is however being obtained by monitoring ground temperatures, soil moisture tensions, moisture content, and the position of the water table at the field sites. This was begun in July 1976. Instrumentation will be increased in 1977 to obtain more detailed information on tensions and water content in the near surface soil.

1. INTRODUCTION

The purpose of this study is to obtain information on the physical properties of soils and mined materials within the AOSERP study area, with emphasis on improving knowledge of soil moisture conditions and their relationship to the kind of vegetation. Ways of improving moisture conditions in mined materials need investigation.

2. LITERATURE REVIEW

Less information is available on sands, which predominate in the AOSERP study area, than on other soils, because of their small agricultural importance. Because sands exhibit a high hydraulic conductivity at low moisture tensions and a very low hydraulic conductivity at high moisture tensions, there is a fairly pronounced moisture level or "field capacity" to which they rapidly drain. Richards (1949) quotes 100 mbars as the tension at field capacity for sandy soils while Russel (1961), Salter, Berry and Williams (1967) and Webster and Beckett (1971) suggest values closer to 50 mbars. Some of the most recent work on the moisture characteristics of sands has been carried out in Australia (Elrick, 1963; Roberts, 1966; Carbon, 1975).

3. MATERIALS AND METHODS

3.1. LABORATORY METHODS

3.1.1. Routine analyses

Preliminary information on particle size separation of the sands has been achieved by dry sieving, using an Allen-Bradley sonic sifter. Particle size analyses by the pipette method, pH, nitrogen content, content of organic and inorganic carbon, and exchangeable cation content, have still to be determined.

3.1.2. Bulk density and core samples

Cores sampled in the field in 2.6 cm diam. brass rings were used to obtain bulk density. With the possible exception of surface soil, the bulk densities of sands are not easily varied, and it has been found possible to obtain the same values as in the field by filling a ring, closed at one end, with disturbed material while tapping it lightly on the bench top. Because sampling intact cores in the field, without disturbance, is very time consuming, these laboratory-packed cores were used in some determinations.

3.1.3. Hydraulic conductivity

Saturated hydraulic conductivity was determined by the constant head method (Klute, 1965). Rings (2.6 cm diam., 6 cm long) were packed to a bulk density similar to that in the field and saturated with distilled water under vacuum. Because of high permeability of the sands, 0.05 mm opening wire mesh screens had to be used in place of paper filters at the ends of the core, so as not to impede the flow, while loss of fine material was minimized by using micro-burettes at the inlet and outlet to reduce the quantity of flow.

Unsaturated hydraulic conductivity was determined using an apparatus similar to that described by Elrick and Bowman (1964). Cellulose acetate filters of suitable pore size for the required pressure range were used at either end of rings packed similarly to those used for saturated conductivity. Pressures were controlled by drilling numerous small holes in the ring wall and enclosing the whole apparatus in a pressurized container.

3.1.4. Moisture retention

Moisture retention curves in the range 0.01 bar to 1 bar have been obtained by the pressure plate method, using small intact cores obtained with minimum disturbance, in individual pressure cells. Because liquid movement is slow in sands at low moisture content, pressure plate results were found to be unreliable at higher tensions. Container thermocouple psychrometers (Korven and Taylor, 1959), which depend on vapour movement, and function well only at higher tensions, were therefore used in the range 1 to 50 bars. Several small "chunks" from the cores used in the pressure plate cells were dried in air and sealed in the psychrometer containers. These were then placed in a water bath. Microvoltmeter readings were made periodically until they stabilized (2 to 24 hours). The moisture content of the sand in each psychrometer container was then determined gravimetrically.

3.2. FIELD METHODS

3.2.1. Field sites and field monitoring

Some field measurements were made during spring 1976 and 11 sites for field installations were selected in May. These were fully instrumented by August. Selection of sites (Table 1) was governed by the need to cover a range of vegetation types with emphasis on the dominant soil parent material which is sand. Sites on sand include all those within the AOSERP camp boundaries and close to them (Figure 1), as well as those at Richardson tower. The Richardson sites were designed to complement the existing Sub-Project VE 6.1 sites which are under Jackpine (*Pinus banksiana*) and have a SW aspect. Sites on the G.C.O.S. dike were desirable in order to compare moisture conditions in tailings sand with those of other sands in the surrounding area, and we are grateful to G.C.O.S. for permission to locate sites there. The site on till at Supertest Hill was chosen because till is a constituent of many of the present overburden piles.

Soils on the sands are mainly Degraded Eutric Brunisols.

TABLE 1. Instrumented site characteristics.

Location		Material	Vegetation	Aspect	Water Table
Richardson's Tower	4	Sand	Jackpine	Flat	>6 m
	5	Sand	Birch/Aspen	NE	2 m
	6	Sand	Birch/Aspen	NE	>6 m
Mildred Lake	1	Sand	Aspen	SW	>6 m
	2	Sand	Jackpine	Flat	6 m
	3	Sand	Birch/Aspen	Flat	--[1]
	4	Sand	Mature Spruce	Flat	2 m
	5	Sand	Aspen	Flat	3 m
Supertest Hill		Till	Aspen	Flat	2 m
G.C.O.S. Dike	1	Sand	Grass[2]	NW	>6 m
	2	Sand	Grass[2]	SE	2 m

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[1] Impeded drainage

[2] Also small spruce and pine

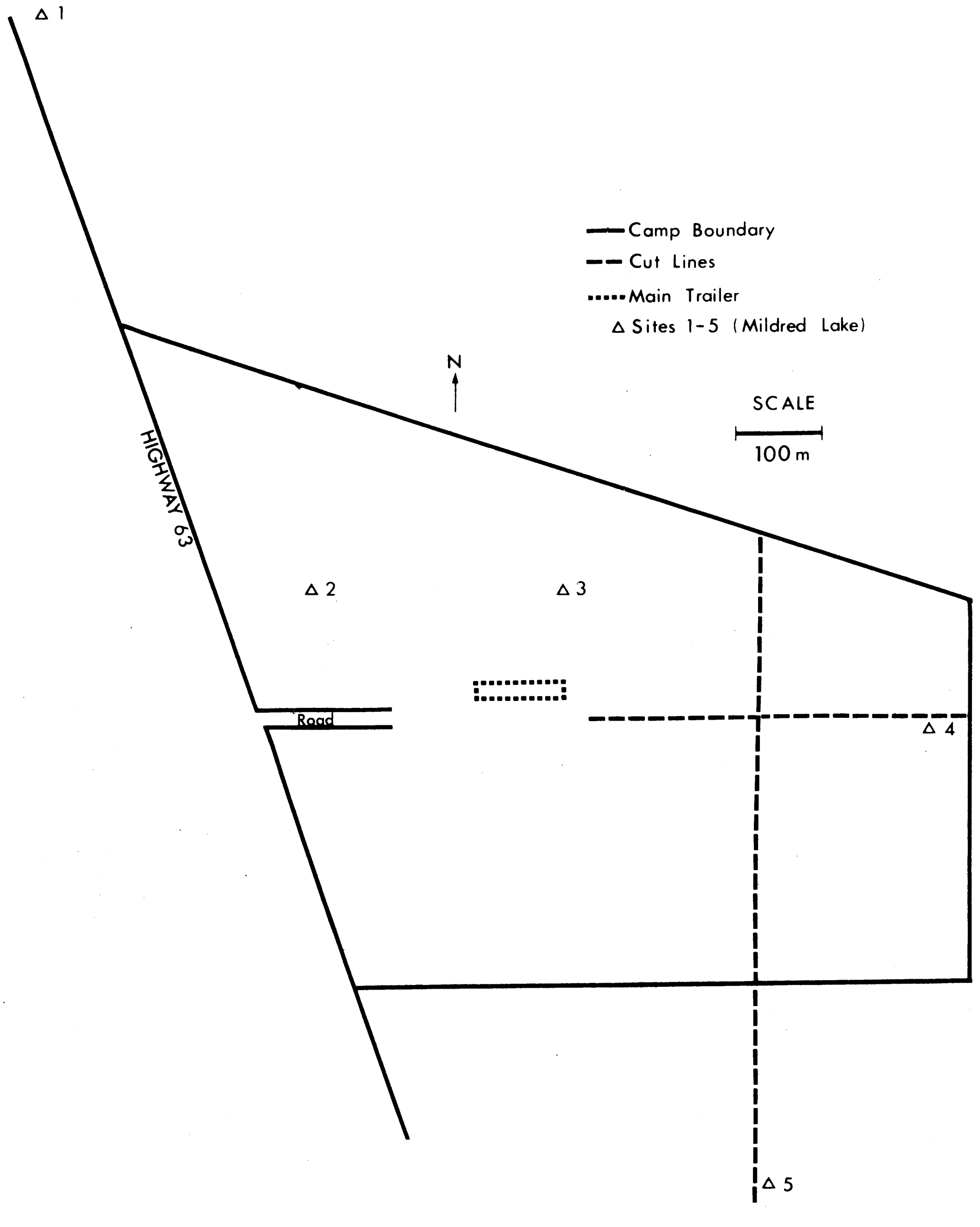

FIGURE 1. Map showing the location of instrumented sites within and close to the AOSERP camp.

The H layer and Ae horizon are very thin or almost absent at sites covered by Jackpine, but are thick at the Aspen-birch (*Populus tremuloides* and *Betula papyrifera*) and Spruce (*Picea glauca*) sites. The soil at Supertest Hill is a Gray luvisol. Because of cost limitations, only a few sites can be monitored intensively, and of necessity, these must be those most readily accessible. The three sites within the AOSERP camp and the two on the dike fall within this category. The sites on camp involve three different kinds of vegetation, Jackpine, Aspen-birch, and Spruce, while the water table varies from relatively deep under the Jackpine to only 2 m below the surface under the Spruce. At the Aspen-Birch site, drainage is impeded to some extent between 2 m and 3 m below the surface by layers of tar sand. The sites on the dike differ from each other both in aspect and depth to the water table. These five sites will be monitored at frequent intervals between early April and late September. Information at the other sites will be obtained less frequently while sites at Richardson tower will be monitored mainly in conjunction with Sub-Project VE 6.1 Occasional readings will be taken during winter at all 11 sites. Supplementary information will be obtained through observations on vegetation type, textural analysis and water table depth at locations other than at the instrumented sites. This supplementary information will help in applying instrumented site information to the area as a whole.

3.2.2. Site instrumentation

All sites are equipped with:

(a) Nine copper-constantan thermocouples at intervals to 600 cm below the surface, or as close to that depth as augering allowed, to measure ground temperatures.

(b) Two neutron probe access tubes, one to 600 cm or to the water table where less deep than 600 cm, and the other to 300 cm, to measure soil moisture at intervals between 10 cm and 600 cm below the ground surface.

(c) A perforated pipe to measure the position of the water table where this was within 600 cm of the surface.

Most sites are equipped with:

(a) Tensiometers in duplicate at 20 cm, 50 cm, 100 cm, 200 cm and 300 cm below the surface, to measure soil moisture tension in the wet range.

(b) Thermocouple psychrometers (Wescor Inc.) in duplicate at 10 cm, 20 cm and 50 cm below the surface, to measure soil moisture tension in the dry range.

3.2.3. Field methods and interpretation

3.2.3.1. Soil temperature. Thermocouples were read with a simple microvoltmeter using an ice-water mixture in a vacuum flask for a reference junction. The microvoltmeter is insulated from cold in winter.

3.2.3.2. Moisture tension. Tensiometers with mercury manometers similar to those described by Webster (1966) were used. Normally they are useful in the range 0 to 0.8 bar, however the low non-sand content of sands in the study area results in very slow liquid movement over most of the unsaturated range and consequently long response times. Even though very fine gauge manometer tubing was used to minimize flow, the useful range of these tensiometers appears to be limited to 0 to 400 mbars at most.

The large unfilled pore space in sand however favours optimum response from thermocouple psychrometers, which are useful in the range 1 to 40 bars. These were installed in augered holes, at most of the sites.

Tensions between 400 mbars and 1 bar have to be estimated from moisture content using moisture retention curves.

3.2.3.3. Soil moisture. Aluminum access tubes for the neutron probe were inserted (by hammering them where necessary) into auger holes which only slightly exceeded the outer diameter of the tubes. Counts of 1 minute duration were taken with a Nuclear Chicago P19 Neutron Probe at depth intervals between 10 cm and 600 cm. Calibration is being carried out by inserting separate but shorter access tubes into augered holes, taking counts, and measuring the moisture content of the augered material gravimetrically. Since snow cover influences near surface readings, the effects of snow depth and density on readings will have to be determined. Computer programs are being developed to handle count data, which should eventually speed up the gathering of moisture information from this source. The present probe, which has had several breakdowns, should be replaced in the spring 1977.

For near-surface moisture determinations, the neutron probe has severe limitations because of its large "sphere of influence", and it is therefore necessary to resort to gravimetric sampling. It is hoped that a thermal method can be developed for near surface measurements as this would reduce site damage.

3.2.3.4. Water table. Water tables were read by blowing down a plastic tube inserted into a well until bubbling was heard.

3.2.3.5. Snow depths. Measurements were made with a ruler, and a mean was calculated from 10 to 15 readings.

4. RESULTS AND DISCUSSION

4.1. LABORATORY RESULTS

4.1.1. Sand size analysis

Sieve analyses for some sands from the AOSERP study area are shown (Table 2). A characteristic in common to all the sands is the high proportion in the medium and fine fractions and small amount in the coarse and very coarse fractions. Amounts of non-sand material are generally small. Considerable variation however occurs in the naturally occurring sands within both the Richardson and Mildred Lake areas while the dike tailings sand, in contrast, is very consistent, falling mostly within the fine sand fraction. The tailings sand is therefore a finer sand than most of the other sands and should therefore have a greater moisture holding capacity.

4.1.2. Bulk density

Bulk densities of C horizon sand were found to vary between 1.55 and 1.65 while those of surface horizons were between 1.10 and 1.40. The value for the dike tailings sand is close to 1.60.

4.1.3. Hydraulic conductivity

Some saturated hydraulic conductivities are shown (Table 3). All are extremely rapid, including those for dike tailings sand, though values for the tailings sand are slower than might be expected from a comparison of sieve analyses. Values for surface horizons are generally greater than for C-horizons.

Unsaturated conductivities are so far only available for dike tailings sand, but were determined for C-horizon material from Richardson tower under sub-project VE 6.1 (Figure 2). Whereas the hydraulic conductivity of the Richardson sand declines extremely rapidly between 30 and 60 mbars, so that for most purposes a true "field capacity" exists, the decline is less marked in tailings sand, where "field capacity", if it really exists, is between 50 mbars and 100 mbars. These results are in reasonable agreement with those of Salter, Berry and Williams (1967), and Webster and

TABLE 2. Particle size distribution of sand samples from the AOSERP study area.

Location or Site		Percent sand in fractions					Non-sand
		VCS >1 mm	CS 1-0.5 mm	MS 0.5-0.25 mm	FS 0.25-0.105 mm	VFS 0.105-0.053 mm	<0.053 mm
Richardson	1	0.0	2.7	49.5	45.1	2.1	0.5
	2	0.0	1.0	23.8	72.3	2.6	0.3
	3	0.0	4.3	37.6	46.4	10.8	0.9
	4	0.0	6.7	48.0	41.3	3.9	0.6
	5	0.0	1.2	13.4	49.2	26.5	8.2
	6	0.0	6.2	72.3	21.4	0.6	0.2
Mildred Lake	1	0.0	0.4	34.5	60.9	3.8	0.4
	2	0.1	2.0	50.5	40.9	2.3	2.3
	3	3.0	2.5	8.1	67.9	15.3	3.9
	4	0.2	2.7	33.8	59.6	3.1	0.4
McLelland Lake		0.3	6.2	37.9	50.4	4.8	0.4
Dike Tailings mean of 10		1.1	4.5	16.3	73.0	4.4	0.7
St. dev.		1.6	2.8	4.0	4.5	2.5	0.4

TABLE 3. Saturated hydraulic conductivities of soil horizon and G.C.O.S. dike tailings sand samples from the instrumented sites.

Site		Horizon or Depth	Hydraulic Conductivity cm per hr
Richardson	4	C	42.2
	6	C	48.2
Mildred Lake	2	Ae	32.7
		Bm	32.7
		C	30.1
	3	Ae	22.8
		Bm	15.4
		C	12.0
G.C.O.S.	1	0-5 cm	16.1
		25 cm	5.7
		300 cm	6.9
		600 cm	7.2
	2	0-5 cm	8.0
		25 cm	8.7

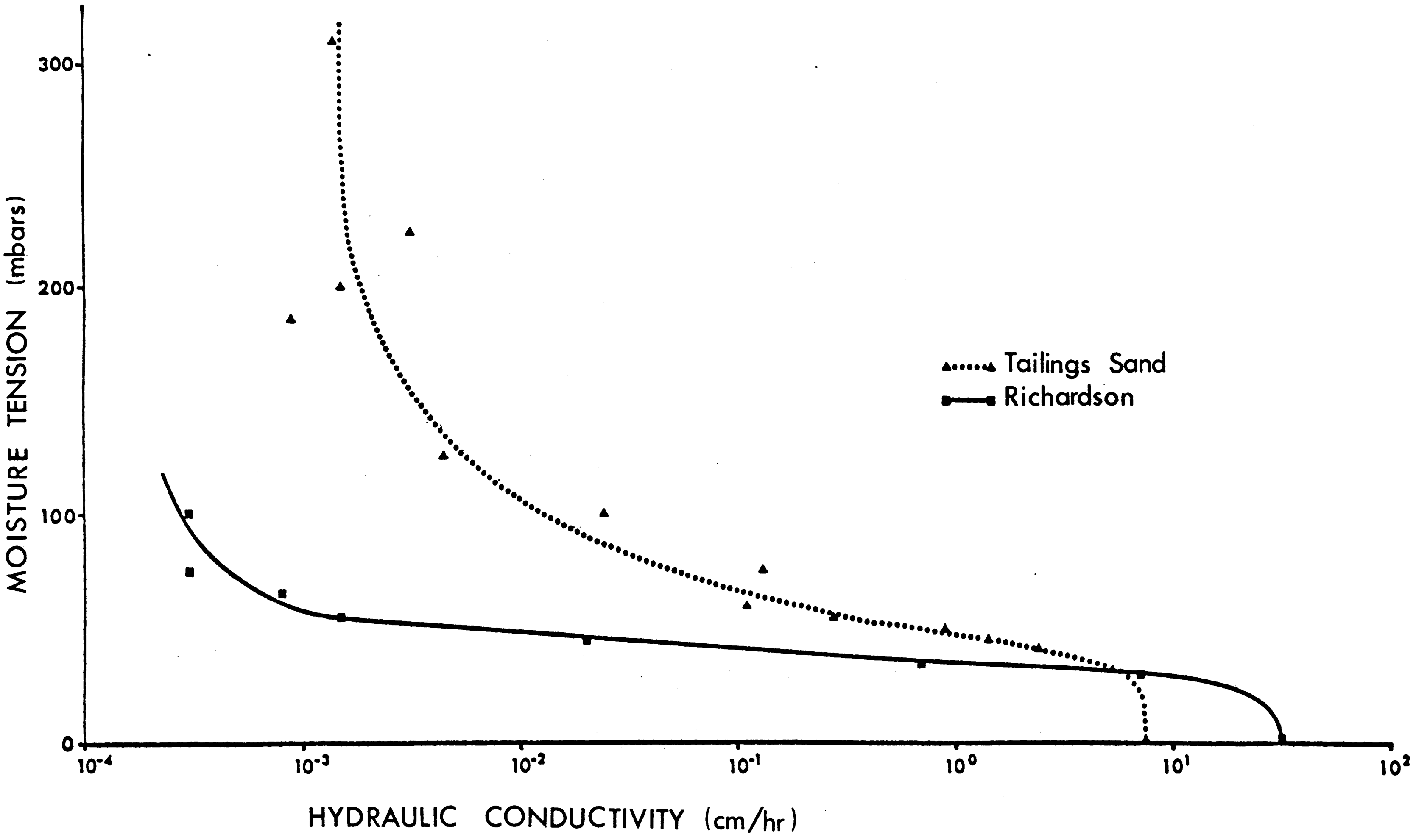

FIGURE 2. Relationship between hydraulic conductivity and moisture tension for tailings sand from the G.C.O.S. dike and for soil C-horizon sand from Richardson tower.

Becket (1971), for sand.

4.1.4. Moisture retention

Moisture retention curves are still being determined but results for Mildred Lake Site 3 are shown (Figure 3). If 50 mbars is the tension at which rapid drainage ceases (field capacity), as has been suggested for some sandy materials (Webster and Becket, 1971) then the moisture holding capacity should be close to 25 per cent by volume. However moisture determinations in the field following rain suggest that drainage becomes slow at around 16 per cent moisture or at a tension of 60 mbars rather than 50 mbars. About 14 per cent moisture or 140 mm of water per m depth of sand should therefore be available to the vegetation. This amount is large. Only slightly more water is available in the Ae horizon than in the C horizon at this tension, though between tensions of 100 mbars and 1 bar, the Ae horizon holds almost twice as much water as the C horizon. Other sands, such as those at Richardson tower, hold much less water than this soil, but determinations on dike tailings sand suggest that its moisture retention curve is similar to that of Mildred Lake Site 3(Figure 4).

4.1.5. Amendments to tailings sand

Some effects of additions of peat and locally derived till on the moisture properties of tailings sand have been investigated. While the addition of 2.5 per cent by weight of peat almost doubled saturated hydraulic conductivity, the addition of 20 per cent of till had no significant effect (Table 4).

TABLE 4. Effect of additions of till and peat to G.C.O.S. dike tailings sand on saturated hydraulic conductivity.

Material	Bulk Density	Hydraulic Conductivity cm per hr
Tailings sand	1.6	7.5
+20% Till	1.6	6.6
+2.5% Peat	1.3	13.2

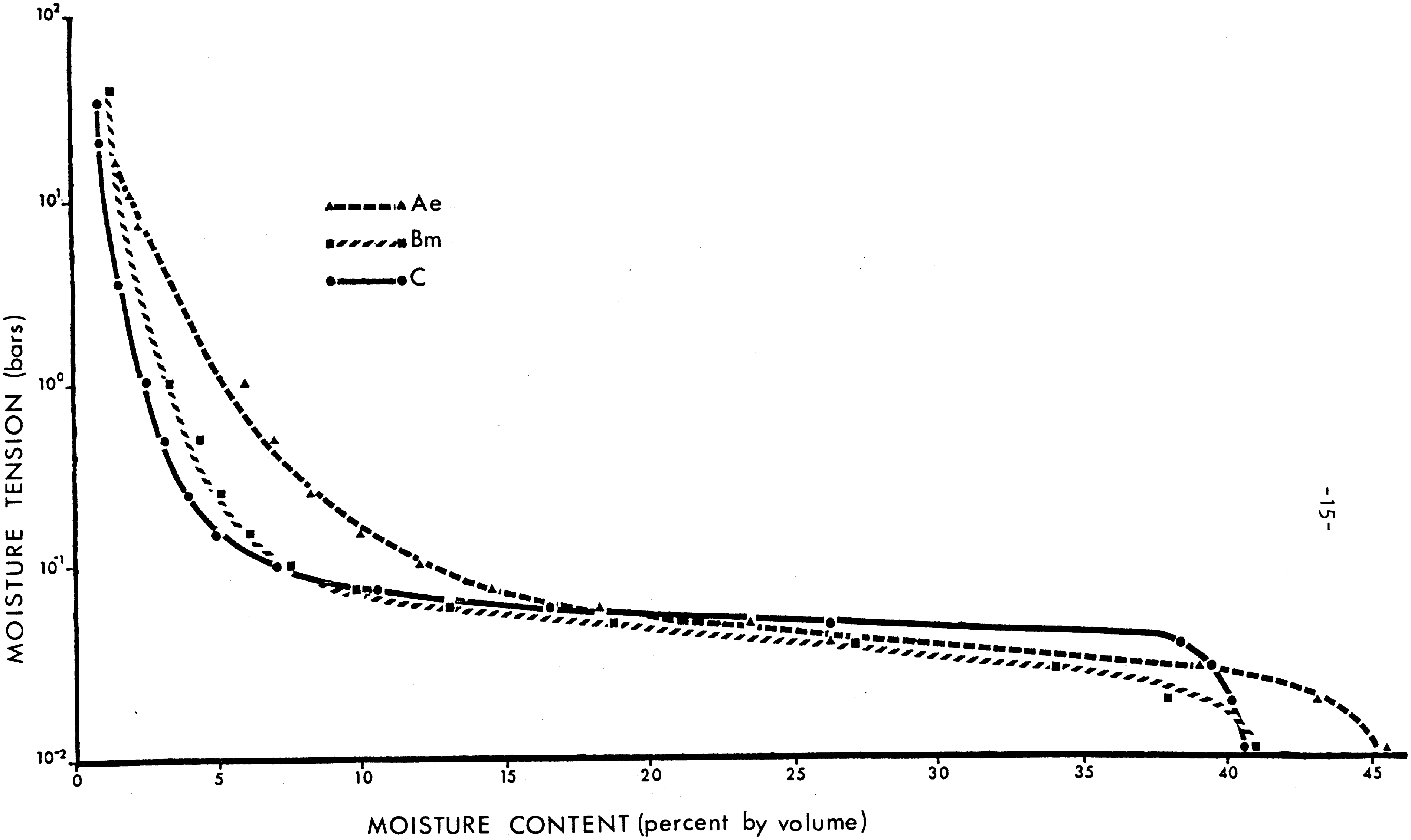

FIGURE 3. Moisture retention curves for different soil horizon samples from Mildred Lake Site 3.

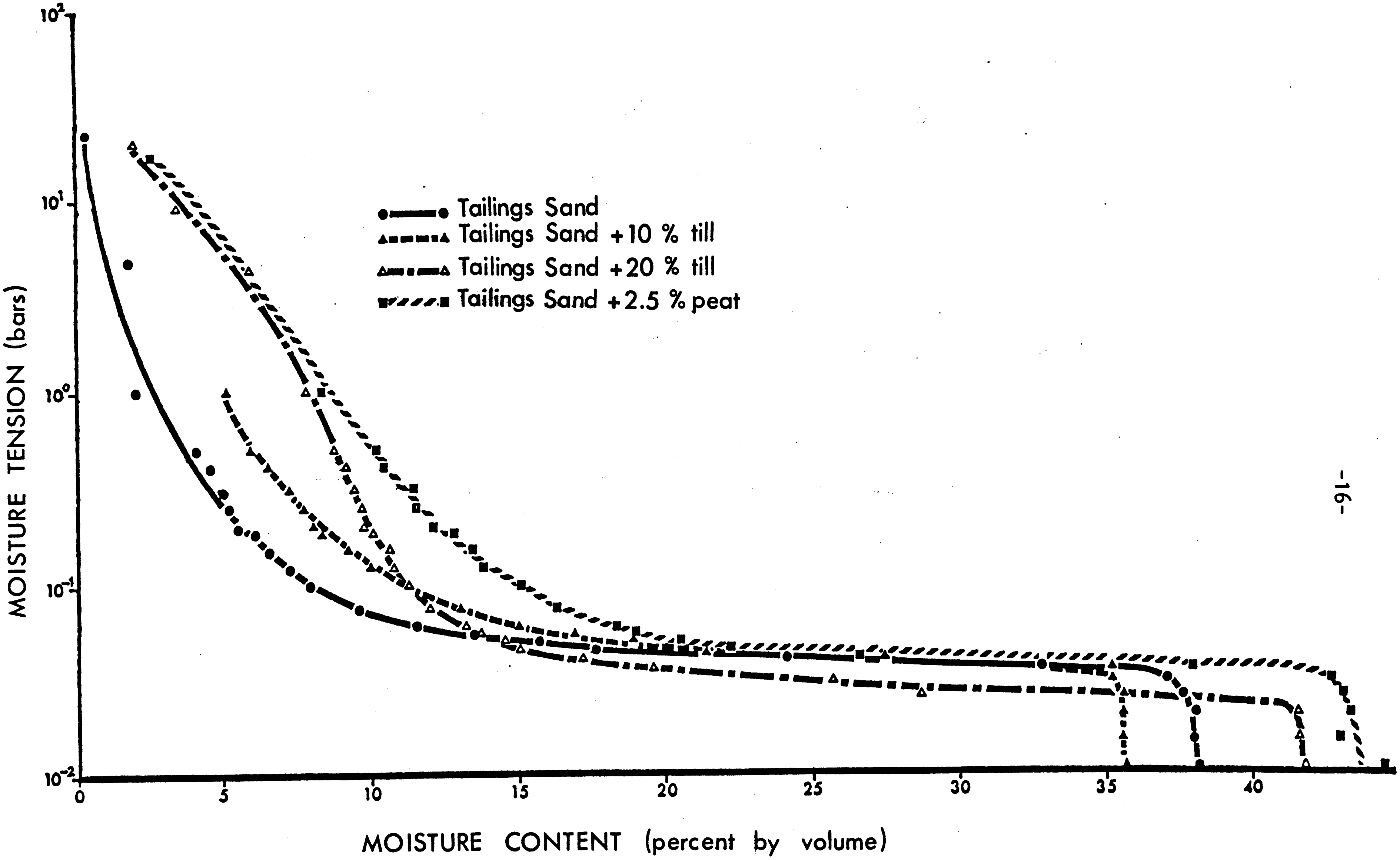

FIGURE 4. The effect of additions of till or peat to G.C.O.S. dike tailings sand on its moisture retention curve.

If 60 mbars is the tension at which rapid drainage of tailings sand ceases, as suggested by moisture determinations following rain, then additions of till appear to affect the water available to vegetation very little (Figure 4), since any increase in moisture holding capacity between tensions of 60 and 100 mbars is compensated by an almost similar increase in water held at very high tensions which is unavailable to plants. A till from another source, higher in silt and clay, gave similar results. Peat however appears more beneficial, since its addition caused moisture holding capacity between tensions of 60 and 100 mbars to increase by more than a third while that held at high tensions increased little.

4.2. FIELD RESULTS

4.2.1. Ground temperatures

Ground temperatures at the instrumented sites are shown for 11 August 1976 (Table 5). Differences in near surface temperatures largely reflect variation in the amount of shading by vegetation. Deep ground temperatures were higher on the dike than elsewhere and have continued so throughout the Fall, and it is assumed that percolating groundwater from the tailings pond is the cause. Deep temperatures are particularly high at G.C.O.S. Site 2 where the water table is only 150 cm beneath the surface.

4.2.2. Moisture following the thaw

The fate of moisture made available during the thaw is of interest because it is a major source of moisture in the spring, and is released when the ground is frozen. Results on the sand at Richardson tower, obtained under sub-project VE 6.1 suggest that little surface runoff occurs during the thaw and most of the meltwater enters the soil. Some weeks after the thaw gravimetric moisture determinations were made at three separate sites. The results (Figure 5) suggest that a large proportion of the meltwater remains at the top of the frozen zone or within it. In each case the "bulge" in moisture is sufficiently large to account for most of the moisture previously held in the snowpack.

TABLE 5. Ground temperatures on 11th August 1976 at some of the instrumented sites.

Depth cm	Site 2	Site 3	Site 4	Super-test Hill	G.C.O.S. 1 Dike NW Aspect	G.C.O.S. 2 Dike SW 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
150	11.0	8.6	6.2	7.4	12.1	15.7
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	-

4.2.3. Moisture in relation to the presence of fine textured layers in sand

During preliminary investigations in the field, it was found that at Richardson Site 4, layers almost saturated with moisture existed within sand of otherwise very low moisture content. Detailed gravimetric sampling (Figure 6) and sand sieve analyses were carried out to a depth of six metres in the hope that the results might have some bearing on methods of artificially increasing the moisture content in sand. It was found that the high moisture levels were related both to very fine sand (r = 0.75, 67 samples) and to non-sand, which was mainly silt (r = 0.67) although layers high in very fine sand and silt did not always coincide. In the case of very fine sand, high moisture levels presumably result from slow movement of water in adjacent coarser material under unsaturated conditions. The results show that it is not necessary to resort to materials high in clay to impede water movement in sand.

4.2.4. Soil moisture tensions and moisture content at the instrumented sites

Full information was being obtained by late July. During the late summer, driest conditions occurred in early August and both moisture and tension results for 10-11 August are shown (Table 6).

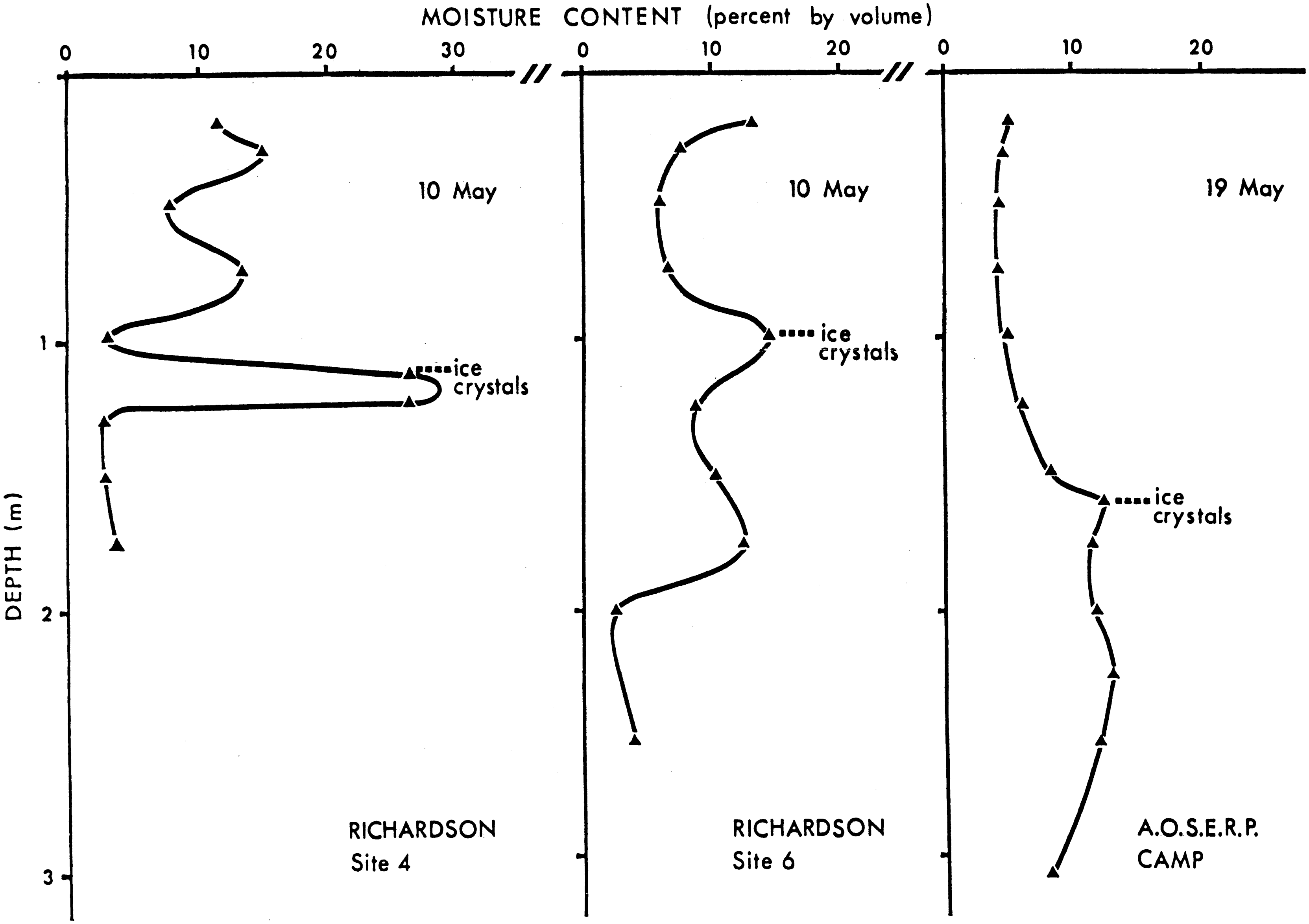

FIGURE 5. Moisture profiles at three separate sites following spring thaw.

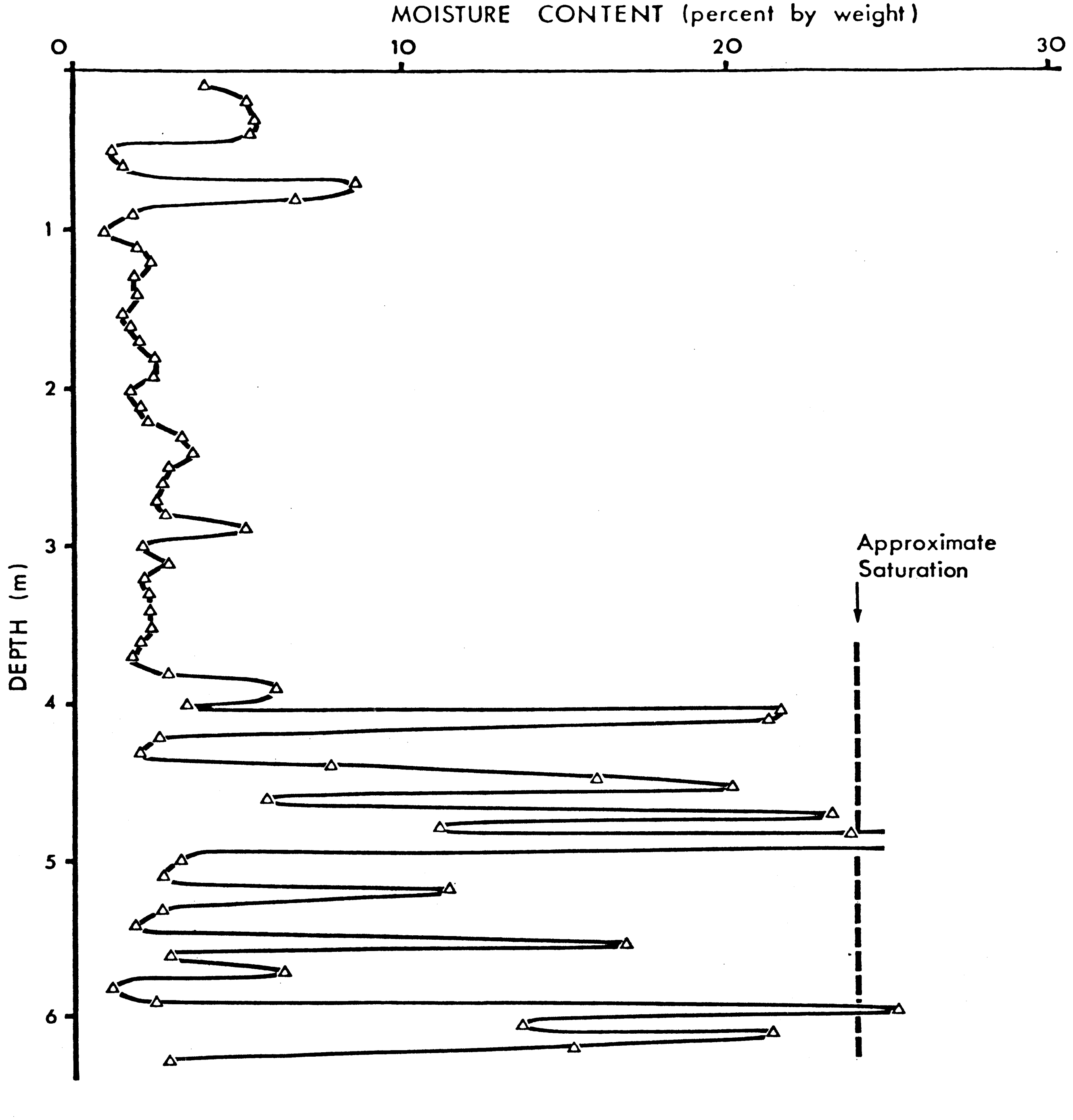

FIGURE 6. A moisture profile in sand which contains layers of finer material.

TABLE 6. Moisture tensions and moisture content on 10-11 August 1976 at some of the instrumented sites.

Depth cm	Mildred Lake 2 (sand)	Mildred Lake 3 (sand)	Mildred Lake 4 (sand)	Supertest Hill (till)	G.C.O.S. 1 Dike NW aspect (tailings)	G.C.O.S. 2 Dike SE aspect (tailings)
			Moisture Tensions (bars)			
10	6.7	5.0	1.4	4.8	4.8	11.0
20	3.8	1.7	0.68	3.3	3.6	7.6
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)[1]	0.08	0.07	(0.00 & 0.014)[1]
300	0.052	(-0.01 & 0.08)[1]			0.08	
			Moisture Content (percent by volume)			
10	1.9	2.6	4.3	10.5	2.1	5.5
20	3.2	4.1	8.6	-	3.4	9.7
50	5.1	6.9	9.4	-	7.0	7.8
100	4.7	8.4	7.4	-	9.9	22.8
200	4.5	9.1	27.1	-	10.8	32.3
300	6.7	8.7	29.9	-	13.2	27.2

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[1] saturation at one or both replicates

Some values are missing from the Supertest site because of instrument failure. Comparing the three sites on the AOSERP camp, moisture levels were least and tensions greatest at Site 2 (under Jackpine) whereas much greater moisture levels and smaller tensions existed at Site 4 (Spruce) where the water table was high. Values were intermediate at Site 3 (Aspen and Birch). The differences between Site 2 and Site 3 moisture levels and tensions undoubtedly reflect differences in the moisture holding capacity of the sand, in turn caused by differences in fine sand and non-sand content (Table 2). Near surface moisture and tension levels on the NW slope of the dike were intermediate between those of Mildred Lake Sites 2 and 3 which is not unexpected considering the very fine sand and non-sand contents (Table 2). Both moisture tensions and moisture content were greater on the SE facing slope than on the NW facing slope of the dike. It is possible for them both to be greater because of a larger peat content and therefore greater moisture holding capacity on the SE slope. Greater tensions on the SE slope than elsewhere are not unexpected, because of aspect. The high moisture levels at depths below 100 cm result from the presence of a water table at 190 cm.

Although the moisture tensions in early August are insufficient to cause excessive moisture stress, general observation suggests that tensions greater than these may have occurred earlier in the year, before the onset of heavy rains in June. After mid-August, heavy rain again raised moisture levels (Table 7), and on 27 August, only the soil at Supertest Hill, with its high clay content, had not reached its full moisture holding capacity. Although the soils became drier again in late September and October, tensions did not again reach early August levels.

TABLE 7. Moisture tensions and moisture content on 27-28 August 1976 at some of the instrumented sites.

Depth cm	Mildred Lake 2	Mildred Lake 3	Mildred Lake 4	Super-test	G.C.O.S. 1 Dike NW aspect	G.C.O.S. 2 Dike NW aspect
			Moisture tensions (bars)			
10	-	-	-	-	-	0.07
20	0.06	0.05	0.02	0.04	0.05	0.06
50	0.05	0.05	0.04	0.18	0.05	0.07
100	0.07	0.14	0.05	0.72	0.07	0.03
			Moisture content (percent by volume)			
10	12.9	14.5	18.5	12.7	8.2	10.4
20	15.7	17.6	22.7	-	9.2	13.1
50	10.4	12.4	13.7	-	13.1	10.5
100	9.5	11.6	9.8	-	9.5	22.5

5. CONCLUSIONS AND RECOMMENDATIONS

Most of the meltwater released during the thaw enters the sands and remains within or near the top of the frozen zone until thawing of the ground is complete in late May.

The sands so far studied drain rapidly following rain, until the soil moisture tension reaches about 60 mbars, after which drainage is slow. In some of the sands studied, the water available to plants at this tension is as great as 140 mm per metre depth, but in others it can be as small as 50 mm per metre depth. The amount of water available in the dike tailings sand at this tension is large. Additions of up to 20 per cent by weight of till to tailings sand do not significantly increase available moisture and have no effect on saturated hydraulic conductivity. Peat additions (2.5 per cent by weight) however increase both available moisture holding capacity and saturated hydraulic conductivity.

Neither the natural soils nor the dike material became sufficiently dry during the latter half of Summer 1976 to cause excessive stress on vegetation.

Ground temperatures are higher on the dike than elsewhere, presumably because of water percolating from the tailings pond.

More information is needed on changes in soil moisture tension and moisture content within the near-surface soil. Increased information on tensions can be obtained by installing additional psychrometers at shallow depths, while information on moisture content can be improved to a limited extent by refinements in calibration of the neutron probe, particularly to take into account the effects of snow. However, either increased gravimetric sampling or preferably the development of an additional means of moisture determination such as a thermal method is also necessary.

6. ACKNOWLEDGEMENTS

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8. APPENDICES

TABLE 1. Ground temperature ($^{\circ}C$) during 1976 at the instrumented sites.

Depth (cm)	July 16	Aug 3	Aug 11	Sept 14	Oct 20	Nov 23
			MILDRED LAKE SITE 1			
20	13.2	13.6	14.8	10.3	3.5	-0.8
50	-	-	-	10.3	-	-
100	10.2	9.1	11.1	9.7	6.2	2.3
150	8.3	8.0	9.5	9.2	6.9	3.5
200	6.7	6.9	8.2	7.8	7.6	4.4
300	5.4	6.3	6.3	6.3	7.4	5.5
450	4.2	4.8	4.7	5.1	6.7	6.2
600	4.1	-	4.4	-	5.6	5.4
			MILDRED LAKE SITE 2			
20	13.4	14.9	15.2	10.3	2.6	-0.8
50	13.3	-	-	10.3	4.0	0.9
100	11.1	11.1	11.2	10.5	5.4	1.8
150	9.4	9.7	11.0	10.1	6.4	3.0
200	7.6	8.5	9.4	9.7	5.8	3.9
300	5.7	6.7	7.2	8.5	7.2	4.9
450	4.0	4.8	5.1	6.5	6.4	5.6
600	3.2	3.7	3.9	5.0	5.1	5.8
			MILDRED LAKE SITE 3			
20	12.1	14.2	14.2	10.3	3.1	-1.8
50	10.9	12.4	12.3	9.7	4.4	0.4
100	8.5	9.7	10.2	9.2	5.6	1.9
150	7.0	7.6	8.6	9.1	6.4	3.1
200	5.5	6.4	-	-	-	-
300	3.7	4.8	5.4	6.7	6.7	5.0
450	2.7	3.7	3.9	4.9	5.6	5.4
600	2.5	3.2	3.2	3.8	4.6	5.0
			MILDRED LAKE SITE 4			
20	9.6	13.3	11.1	9.2	2.8	-0.8
50	8.2	10.8	10.6	8.6	3.6	0.5
100	5.6	7.7	8.0	7.5	4.5	1.9
150	4.1	6.3	6.2	6.7	4.9	2.9
200	2.4	5.7	4.7	5.9	5.1	3.6
300	1.5	4.3	3.4	4.8	5.0	4.2
450	.12	3.2	2.5	3.6	4.4	4.2
600	1.5	3.1	2.1	2.8	3.6	3.9

(continued)

TABLE 1 (continued)

Depth (cm)	July 16	Aug 3	Aug 11	Sept 14	Oct 20	Nov 23
MILDRED LAKE SITE 5						
20	12.5	14.2	14.0	9.9	2.3	-2.9
50	11.5	12.2	12.4	9.1	3.6	-0.3
100	9.3	10.0	10.5	9.0	4.9	1.5
150	7.7	8.3	9.0	8.5	5.6	2.6
200	6.1	7.1	7.0	7.7	6.2	3.4
300	4.1	4.9	5.4	6.4	6.0	4.7
450	2.8	3.3	3.7	4.6	5.1	5.1
SUPERTEST HILL						
20	10.5	12.8	12.8	9.1	4.2	0.3
50	9.2	10.9	11.1	9.1	5.1	1.4
100	7.2	8.6	8.9	8.5	6.0	3.0
150	5.6	7.4	7.4	7.7	6.4	4.0
200	4.9	6.3	6.2	7.2	6.2	4.5
300	3.3	3.7	4.8	5.9	5.9	5.0
450	-	3.9	-	4.6	5.1	5.1
600	-	3.6	-	4.0	4.4	4.7
GCOS DIKE SITE 1						
1	-	17.5	24.7	8.5	-7.8	-3.3
5	-	17.4	24.2	8.3	0.5	-3.1
20	-	16.8	17.8	9.1	1.9	-3.1
50	-	15.7	15.5	10.3	3.6	0.5
100	-	13.6	13.8	11.1	5.8	2.7
150	-	12.4	12.3	11.4	7.6	4.2
200	-	11.9	11.3	11.3	8.3	5.1
300	-	10.2	9.7	10.8	9.2	6.9
450	-	8.8	8.0	9.4	-	8.2
600	-	8.3	7.4	8.5	9.1	8.7
GCOS DIKE SITE 2						
1	-	19.7	32.3	11.9	0.5	-2.9
5	-	20.3	30.1	11.0	0.9	-2.9
20	-	21.1	22.7	12.2	4.2	-0.6
50	-	19.7	18.3	11.8	8.2	3.0
100	-	16.9	16.5	14.9	10.8	6.2
150	-	15.9	15.8	15.0	11.9	8.2
200	-	15.3	14.8	15.3	13.1	9.5
300	-	14.4	13.5	15.0	14.3	11.8
450	-	13.8	13.3	14.8	14.9	13.8

(continued)

TABLE 1 (continued)

Depth (cm)	July 21	July 28	Aug 18	Sept 26	Nov 26
			RICHARDSON SITE 4		
20	14.6	15.0	14.9	7.2	-
50	13.2	13.5	14.9	8.4	-
100	11.4	12.1	13.4	8.9	-
150	10.0	10.3	11.4	9.2	-
200	8.7	9.3	9.7	8.9	-
300	6.5	7.1	7.4	8.3	-
450	4.3	4.6	4.9	6.7	-
600	3.9	3.8	3.7	5.4	-
			RICHARDSON SITE 5		
20	11.2	11.6	11.9	9.8	-8.9
50	9.7	10.1	11.1	7.4	-0.8
100	8.1	8.5	9.4	7.2	1.8
150	6.3	6.9	7.3	6.8	3.1
200	5.1	5.5	5.7	6.3	4.1
300	4.0	4.5	4.4	5.5	4.6
450	3.5	3.9	3.7	4.9	4.8
			RICHARDSON SITE 6		
20	12.9	13.4	13.9	6.8	-3.5
50	11.6	12.0	13.4	8.0	-1.2
100	10.1	10.5	11.6	8.5	0.9
150	8.8	9.1	9.8	8.7	2.1
200	7.7	8.2	8.5	8.3	3.1
300	5.8	6.5	6.6	7.6	4.2
450	4.1	4.7	4.5	6.1	5.1
600	3.5	4.1	3.5	4.8	5.1

TABLE 2. Soil moisture tensions (bars) during 1976 from tensiometers (<0.40) and psychrometers (>1.0).

Depth (cm)	Aug 3	Aug 4	Aug 11	Aug 12	Aug 27	Sept 13	Sept 14	Sept 16
MILDRED LAKE SITE 2								
10	-	-	8.2	7.6	-	-	-	-
20	-	-	5.1	5.8	0.056	0.089	0.091	0.11
50	0.11	0.11	0.14	0.15	0.053	0.062	0.067	0.070
100	0.064	0.066	0.070	0.069	0.065	0.065	0.129	0.062
200	0.060	0.061	0.067	0.065	0.069	0.045	0.044	0.040
300	-	0.050	0.052	0.043	0.062	-	-	-
MILDRED LAKE SITE 3								
10	-	-	5.0	5.0	-	-	-	-
20	-	-	3.3	3.2	0.046	0.086	0.089	0.12
50	0.15	0.15	0.17	0.19	0.049	0.065	0.068	0.072
100	0.11	0.11	0.12	0.12	0.14	0.12	0.11	0.11
200	0.066	0.067	0.069	0.073	0.076	0.066	0.070	0.070
300	0.031	0.008	0.033	0.022	0.028	0.064	0.015	0.015
MILDRED LAKE SITE 4								
10	-	-	3.0	3.0	-	-	-	-
20	0.38	-	0.68	0.75	0.019	0.054	0.050	0.77
50	0.078	0.077	0.087	0.082	0.036	0.056	0.051	0.058
100	0.069	0.071	0.087	0.073	0.053	0.044	0.038	0.041
200	-0.016	-0.015	-0.010	-0.012	-0.012	-0.012	-0.016	-0.015
SUPERTEST HILL								
10	-	-	5.5	5.5	-	-	-	-
20	-	-	6.0	6.0	0.040	0.072	-	0.20
50	0.65	0.67	4.2	4.2	0.18	0.22	-	0.28
100	0.53	0.60	0.63	0.66	0.72	0.44	-	0.34
200	0.20	0.059	0.075	0.076	-	0.13	-	0.14
GCOS DIKE SITE 1								
10	-	-	2.2	1.0	-	-	-	-
20	0.22	0.37	-	-	0.052	0.071	0.070	0.093
50	0.11	0.085	0.094	0.094	0.050	0.059	0.059	0.064
100	0.023	0.048	0.068	0.066	0.071	0.044	0.043	0.048
200	-	0.057	0.071	0.075	0.054	0.047	-	0.040
300	0.076	0.083	0.083	0.066	0.056	0.073	0.060	0.066
GCOS DIKE SITE 2								
10	-	-	11.0	11.7	0.073	0.26	0.39	6.0
20	-	0.60	7.6	8.6	0.060	0.25	0.32	0.54
50	0.19	0.18	0.17	0.19	0.072	0.053	0.052	0.058
100	0.042	0.040	0.039	0.037	0.031	0.026	0.022	0.023
200	0.009	0.010	0.004	0.008	0.003	0.004	-	-0.012

(continued)

TABLE 2 (continued)

Depth (cm)	Aug 1	Aug 13	Aug 17	Aug 20	Aug 27	Sept 1	Sept 24
				RICHARDSON SITE 4			
10	-	-	-	-	-	-	-
20	0.088	>0.2	>0.2	>0.2	>0.2	>0.2	>0.2
50	0.092	0.14	0.15	0.14	0.16	0.17	0.21
100	0.081	0.079	0.092	0.083	0.085	0.091	0.098
200	0.14	0.14	0.045	0.051	0.058	0.043	0.046
300	0.037	0.036	0.045	0.035	0.048	0.039	0.048
				RICHARDSON SITE 6			
10	-	-	-	-	-	-	-
20	0.097	>0.2	>0.2	>0.2	>0.2	>0.2	>0.2
50	0.11	0.22	0.14	0.15	0.15	>0.2	>0.2
100	0.059	0.063	0.078	0.069	0.067	0.089	0.088
200	0.013	0.053	0.059	0.056	0.051	0.058	0.060
300	0.048	0.046	0.057	0.048	0.047	0.092	0.027

TABLE 3. Moisture contents (percent by volume) during 1976 from neutron probe readings, and from gravimetric sampling (bracketted).

Depth (cm)	July 16	Aug 10	Aug 27	Aug 28	Sept 14	Sept 17	Nov 23
MILDRED LAKE SITE 1							
0-5	(7.1)	-	(12.1)	-	-	-	-
10	8.6	-	10.1	-	-	-	8.9
	(4.9)		(8.9)				
20	11.6	-	14.4	-	-	-	11.9
30	11.1	-	15.0	-	-	-	11.4
50	8.4	-	11.5	-	-	-	7.3
100	7.2	-	12.4	-	-	-	8.5
150	4.4	-	4.3	-	-	-	6.8
200	4.7	-	3.3	-	-	-	6.3
300	9.6	-	7.1	-	-	-	5.4
400	6.0	-	6.7	-	-	-	7.5
500	8.2	-	8.1	-	-	-	8.6
600	12.9	-	12.8	-	-	-	6.7
MILDRED LAKE SITE 2							
0-5	(7.2)	(1.7)	(12.9)	(12.3)	(11.8)	(6.3)	
10	8.8	1.9	12.9	10.6	7.7	5.9	9.5
	(6.9)	(2.5)	(9.0)	(7.6)	(7.1)	(5.0)	
20	10.8	3.2	15.7	14.0	10.2	8.5	12.2
30	10.0	4.1	13.2	12.1	9.3	8.4	9.1
50	7.6	5.1	10.4	8.7	7.1	6.6	5.6
100	5.8	4.7	9.5	8.5	6.8	6.1	4.8
150	4.0	4.0	7.4	7.4	7.2	7.1	5.1
200	5.1	4.5	4.5	4.5	7.6	7.5	6.2
300	7.2	6.7	6.1	6.0	5.7	5.7	5.6
400	5.0	5.3	5.2	5.1	5.1	4.8	5.0
500	3.7	3.8	3.8	3.5	3.9	3.6	3.2
600	29.9	29.4	29.4	29.5	29.6	29.2	19.0
MILDRED LAKE SITE 3							
0-5	(15.6)	(5.5)	(17.7)	(49.9)	(13.5)	(10.5)	
10	11.5	2.6	14.5	12.4	7.9	6.2	13.4
	(9.9)	(3.1)	(18.6)	(12.1)	(11.4)	(10.0)	
20	12.3	4.1	17.6	14.7	10.8	9.1	14.0
30	12.0	6.4	16.0	14.8	11.6	10.7	13.3
50	9.4	6.9	12.4	11.5	10.7	10.1	10.7
100	9.4	8.4	11.6	12.5	13.7	13.8	13.6
150	11.6	10.3	8.9	8.8	8.1	8.1	9.0
200	9.3	9.1	8.6	8.3	8.0	7.8	8.7
300	8.4	8.7	8.5	8.7	8.6	9.1	8.3
400	4.7	4.8	4.7	4.8	4.7	4.7	4.2
500	1.8	2.1	1.9	1.8	2.1	2.2	2.0
600	2.8	3.1	2.7	2.7	2.7	3.1	2.8

(continued)

TABLE 3 (continued)

Depth (cm)	July 16	Aug 10	Aug 27	Aug 28	Sept 14	Sept 17	Nov 23/24
			MILDRED LAKE SITE 4				
0-5	(11.9)	(3.9)	(16.9)	(18.0)	(6.5)	(22.0)	
10	15.4	4.3	18.5	15.9	14.1	12.0	15.3
	(22.0)	(3.5)	(16.5)	(13.7)	(18.6)	(15.2)	
20	19.7	8.6	22.7	22.1	20.2	18.7	22.1
30	17.4	11.3	19.8	18.6	17.8	17.7	16.3
50	10.5	9.4	13.7	13.2	12.3	11.9	10.4
100	8.2	7.4	9.8	9.9	11.8	11.7	9.7
150	9.6	8.8	8.3	8.6	9.0	9.5	8.6
200	25.7	27.1	27.1	26.4	27.7	17.6	26.0
			MILDRED LAKE SITE 5				
0-5			(16.5)		(12.9)		
10	13.2	-	17.1	-	9.3	-	15.8
			(12.0)		(8.3)		
20	14.5	-	19.0	-	12.8	-	14.4
30	12.6	-	16.4	-	11.4	-	9.7
50	11.1	-	15.0	-	11.5	-	12.8
100	5.1	-	14.1	-	8.8	-	8.0
150	5.6	-	4.6	-	6.0	-	6.2
200	7.9	-	5.4	-	5.2	-	12.2
300	21.7	-	19.0	-	19.1	-	20.5
			SUPERTEST HILL[1]				
0-5	(15.8)	-	-	(12.2)		(6.9)	
10	22.9	-	-	20.1	-	14.1	30.1
	(10.5)			(12.7)		(7.9)	
20	27.5	-	-	27.0	-	24.5	30.7
30	27.7	-	-	28.8	-	28.8	28.8
50	24.5	-	-	23.0	-	23.5	23.4
100	24.9	-	-	22.1	-	22.7	22.9
150	23.6	-	-	23.0	-	22.7	22.1
200	23.4	-	-	23.1	-	22.7	22.3
300	21.7	-	-	23.4	-	23.6	23.3

(continued)

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[1] Neutron probe calibration in doubt.

TABLE 3 (continued)

Depth (cm)	July 16	Aug 10	Aug 27	Aug 28	Sept 14	Sept 17	Nov 23/24
			GCOS DIKE SITE 1				
0-5	-	(1.1)	(17.7)	(15.2)	(11.1)	(3.8)	
10	-	2.1	8.2	7.4	10.6	8.1	9.0
		(2.2)	(8.2)	(8.5)	(10.0)	(4.8)	
20	-	3.4	9.2	7.7	11.7	10.3	9.6
30	-	4.1	9.1	7.8	10.1	8.8	8.2
50	-	7.0	13.1	11.8	12.1	11.1	9.1
100	-	9.9	9.5	9.9	12.0	11.8	10.0
150	-	10.4	10.2	9.8	11.7	12.0	10.5
200	-	10.8	10.4	10.1	10.3	10.9	10.5
300	-	13.2	12.3	12.0	12.0	13.1	12.6
400	-	12.7	12.0	11.8	11.7	12.1	11.9
500	-	17.0	16.0	16.0	15.5	16.5	15.9
600	-	15.6	15.5	15.0	14.9	15.1	17.3
			GCOS DIKE SITE 2				
0-5	-	(1.3)	(17.3)	(13.1)	(6.1)	(1.7)	
10	-	5.5	10.4	9.0	9.4	-	9.5
		(3.9)	(10.4)	(4.7)	(15.2)	(6.0)	
20	-	9.7	13.1	12.1	14.3	13.6	14.4
30	-	11.5	14.7	14.4	17.3	16.4	16.5
50	-	7.8	10.5	9.8	10.8	10.8	12.4
100	-	22.8	22.5	22.5	23.2	24.3	28.8
150	-	24.1	25.2	24.8	28.2	28.5	39.9
200	-	32.3	31.0	31.7	32.5	33.0	33.1
300	-	27.2	27.3	27.7	28.4	27.7	30.2

Depth (cm)	July 5	July 10	July 20	Sept 11	Sept 24	Nov 26
			RICHARDSON SITE 4			
10	1.5	0.9	1.6	1.1	0.5	-
20	3.4	2.6	3.3	2.4	1.7	-
30	4.9	3.7	4.2	3.6	2.6	-
50	7.4	6.0	5.2	4.6	3.8	-
100	3.2	3.0	3.0	2.5	2.4	-
150	3.4	3.2	3.1	2.7	2.7	-
200	3.4	3.2	3.2	2.6	2.4	-
300	5.2	5.4	5.4	4.9	4.7	-
400	9.9	9.8	9.8	9.9	9.9	-
500	13.8	13.9	13.9	12.5	13.9	-
600	6.9	7.4	7.4	7.2	7.3	-

(continued)

TABLE 3 (continued)

Depth (cm)	July 5	July 10	July 20	Sept 11	Sept 24	Nov 26
			RICHARDSON SITE 5			
10	5.1	3.5	6.3	4.5	3.0	21.3[1]
20	7.0	5.0	7.1	6.3	4.8	15.3[1]
30	6.2	5.5	6.6	6.2	5.3	9.4
50	7.2	6.6	6.7	6.8	6.2	8.7
100	10.2	9.1	8.4	6.8	6.5	9.1
150	12.4	11.7	11.3	10.3	11.1	11.5
200	29.5	28.9	28.8	27.9	28.4	27.9
300	-	33.1	32.8	32.6	32.6	32.3
			RICHARDSON SITE 6			
10	1.8	1.2	1.9	0.7	0.5	18.9[1]
20	2.3	1.7	2.3	1.1	1.1	11.4[1]
30	2.2	1.6	2.3	1.2	1.5	6.8
50	2.3	2.1	2.9	1.7	1.7	4.7
100	2.8	2.6	2.7	2.2	1.9	2.6
150	3.2	2.9	2.9	2.3	2.1	1.8
200	2.8	2.9	2.5	2.4	2.3	1.9
300	3.7	3.8	3.6	3.3	3.3	3.2
400	2.2	2.7	2.5	2.3	2.2	2.3
500	1.7	1.9	1.8	1.6	1.7	1.6
600	1.9	1.9	1.9	1.5	1.9	1.4

---

[1] Neutron probe calibration in doubt.

TABLE 4. Water table levels (m below ground level) at instrumented sites during 1976

Site	June 24	July 14	Aug 3	Aug 11	Sept 17	Nov 23
Mildred 2	5.86	5.88	5.86	5.85	5.90	5.90
4	1.85	1.90	2.00	2.02	2.01	2.28
5	3.71	-	3.76	4.07	3.87	3.97
Supertest		2.30	2.75	2.83	2.65	-
GCOS 2	-	-	1.91	1.87	1.76	1.59

Site	June 25	July 12	July 21	Aug 27	Sept 26	Nov 26
Richardson 5	2.36	2.33	2.27	2.25	2.23	1.49

Water tables were more than 6 m below the surface at Mildred Lake Site 1, GCOS dike Site 1 and at Richardson Site 4 and were not measured. A well at Mildred Lake Site 3 was unsuccessful.

PART II. STUDIES OF CHEMICAL PROPERTIES OF SOILS AND METHODS OF IMPROVING MINED MATERIALS FOR PLANT GROWTH

L.W. TURCHENEK

W.B. McGILL

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ABSTRACT

The objectives of this project are to characterize in detail undisturbed soils and soil materials to be reclaimed, and to develop ways of improving soil processes which contribute to production of a stable soil-plant system.

Analysis of tailings sand shows that very poor nutrient status and coarse texture are major problems in its reclamation. Indoor lysimeters are being used to study rates of leaching of plant nutrients, improvement of water retaining properties and plant growth with fertilization in tailings sand treated as follows: (1) no treatment, (2) glacial till mixed into the surface of sand, (3) one subsurface till layer in the sand, (4) two subsurface till layers in the sand, and (5) peat mixed into the surface of the sand. Results to date show that Treatment 5 produced the highest yield of brome grass, although only Treatment 2 yielded poorly. Tensiometers indicated that Treatment 5 attained the driest state while Treatment 2 remained relatively moist throughout the summer. To study reclamation of tailings sand under environmental conditions of the oil sands area, lysimeters with similar treatments have been installed at the AOSERP field camp at Mildred Lake.

Of the plant nutrients, particular attention is being given to nitrogen (N) because of its quantitative importance, its ecological significance and its complicated cycle which includes a number of loss mechanisms. The experiments on the N cycle in progress or planned are as follows: (1) determination of natural immobilization and mineralization in forest litters; (2) study of the effect of different soil treatments on N uptake efficiency by grasses and legumes and on the recycling rate of N through this system; (3) study of the effect of time of N application on its efficiency of uptake by grasses; (4) determination of the decomposition rates of organic materials; (5) determination of the effect of till on remineralization of immobilized N in sand-till and sand-peat-till mixtures; and (6) study of the rate of N turnover through established grasses on steep slopes of tailings sand (GCOS dike). These experiments are being carried out with the

aid of ^{15}N and ^{14}C tracer techniques. Studies of phosphorus, potassium and micronutrients using the same facilities and similar techniques to the N experiments will also be carried out.

1. INTRODUCTION

The major objectives in soil reclamation research is the development of ways of improving soil processes which contribute to the production of a stable soil-plant system. The main soil materials requiring reclamation are tailings sand and overburden materials which result from open pit mining operations; disturbed surface soils will also require development of reclamation methods should *in situ* oil extraction become widely used. Tailings sand may be the most difficult material to reclaim, whereas overburden materials which are free of lean oil sand may have potential as amendments which could improve soil properties of tailings sand for plant growth.

Lysimeters provide a means of studying chemical and physical characteristics and processes of soils in great detail. They are widely used for measuring the percolation of water through soils and determining the soluble constituents removed in the drainage water (Broadbent and Chapman, 1949; Shaw and Robinson, 1960; McIlroy and Angus, 1963; Pratt *et al*, 1967; Low and Armitage, 1970; Upchurch *et al*, 1973; Severson *et al*, 1975). In scale, they lie between greenhouse pot experimentation and use of field plots; they have advantages and disadvantages over both. The objectives of lysimeter experiments are to study soil processes in tailings sand, to measure physical and chemical properties of the sand and to determine changes in these properties resulting from amendments such as addition of overburden materials to the sand. More specifically, the following soil properties and processes can be measured; salt, plant nutrient and colloid movement; physical properties such as soil moisture tension; changes in soil organic matter; soil structural changes; physical-chemical properties of colloids; movement of fertilizers; and plant response to different treatments and fertilizers.

In a reclamation scheme where the overall objective is formation of a stable soil-plant system, information on the biogeochemical cycling of nutrient elements is necessary for long term planning and predictions. Major and minor nutrient elements could be supplied from fertilizers or from additions of peat and glacial till to tailings sand. Nitrogen, in addition to coming from these sources, may also be added to the system on a continuing basis through biological fixation, soil adsorption and precipitation (Stevenson, 1965). Because of its quantitative importance, its ecological significance and the multitude of loss mechanisms, N cycling requires particular attention. The N 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. Part of this information can be obtained from the literature and part from *in situ* measurements. It is known from the literature that the soil physical and chemical environment has a substantial effect on soil microorganisms and on their role in nutrient cycling (Stevenson, 1965; McLaren and Skujins, 1968; Bacan, 1968). In tailings sand, changes in the soil environment can be brought about by addition of peat, till or other materials, as indicated previously. The effects of these on nutrient cycling can be determined with the aid of tracer techniques utilizing ^{14}C and ^{15}N (Jansson, 1971). Several experiments have been initiated to study the N cycle in natural and reclaimed soils with the aid of ^{15}N. Most of these use the micro-plot technique whereby small soil plots are laterally isolated from the main body of soil by means of cylinders (Popovic and Nommik, 1972).

2. RESUME OF CURRENT STATE OF KNOWLEDGE

Soils and sediments of the Athabasca oil sands area have been sampled and analyzed for the purpose of providing a data base for reclamation of soils and more specifically for providing information about materials being used in experiments on reclamation of tailings sand and overburden materials. The soil descriptions and analyses are available from the Department of Soil Science.

Data for tailings sand and a sample from an overburden pile are given in Table 1 to indicate the properties which may be limiting to plant growth. They include a high sand content, resulting in low water holding capacity and low nutrient retention, high pH, non-wettability, low organic matter content, and low fertility as indicated, for example, by the very low N content. Amending tailings sand with clay-bearing materials such as till or with peat may improve both chemical and physical soil properties. Although the pH is high, natural leaching along with fertilizer and SO_2 additions may cause rapid acidification unless steps such as addition of lime to neutralize the sand are taken. Many peats in the area are acidic (Project VE 5.2) and amendments with these would not contribute to buffering capacity in the neutral range. Peats from sedge fens, however, are neutral and may be more useful in this regard. Clay added in the form of glacial till, lacustrine materials or shale could increase the buffering capacity, nutrient supply and water holding capacity of tailings sand. By layering such material below the soil surface, prolonged water retention in porous materials can be created (Saxena *et al*, 1975). Clays and organic materials can interact with sand to produce aggregates and thereby improve the physical status of a soil (Emerson, 1959; Greenland, 1965). Moreover, total nitrogen and carbon contents are higher in clay fractions of soils or in clay-and silt-sized microaggregates (Chichester, 1959; Turchenek and Oades, 1976). The interactions consist of sesquioxide and Ca linkages between clays and organic molecules as well as various types of physical sorption and chemi-sorption mechanisms (Edwards and Bremner, 1967; Greenland, 1971; McGill and Paul, 1976). The implication is that

TABLE 1. Some properties of tailings sand and overburden materials

Property		Tailings 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	0.01	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 (μg/g)		28	26	25	36
Extractable $SO_4^=$		0.05	0.08	0.04	0.09
CEC (me/100 g)		0.3	6.5	10.5	133.3
Exchangeable Cations (me/100 g)	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	109	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

clay addition is necessary for interactions with N-bearing organic compounds in order to build up the N-status of materials such as tailings sand.

Materials which could be used as amendments are abundant in the Athabasca oil sands area; glacial till and peat are among the constituents of Pleistocene and Recent deposits. Clayey material is available from the Clearwater formation in many areas, and limestone can be obtained from the Waterways formation (Carrigy and Kramers, 1975; Crown and Twardy, 1970). The interactions of these materials with tailings sand and assessment of their effectiveness as aids in reclamation are major objectives of this study.

3. STUDY AREAS

Lysimeter investigations are being carried out in two areas. One set of 10 lysimeters has been established indoors at the Soil Science (University of Alberta) farm at Ellerslie. A second set of 10 (of a different design) have been installed outdoors at the AOSERP field camp at Mildred Lake. These lysimeter installations will be referred to, henceforth, as indoor lysimeters and outdoor lysimeters. Experiments on N cycling are being conducted at the AOSERP field camp and on the GCOS dike.

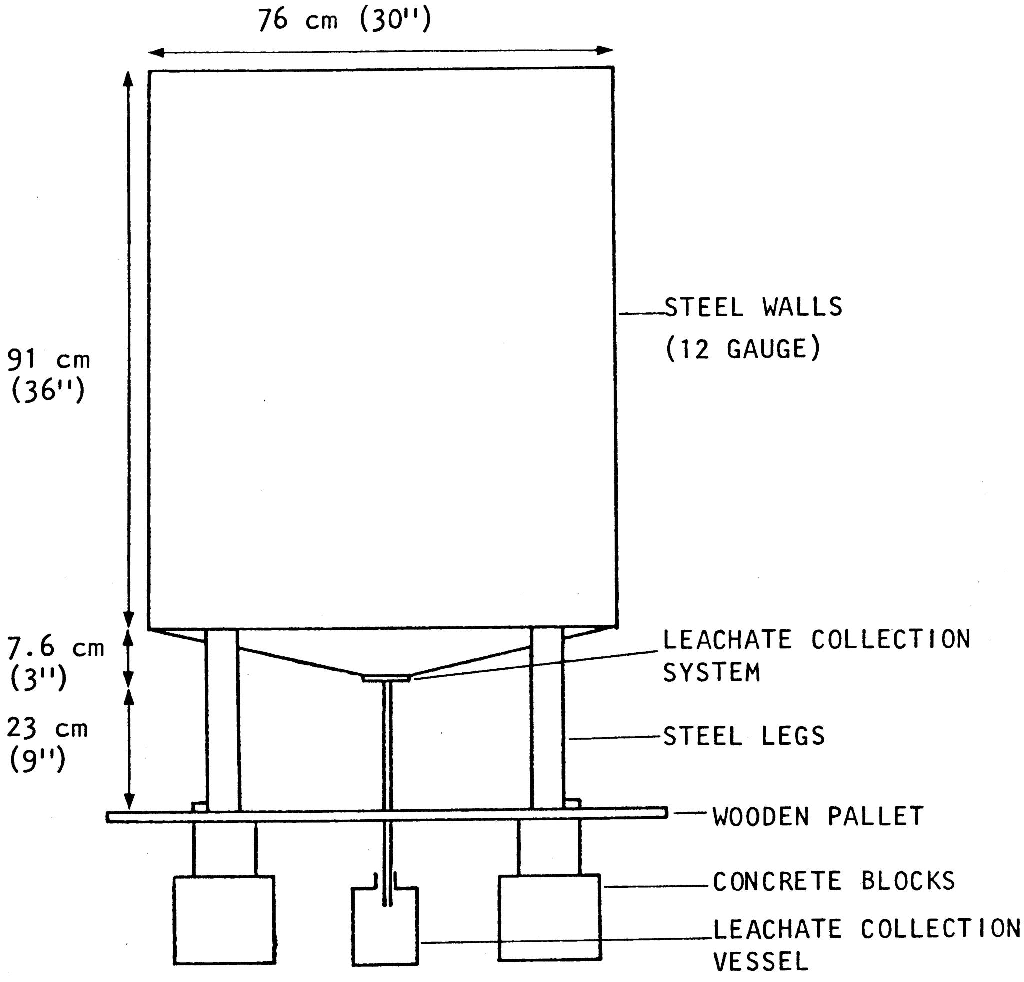

FIGURE 1. Cross-sectional diagram of indoor lysimeter.

4. INDOOR LYSIMETERS

4.1. MATERIALS AND METHODS

Lysimeters were fabricated from 12 gauge steel according to specifications indicated in Figure 1. The inside surfaces of the lysimeters were coated with epoxy resin to prevent chemical interactions between soil and the steel walls. The outside surfaces were painted with white anti-rust paint. The outlet in each lysimeter was fitted with a porous ceramic cup (1 bar entry value) for collection of drainage water (Figure 2). Tubing with 3 mm pores with polyester cloth was also fitted into the outlets to drain off free water. A column of water in a 50 cm length of plastic tubing (5 mm I.D.) connected to the porous cup produced a constant 50 mbar tension on the soil at the bottom of the lysimeter.

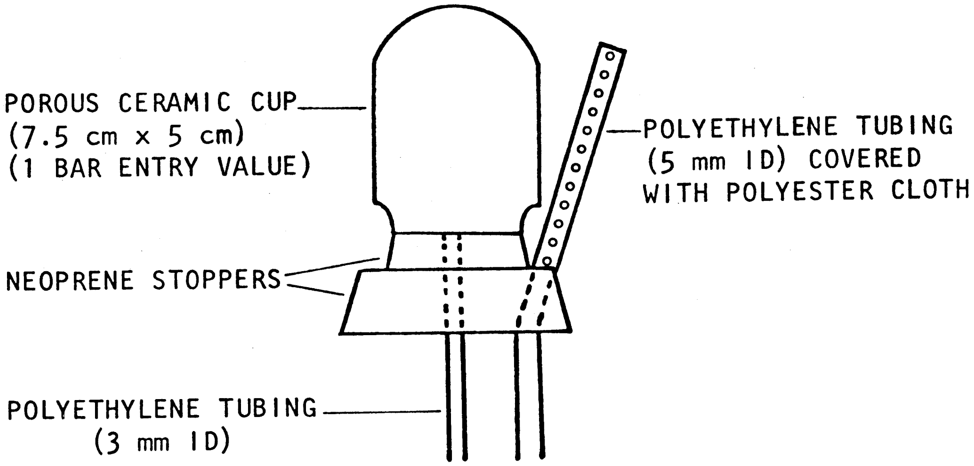

FIGURE 2. Cross-sectional diagram of leachate collection system in indoor lysimeters.

The lysimeters were filled with tailings sand and treated as follows, in duplicate:

(1) control - tailings sand without treatment
(2) glacial till mixed into top 15 cm at a 1:4 (w/w), 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 depths
(5) mesic peat mixed into top 15 cm at a 1:20 (w/w), peat:sand ratio.

Properties of the peat and glacial till used in the treatments are given in Table 1.

The lysimeters were installed indoors in early spring, 1976, and distilled water was applied to begin leaching. They were moved outdoors in May, 1976, and one set of the duplicate treatments was sown with brome grass at a rate of 10 kg/ha and fertilized with N, P, K and S at rates of 100, 40, 100 and 10 kg/ha respectively. Except for occasional artificial application of water until mid-June, rainfall was the only source of water.

Tensiometers were placed at 10 and 20 cm depths in all lysimeters and at 50 and 75 cm depths in only a few. Leachate was collected weekly or bi-weekly and stored at 2-3 C. A few drops of toluene were added to leachate collection bottles to retard microbial activity. Determinations of pH, conductivity, C, N, P, Ca, Mg, Na, K, Fe, Mn, Si, Al, Cl, and SO_4 were made according to methods in the "Manual on Soil Sampling and Methods of Analysis" (McKeague, 1976).

4.2. RESULTS AND DISCUSSION

4.2.1. Leachate analysis

Phosphate, chloride and aluminum were not detected in leachates from any of the lysimeters. Traces of nitrate and ammonium were detected in only a few leachate samples. The concentrations of Ca, Mg, Fe and Mn increased slightly with amount of leaching. Concentrations of K, and particularly of Na and SO_4

(Figures 3, 4 and 5) decreased somewhat. The pH of leachates from all treatments showed only a slight drop and conductivitiy decreased in most treatments (Figures 3, 4 and 5). The data show that Na and SO_4 are being relatively rapidly removed from all tailings sand treatments whereas other ions, particularly the divalent cations, are retained (Appendix 1). Since these ions are essential plant nutrients, their retention in the soil would be beneficial. Nevertheless, they are being removed by the leaching process and with time, these nutrients could be depleted.

4.2.2. Plant growth

Although all treatments received a blanket fertilizer application as mentioned above, the growth of brome grass in the lysimeters was tallest and most dense in tailings sand with peat mixed into the surface. Growth in pure tailings sand and in treatments with buried till layers was relatively good, but growth in the treatment with till mixed into the surface was sparse and plants were small. These observations through the summer were substantiated by determinations of dry weights of plant tops harvested in early October (Table 2). The pH of the top 5 cm of soil was determined at the time of harvest to determine if it might be a factor in plant growth (Table 2). The pH had dropped from that of tailings sand (8.3) in all treatments, but it remained at the high level of 8.0 in the till surface amendment.

TABLE 2. Dry matter production and pH of soil surface in indoor lysimeters

Lysimeter Treatment	Weight of brome grass (g)	pH
1. Control	116	7.0
2. Surface till	62	8.0
3. One till layer	106	6.8
4. Two till layers	116	6.7
5. Surface peat	128	6.0

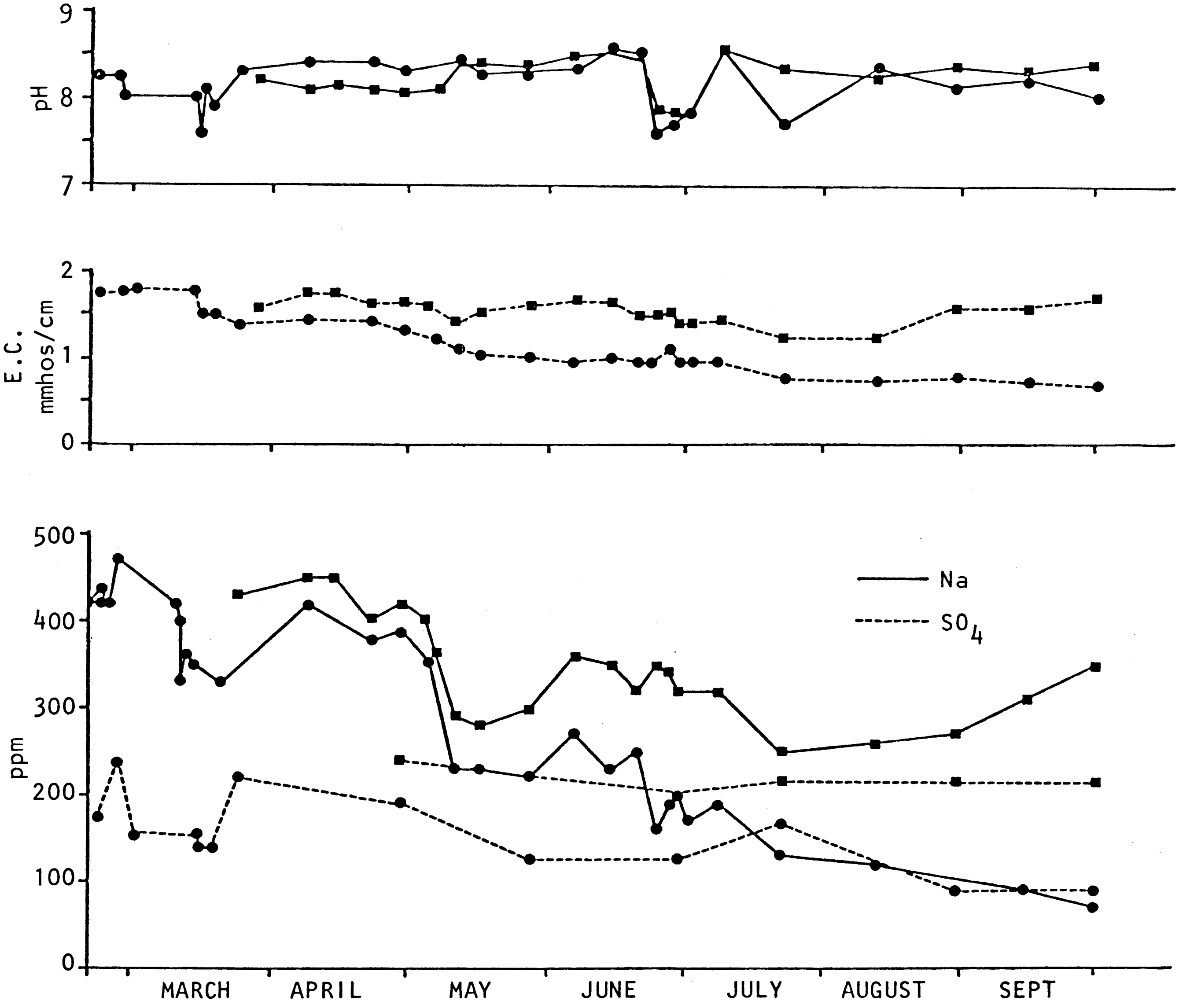

FIGURE 3. Changes in pH, conductivity, and Na and SO_4 contents with time in untreated tailing sand with (boxes) and without (circles) brome grass.

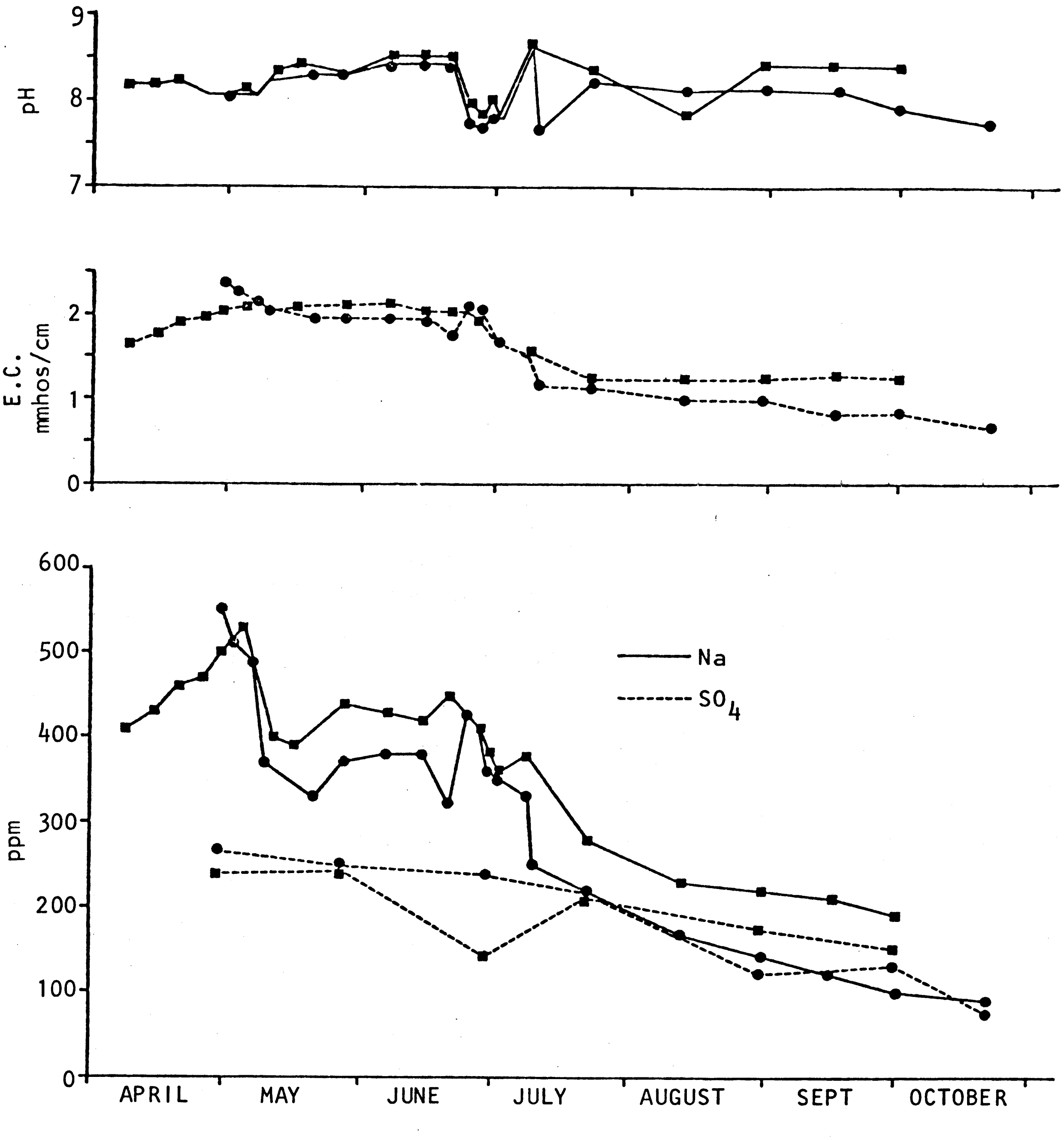

FIGURE 4. Changes in pH, conductivity, and Na and SO_4 contents with time in tailing sand mixed with glacial till with (boxes) and without (circles) brome grass.

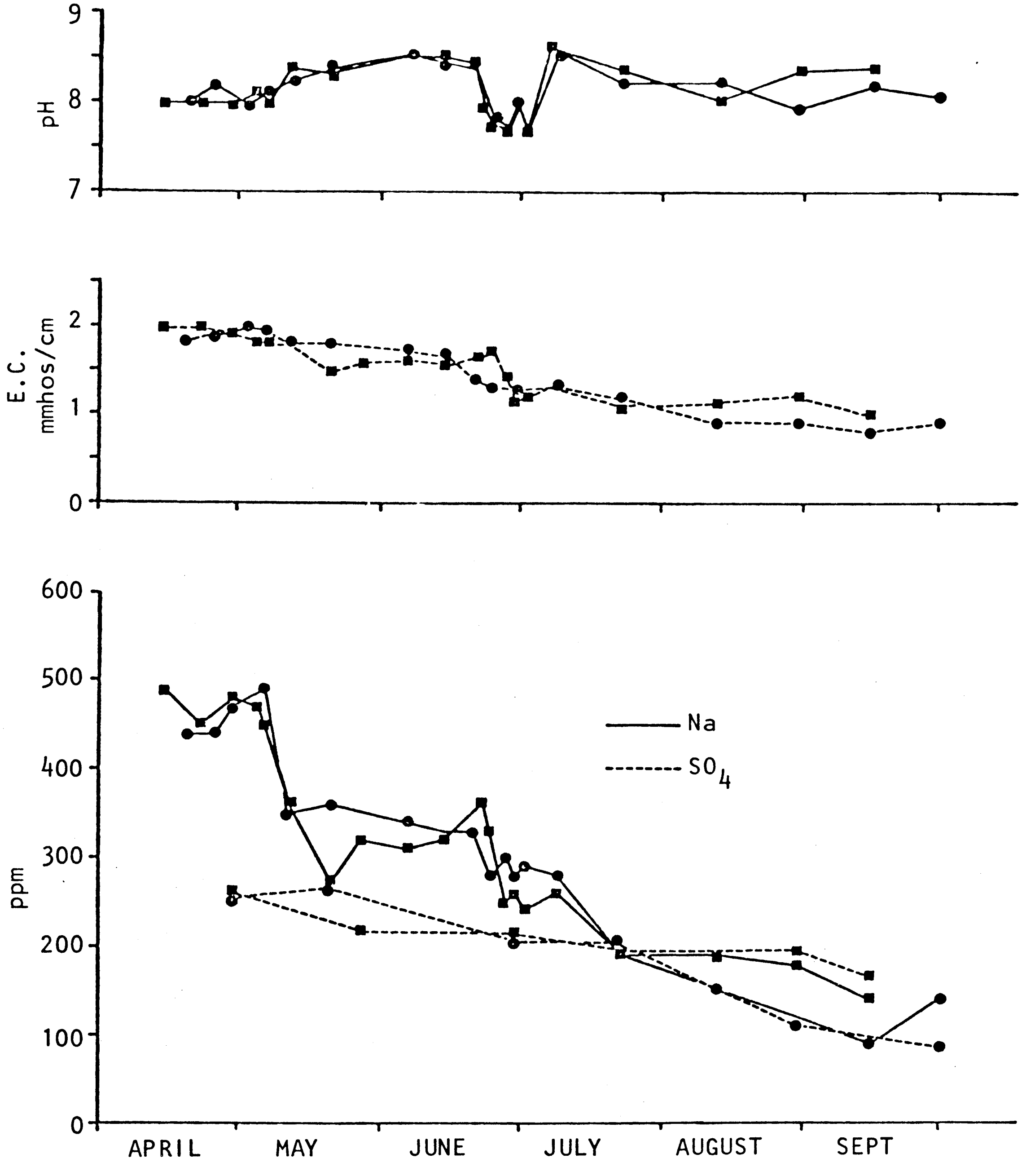

FIGURE 5. Changes in pH, conductivity, and Na and SO_4 contents with time in tailing sand mixed with mesic peat with (boxes) and without (circles) brome grass.

The effect of pH on nutrient availability may be one factor that caused poor growth. Throughout the growing season, leaves of brome grass in the surface till treatment showed purple coloration, possibly indicating P deficiency. A possibility which requires further investigation involves the effect of Na in tailings sand on dispersion of clay in the glacial till; this can result in temporary water saturation of the soil surface and in formation upon drying of a dense, impervious surface unsuitable for plant growth.

The pH of the soil surface in all lysimeter treatments except Treatment 2 dropped rather rapidly, considering that the period of leaching was only eight months. The intensity of leaching, in terms of the amount of water received, was 55 cm (22 inches). This is approximately double the precipitation during the growing season at Ft. McMurray. The drop to pH 6.0 in Treatment 5 indicates that the peat itself, in addition to the leaching effect, has contritubed to the acidity of the surface. On the other hand, the till in Treatment 2 apparently contributed to maintaining the surface pH at a high level. Interactions of sand-till-peat mixtures would be interesting to study in this regard. Also, studies should include determinations of soil and leachate pH at various depths in the lysimeters to obtain a more complete understanding of its effect on plant growth; such measurements will be included in future experimentation.

4.2.3. Soil moisture tension

The soil moisture tension in lysimeters without plants did not rise above 50 mbar and was normally below 25 mbar throughout the period of leaching from March to October, 1976. Moisture tensions in lysimeters sown with brome grass, on the other hand, varied greatly, particularly near the end of the growing season (Table 3). The driest conditions were attained in the surface peat treatment. After a period of rainfall, moisture tensions in all lysimeters were low. During drier periods, tensions increased considerably in all but Treatment 2. The moisture tensions increased to high levels in all treatments at the time of harvest on October

TABLE 3. Soil moisture tensions at various depths in indoor lysimeters sown to brome grass.

Date		Precipitation (cm)	Soil Moisture Tension (mbar)											
			Treatment 1				Treatment 2		Treatment 3		Treatment 4		Treatment 5	
			10 cm	20 cm	50 cm	75 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm
Feb.-March[1]		3.95	25-40	20-27	10-16	8-13	38-60	15-30	22-25	15-19	30-51	20-25	30-47	20-29
April[1]		7.89	16-29	13-25	<10-14	<10	<20-28	10-27	<20	<10-17	<20-23	10-20	17-50	13-29
May[1]		7.13	<20-31	10-27	<10-16	<10	<20-35	<10-36	<20-30	<10-25	<20-28	11-20	20-34	16-24
June[1]		15.44	<20-30	<10-22	<10-18	<10	<20-40	<10-32	<20-34	<10-26	<20-29	<10-24	<20-40	<10-26
July	1	0.54												
	2	-	<20	16	6	11	<20	21	<20	20	<20	16	<20	13
	4	0.38												
	7	-	32	16	8	14	36	24	29	22	30	18	36	25
	9	0.48	30	18	8	11	30	24	28	22	30	18	32	23
	10	0.02												
	12	0.02	30	20	3	11	31	23	33	21	35	29	32	21
	13	0.16												
	14	0.15												
	17	0.28												
	18	0.04												
	21	0.20												
	23	-	83	27	11	7	66	29	35	28	35	20	450	310
	26	0.05												
	27	0.84												
	28	0.63	<20	33	17	8	<20	45	<20	44	<20	44	26	19
	29	0.01												
	30	0.54												
	31	2.65												

(continued)

TABLE 3 (continued)

Date	Precipitation (cm)	Soil Moisture Tension (mbar)											
		Treatment 1				Treatment 2		Treatment 3		Treatment 4		Treatment 5	
		10 cm	20 cm	50 cm	75 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm
Aug. 3	0.82												
4	0.50	<20	20	8	8	<20	23	<20	26	20	20	23	<44
6	0.01												
7	0.08	45	25	9	3	31	23	39	29	37	23	19	11
8	0.41												
9	0.35												
10	tr	101	76	10	3	32	30	50	66	32	70	484	502
13		444	258	10	0	52	34	225	183	381	297	648	596
16	1.67												
17	0.74												
18	0.04												
19	0.37												
20	0.07												
22	0.02												
23	tr	325	229	18	7	64	42	86	590	192	515	584	484
24	0.02												
25	1.72												
26	0.87												
30	0.02												
31	-	454	108	35	11	54	32	82	270	231	206	656	587
Sept. 1	1.35												
5	1.46												
6	0.33												
7	0.13	<20	<10	56	21	<20	<10	<20	<10	<20	16	26	22
10	-	58	40	68	23	34	26	38	50	44	40	294	174
11	0.70												

(continued)

TABLE 3 (continued)

Date	Precipitation (cm)	Soil Moisture Tension (mbar)											
		Treatment 1				Treatment 2		Treatment 3		Treatment 4		Treatment 5	
		10 cm	20 cm	50 cm	75 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm
Sept. 12	0.19												
16	-	632	391	103	21	50	38	53	282	88	394	504	368
23	0.17												
24	0.04												
29	0.03												
Oct. 1	-	756	674	420	47	755	576	682	404	738	645	835	765
2	0.57												
3	0.27												
7	-	710	265	235	30	-	-	-	-	705	610	804	757
13	0.42												
18	tr												
22	tr												
23	tr												

---

[1] Total precipitation and range of tensions for whole month.

7, which occurred after a relatively lengthy, dry period. It is not possible to relate the moisture tension data directly to the type of treatment in each cylinder; in fact, the moisture tensions are probably more directly related to the amount of growth of brome grass and the resulting higher or lower rates of water uptake by the plants. A water balance study is needed, therefore, to determine difference in water storage capacity among the various treatments.

4.3. CONCLUSIONS

(1) Ions in the soil solution of tailings sand and of sand amended in various ways were removed rather rapidly under intense leaching conditions.

(2) The pH of the surface of tailings sand or tailings sand mixed with peat decreased rapidly. However, the pH of leachates decreased only slightly after 8 months leaching.

(3) With fertilization, the highest yields of brome grass were obtained from tailings sand mixed with peat. Mixing glacial till with tailings sand appeared to have a detrimental effect on plant growth during the first season of growth.

4.4. IMPLICATIONS AND RECOMMENDATIONS

The leaching of Na and SO_4 is a desirable process since their initially high concentrations in the soil solution may be detrimental to healthy plant growth. However, loss of other nutrient elements is undesirable. Means of preventing leaching losses of these elements should be investigated. The treatments discussed in this report may, over the long term, have such an effect.

Although a mixture of glacial till and tailings sand resulted in poor growth of brome grass, even with fertilization, it must be emphasized that results over the long term may be quite different. The clay and carbonate components of glacial till are considered to be potential sources of nutrients and of nutrient retaining capability; for this reason, continued and intense study of interactions between tailings sand and till, as well as peat, are considered essential.

Because the effectiveness of the soil treatments in conserving soil water could not be ascertained, additional measurements in combination with tensiometers will be required.

4.5. NEED FOR FURTHER STUDY

Lysimeters are being used for long term studies with measurements discussed in this report to be continued in the future. The lysimeters were moved indoors again in November, 1976, and all further investigations will be carried out under artificial lighting (installed in January, 1977). The five lysimeters presently without plant growth will also be sown with brome grass. It is expected that at least two growing seasons, with two harvests per growing season, can be simulated during one year.

The present method of leachate collection is unsatisfactory for providing detailed information about ion movement in the soil solution. Leachate collected at the bottom of a lysimeter provides no information about changes with depth in ion concentrations, pH, etc. For this reason, micro-samplers for soil solution will be installed at various depths in at least a few lysimeters.

Tensiometer measurements will be supplemented by psychrometer measurements in the soil surface. Plant samples will be analyzed in order to determine nutrient balance in the lysimeters. Changes in organic matter, clays and soil structure are long term processes and will be studied after several seasons of leaching and plant growth in the lysimeters.

5. OUTDOOR LYSIMETERS

5.1. MATERIALS AND METHODS

The outdoor lysimeters installed at the AOSERP field camp at Mildred Lake are 122 cm (4 feet) deep x 91 cm (3 feet) diameter, open-ended cylinders made from 0.64 cm (0.25 inch) fiberglass. The cylinders were installed by placement in an excavation, filling in with tailings sand amended in various ways, and filling in between lysimeters with sand removed from the excavation. They were installed in two rows of five cylinders spaced 90 cm apart and with 5 cm left protruding above the soil surface. The material below the lysimeters is fluvial sand, and the lysimeters are located in the NW corner of a 5 acre clearing. This site was selected in order to provide minimum interference to drainage of lysimeter water into the underlying material. The five duplicated lysimeter treatments are:

(1) control - tailings sand without treatment
(2) mesic peat mixed into the top 30 cm of tailings sand (1:1 (v/v) peat:sand ratio)
(3) glacial till mixed into the top 30 cm of tailings sand (1:5 (v/v) till:sand ratio)
(4) glacial till plus mesic peat mixed into the top 30 cm of tailings sand (in above ratios)
(5) mesic peat mixed into tailings sand surface (as in Treatment 2) plus 5 cm glacial till layered at 45-50 cm from the soil surface.

The lysimeters have been fitted with water samplers (otherwise known as tension lysimeters) at the 100 cm depth, thermocouples at various depths and with neutron probe access tubes for moisture content determinations. Sowing with a grass-legume mixture, fertilization, and installation of tensiometers, psychrometers and platinum electrodes for measuring redox potential will be carried out in spring, 1977.

5.2. COMMENTS

The objectives of the outdoor lysimeter studies are much the same as those of the indoor lysimeters. Although they will provide less detailed information than the indoor lysimeters, they will serve as a bridge between the indoor lysimeters and larger scale field conditions. Information about leaching characteristics will not be as detailed as in the indoor lysimeter experiments, but with the greater amount of monitoring equipment installed, more detailed information about soil physical conditions should be obtained. It is anticipated that useful results can be obtained from measurements over 3 growing seasons, but measurements should continue for as long as possible.

6. NUTRIENT CYCLING STUDIES

6.1. EXPERIMENT 1

6.1.1. Objective

Determination of natural mineralization and immobilization under natural conditions from forest litters. Mineralization, the transformation of organic N forms to the plant available mineral form, and immobilization, the utilization of mineral N by plants and microorganisms and conversion to an organic form, are major components of the N cycle. Much N in forest soils is tied up in the litter layers. Determination of the rates of these processes and the quantities of N involved are the objectives of this study.

6.1.2. Materials and methods

Open-ended cylinders, 30 cm x 30 cm, were made from 16 gauge steel and were provided with 2 holes near the top (2 cm diam.) to facilitate insertion and removal from the soil. Nitrogen was applied in the form of $(^{15}NH_4)_2SO_4$ (95 atom % excess) at a rate providing 0.0366 g N per cylinder.

The experimental design included a control, 1 treatment, 3 sampling dates and 4 replicates at each of 4 sites. Sixteen cylinders were inserted 25 cm into the soil and 30 cm apart in a 4 x 4 grid at each site. Sites were selected under stands of pine (*Pinus banksiana*), aspen (*Populus tremuloides*), white spruce (*Picea glauca*) and mixed wood.

The $(^{15}NH_4)_2SO_4$ was diluted to 400 ml and applied with syringes just below the surface and in the middle of the litter layer. The controls were sampled and N was added to the microplots in mid-June, 1976. Replicates were sampled in July, August and September. Sampling consisted of separation of live plant tops, fresh litter (L layer), partly- and well-decomposed litter (FH layer), litter-Ae interface, Ae horizon and AB or B horizons. All samples were subdivided into >2 mm and <2 mm fractions and roots were separated into small (<1 mm diam.) and large (>1 mm diam.) sizes. Samples were ground prior to analysis.

Total nitrogen was determined by the semi-micro Kjeldahl method and ammonium and nitrate by steam distillation after treatment with MgO and DeVarda's alloy, respectively (McKeague, 1976). A Micro-mass 602C mass spectrometer was used for ^{15}N determinations in total N, nitrate and ammonium distillates. Total carbon was determined with a Leco induction furnace (McKeague, 1976).

6.2. EXPERIMENTS 2, 3 AND 4

6.2.1. Objectives

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.

Experiment 3: Study of the effect of time of N application on its efficiency of uptake by an established stand of a grass-legume mixture in tailings sand amended with peat.

Experiment 4: Determination of decomposition rates of ^{14}C- and ^{15}N-labelled plant materials added to sand-peat mixtures in the field.

6.2.2. Materials and methods

A plot of reclaimed tailings sand with a level surface was established for these experiments. The plot is 10 m x 7 m x 1.5 m deep, is laterally separated from the surrounding soil with polyethylene sheeting, and is separated into 3 compartments. An area of deep fluvial sand was chosen for the plot so that drainage from the tailings sand would not be hindered by the underlying material. Tailings sand in the 3 compartments was treated as follows: (1) mesic peat mixed into the top 30 cm (1:1 (v/v) ratio); (2) glacial till plus peat mixed into the top 30 cm (1:5 and 1:1 (v/v) ratios respectively); (3) mesic peat mixed into the surface as in (1) plus a till barrier placed at the 45-50 cm level. The plot was sown with brome grass, creeping red fescue and crested wheat grass at rates of 5 kg/ha and with alfalfa, sweet clover and alsike clover at rates of 10 kg/ha. Application of N, P, K and S was made at rates of 100, 40, 100 and 10 kg/ha respectively.

The plot design for Experiment 2 consists of the 3 soil treatments described, 9 sampling dates and 4 replicates. In the spring of 1977, microplots of soil will be isolated by means of 61 cm (2 foot) by 20 cm (8 inch) cylinders. Labelled N will also be added at this time and sampling will proceed over two growing seasons. Plants, litter and mineral soil will be fractionated and analyzed for total N, NH_4-N, NO_3-N and ^{15}N levels.

Experiment 3 consists of 3 times of N application, 3 sampling dates during 1977 and 4 replicates. Cylinders, as described above, will be used to isolate micro-plots in the peat amended soil. Sampling and analysis will be carried out as described for Experiment 2.

The design of Experiment 4 involves 1 treatment, 8 sampling dates and 4 replicates. Installation of cylinders and sampling will be carried out as described above in a portion of the plot amended with peat in the surface. Tops of brome grass labelled with ^{14}C and ^{15}N will be added to the soil surface in spring, 1977, and sampling will be carried out at intervals until June, 1978, or possibly until May or June, 1979.

6.3. EXPERIMENT 5

6.3.1. Objective

Determination of the effect of glacial till and peat on rate of remineralization of immobilized N in sand-till, sand-peat and sand-till-peat mixtures.

6.3.2. Materials and methods

Approximately 1 kg of sand-till, sand-peat and sand-till-peat mixtures in various proportions will be incubated with and without PKS fertilization after addition of ^{14}C-acetate and $(^{15}NH_4)_2SO_4$. At 13 intervals up to 20 weeks after start of incubation, samples will be removed for determination of ^{14}C count, mineral N and ^{15}N, total N, and nature of C and N compounds and their complexing with clay.

6.4. EXPERIMENT 6

6.4.1. Objective

Study of the rate of N turnover through established grasses (mainly fescue) on steep slopes of tailings sand. The experiment is designed to determine the rate at which N consumed by plants is converted to organic matter and remineralized in the soil for succeeding crops.

6.4.2. Materials and methods

The experimental site is located on the ENE side of the GCOS dike just above the first berm. The area has been vegetated for 5 years. The experimental design consists of 1 treatment, 8 sampling dates and 4 replicates. Cylinders (60 cm long and 20 cm diam.) were pushed into the soil in 4 rows of 8 cylinders each with about 1 m between cylinders and 3 m between rows. Mineral-N in the form of $(NH_4)_2SO_4$ labelled with ^{15}N (10 atom % excess) was added at a rate equivalent to 50 kg N/ha.

Sampling at intervals from July, 1976 to September, 1977, consists of removal of cylinders with soils intact and separation of live tops, standing dead tops, litter on the soil surface, peat layer, mineral soil to 30 cm and mineral soil from 30-60 cm. Plant roots will be separated from the various layers and analysis will be carried out for total N, NH_4-N, NO_3-N and ^{15}N levels in these.

6.5. COMMENTS

As already indicated, Experiments 1 and 6 were initiated in summer, 1976 and some results should be obtained by the middle of 1977. The plot for Experiments 2, 3 and 4 was prepared in fall, 1976. Experiment 5, to be conducted in the laboratory, will begin in winter, 1977. Although emphasis is being placed on the N nutrition problem in tailings sand reclamation, incorporation of P and K studies in the experiments described above is being planned. They will be designed to determine whether peat and till additions to tailings sand contribute to P and K status, how they interact, and at what rates they cycle through the soil-plant system. Similar investigations in relation to micronutrient elements are also being considered.

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8. APPENDICES

8.1. LEACHATE ANALYSIS OF INDOOR LYSIMETERS[1]

LYSIMETER 1

Date	pH	E.C. (mmhos/cm)	C (µg/ml)	Si (µg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
Mar. 29	8.20	1.6	54	3.6	38	18	430	22	0.1	0.4	
Apr. 9	8.10	1.7	62	4.1	40	18	450	22	0.0	0.5	
Apr. 15	8.15	1.7	74	4.0	43	19	450	22	0.0	0.5	
Apr. 23	8.10	1.6	80	4.0	47	22	400	21	0.0	0.5	
Apr. 30	8.05	1.7	61	4.0	60	26	420	24	0.1	0.6	240
May 5	8.10	1.6	66	4.0	57	25	400	21	0.2	0.6	
May 7	8.10	1.6	60	3.8	54	21	360	21	0.1	0.6	
May 12	8.36	1.4	66	4.9	52	24	290	19	0.2	0.5	
May 17	8.39	1.6	78	4.2	56	25	280	19	0.1	0.6	
May 28	8.38	1.6	78	4.2	56	25	300	17	0.0	0.5	222
June 7	8.49	1.7	81	4.2	57	26	360	19	0.1	0.5	
June 15	8.51	1.7	87	4.6	58	25	350	18	0.1	0.5	
June 21	8.43	1.5	75	4.6	51	24	320	18	0.1	0.4	
June 25	7.89	1.5	75	4.5	56	29	350	18	0.3	0.4	
June 28	7.86	1.6	78	4.9	58	29	340	19	0.3	0.5	
June 30	7.84	1.4	81	5.3	52	26	320	20	0.1	0.5	203
July 2	7.82	1.4	82	6.1	53	28	320	20	0.1	0.6	
July 9	8.59	1.5	84	4.2	55	29	320	22	0.4	0.5	
July 23	8.35	1.2	93	2.2	53	27	280	18	0.2	0.2	218
Aug. 13	8.26	1.2	95	9.3	59	31	260	15	0.1	0.4	
Aug. 31	8.37	1.6	107	1.9	69	36	270	21	0.1	0.5	
Sept. 16	8.30	1.6	102	1.9	63	37	310	18	0.1	0.1	
Oct. 1	8.47	1.7	105	1.2	57	39	350	20	0.0	0.0	215

LYSIMETER 2

Date	pH	E.C. (mmhos/cm)	C (µg/ml)	Si (µg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
Apr. 9	8.20	1.7	77	5.9	40	20	410	21	0.0	0.4	
Apr. 15	8.20	1.8	86	6.2	47	23	430	21	0.1	0.5	
Apr. 20	8.25	1.9	92	6.0	55	25	460	23	0.1	0.6	
Apr. 26	8.10	2.0	104	5.7	62	27	470	24	0.2	0.5	
Apr. 30	8.10	2.0	103	5.7	69	31	500	25	0.1	0.5	240
May 5	8.15	2.1	104	5.8	72	32	530	27	0.3	0.5	
May 7	8.10	2.1	117	5.8	74	33	490	25	0.7	0.6	
May 12	8.37	2.0	108	6.4	73	33	400	24	0.3	0.4	
May 17	8.44	2.1	108	3.8	73	33	390	23	0.1	0.4	
May 28	8.34	2.1	117	5.3	74	33	440	21	0.0	0.4	244
June 7	8.56	2.1	111	5.8	72	33	430	21	0.1	0.4	
June 15	8.52	2.0	114	6.8	71	33	420	22	0.2	0.4	
June 21	8.54	2.0	111	5.8	79	33	450	23	0.2	0.4	
June 25	7.97	2.0	108	5.3	71	34	430	23	0.5	0.4	
June 28	7.83	2.0	105	5.8	67	33	410	24	0.4	0.3	
June 30	8.04	1.7	102	7.8	61	31	380	24	0.2	0.4	142
July 2	7.89	1.6	93	7.0	61	32	360	25	0.2	0.3	
July 9	8.66	1.6	93	6.4	56	30	380	23	0.2	0.2	
July 23	8.37	1.2	93	2.2	53	27	280	18	0.2	0.2	215
Aug. 13	7.81	1.2	83	5.5	52	29	230	18	0.1	0.2	
Aug. 31	8.43	1.2	74	2.7	56	29	220	16	0.0	0.2	177
Sept. 16	8.41	1.3	69	3.1	60	31	210	14	0.1	0.1	
Oct. 1	8.39	1.2	64	3.5	60	33	190	16	0.1	0.1	153

LYSIMETER 3

Date	pH	E.C. (mmhos/cm)	C (μg/ml)	Si (μg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
May 7	8.20	2.0	94	4.4	76	25	460	25	0.0	0.8	
May 12	8.28	1.9	96	4.2	76	35	410	23	0.1	0.6	
May 17	8.41	2.0	105	3.6	88	39	380	25	0.0	0.7	
May 28	8.27	2.0	105	5.0	98	46	370	23	0.1	0.7	240
June 7	8.52	2.1	102	4.1	107	51	360	24	0.1	0.8	
June 15	8.48	2.1	108	4.1	110	56	390	25	0.0	0.7	
June 21	8.44	2.1	109	4.4	117	60	380	25	0.3	0.8	
June 25	7.79	2.2	108	4.4	137	70	390	27	0.4	0.9	
June 28	7.77	2.1	114	4.9	125	69	360	24	0.4	0.7	
June 30	7.94	1.8	105	4.4	105	59	340	24	0.1	0.6	258
July 2	7.87	1.8	97	5.2	98	56	320	22	0.1	0.6	
July 9	8.67	1.6	96	3.4	89	53	340	23	0.2	0.5	
July 23	8.39	1.2	86	2.5	72	39	240	16	0.0	0.5	226
Aug. 13	8.42	1.2	77	1.7	59	35	220	11	0.2	0.4	
Aug. 31	8.46	1.3	74	2.0	63	35	220	12	0.0	0.4	182
Sept. 16	8.48	1.2	69	1.6	58	32	220	7	0.1	0.3	
Oct. 1	8.38	1.3	64	1.8	47	35	210	9	0.1	0.1	156

LYSIMETER 4

Date	pH	E.C. (mmhos/cm)	C (μg/ml)	Si (μg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
May 7	8.20	2.2	124	4.8	72	34	520	28	0.0	0.9	
May 12	8.35	2.0	115	4.0	81	39	380	23	0.0	0.9	
May 17	8.41	2.0	120	4.2	83	40	380	23	0.1	0.9	
May 27	8.36	2.0	117	4.0	75	39	360	22	0.0	0.7	251
June 7	8.51	2.0	111	3.8	82	41	380	23	0.0	0.8	
June 15	8.50	2.0	112	4.1	88	43	370	23	0.0	0.8	
June 21	8.48	1.9	108	4.5	87	44	390	22	0.9	0.7	
June 25	7.98	2.1	111	3.8	95	51	400	24	0.4	0.9	
June 28	7.78	2.0	111	4.9	97	54	390	22	1.1	0.8	
June 30	7.99	1.9	108	4.8	93	51	380	25	0.2	0.7	248
July 2	7.96	1.8	105	4.4	88	50	340	24	0.1	0.7	
July 9	8.65	1.8	99	3.6	87	50	370	27	0.0	0.7	
July 23	8.28	1.3	100	0.7	78	44	270	18	0.0	0.6	240
Aug. 13	8.11	1.2	89	1.0	68	39	250	13	0.1	0.5	
Aug. 31	8.17	1.4	80	1.4	69	39	240	12	0.0	0.4	262
Sept. 16	8.34	1.5	77	1.4	64	42	240	11	0.1	0.0	
Oct. 1	8.39	1.5	80	1.4	63	44	240	10	0.0	0.0	206

LYSIMETER 5

Date	pH	E.C. (mmhos/cm)	C (µg/ml)	Si (µg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
Apr. 15	8.00	2.0	110	4.2	54	25	490	24	0.1	0.6	
Apr. 23	8.00	2.0	119	3.5	56	27	450	23	0.1	0.7	
Apr. 30	8.00	1.9	109	3.4	53	25	480	22	0.0	0.6	260
May 5	8.10	1.8	106	3.7	55	20	470	25	0.0	0.6	
May 7	8.00	1.8	102	3.7	50	23	450	24	0.0	0.7	
May 12	8.38	1.7	102	4.4	60	27	360	22	0.2	0.6	
May 21	8.33	1.5	78	3.5	57	26	270	18	0.1	0.6	
May 28	8.40	1.6	94	3.9	60	27	320	19	0.1	0.6	217
June 7	8.52	1.6	93	4.1	61	29	310	20	0.1	0.7	
June 15	8.50	1.6	92	4.3	60	29	320	20	0.1	0.6	
June 21	8.44	1.6	93	4.4	60	29	350	20	0.6	0.6	
June 23	7.98	1.6	93	4.8	59	29	360	23	0.6	0.5	
June 25	7.76	1.7	87	4.4	81	44	330	25	0.5	0.8	
June 28	7.71	1.4	76	4.9	59	30	250	19	0.5	0.5	
June 30	7.99	1.1	62	3.8	63	32	260	23	0.8	0.6	215
July 2	7.68	1.2	81	5.2	67	34	240	22	0.4	0.5	
July 9	8.59	1.3	84	3.7	69	35	260	24	0.2	0.6	
July 23	8.38	1.1	82	2.3	68	35	190	18	0.1	0.5	192
Aug. 13	8.03	1.1	86	3.2	70	35	190	14	0.3	0.5	
Aug. 23	8.38	1.2	56	1.3	74	35	180	17	0.0	0.3	196
Sept. 16	8.40	1.0	-	0.8	49	34	140	18	0.0	0.1	168

LYSIMETER 6

Date	pH	E.C. (mmhos/cm)	C (μg/ml)	Si (μg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
May 5	8.00	2.2	132	4.1	65	32	560	26	0.0	0.8	
May 7	8.10	2.2	126	3.8	61	29	550	27	0.0	0.9	
May 10	8.43	2.0	102	4.1	64	31	440	24	0.0	0.8	
May 21	8.39	1.8	93	3.8	67	33	350	22	0.1	0.8	
May 27	8.24	1.8	96	5.1	56	25	310	18	0.3	0.6	253
June 7	8.55	1.8	84	3.8	73	37	290	20	0.0	0.9	
June 15	8.45	1.6	81	4.2	75	39	320	21	0.1	0.9	
June 21	8.51	1.6	87	5.2	69	36	360	21	1.2	0.8	
June 25	7.80	1.6	84	4.1	78	42	340	22	0.8	0.8	
June 28	7.75	1.7	81	4.4	100	56	290	25	0.9	1.0	
June 30	8.01	1.4	69	4.4	82	56	250	22	0.1	0.8	236
July 2	7.81	1.3	66	4.1	80	47	250	20	0.0	0.7	
July 9	8.64	1.4	69	5.2	83	51	280	19	0.2	0.7	
July 23	8.40	1.2	69	3.0	78	43	190	14	0.0	0.7	206
Aug. 13	8.26	1.1	77	3.8	72	44	210	11	0.3	0.6	
Aug. 31	8.25	1.2	74	1.8	69	41	200	9	0.3	0.4	212
Sept. 16	8.11	1.2	74	0.8	59	35	190	6	0.2	0.3	
Oct. 1	7.99	1.0	64	0.8	57	34	180	7	0.1	0.2	215
Oct. 22	7.88	1.0	55	0.6	42	23	150	8	0.7	0.2	111

LYSIMETER 7

Date	pH	E.C. (mmhos/cm)	C (µg/ml)	Si (µg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
Apr. 20	8.00	1.8	98	4.2	53	25	440	23	0.1	0.6	
Apr. 26	8.20	1.9	101	4.0	55	27	440	23	0.0	0.7	
Apr. 30	8.05	1.9	103	3.9	48	22	470	24	0.1	0.7	253
May 3	8.00	2.0	106	4.0	56	26	480	25	0.4	0.7	
May 7	8.10	1.9	84	3.8	65	31	490	24	0.2	0.7	
May 12	8.23	1.8	96	4.8	62	28	350	22	0.4	0.6	
May 21	8.37	1.8	96	4.1	65	29	360	19	0.2	0.6	268
June 7	8.53	1.7	87	4.4	60	28	340	20	0.3	0.6	
June 15	8.47	1.6	78	4.4	60	27	330	19	0.2	0.5	
June 21	8.39	1.4	86	4.9	60	28	330	21	0.5	0.6	
June 25	7.84	1.3	72	3.9	54	26	280	19	0.4	0.4	
June 28	7.75	1.3	72	4.7	55	27	300	19	0.4	0.4	
June 30	7.99	1.2	75	3.7	57	28	280	21	0.2	0.5	208
July 2	7.67	1.3	69	4.2	59	30	290	26	0.3	0.4	
July 9	8.58	1.3	75	4.4	60	31	280	23	0.3	0.4	
July 23	8.25	1.2	73	2.8	62	30	190	19	0.0	0.2	203
Aug. 13	8.25	0.9	61	5.2	57	29	150	14	0.1	0.3	
Aug. 31	7.95	0.9	53	0.6	58	29	120	9	0.2	0.2	111
Sept. 16	8.19	0.8	55	0.8	64	31	90	13	0.0	0.1	
Oct. 1	8.10	0.9	58	0.6	68	31	140	10	0.1	0.1	89

LYSIMETER 8

Date	pH	E.C. (mmhos/cm)	C (μg/ml)	Si (μg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
Apr. 30	8.10	2.4	128	3.9	77	37	550	29	0.0	1.0	268
May 3	8.10	2.3	129	3.8	73	36	510	30	0.1	1.0	
May 7	8.10	2.1	117	3.7	72	36	490	29	0.0	0.9	
May 10	8.28	2.0	105	3.8	78	37	370	26	0.1	0.9	
May 21	8.31	2.0	102	3.6	77	36	330	21	0.0	0.8	
May 28	8.32	2.0	108	3.7	76	36	370	23	0.2	0.9	248
June 7	8.47	2.0	111	3.5	76	36	380	32	0.2	0.9	
June 15	8.47	1.9	108	3.9	73	35	380	23	0.0	0.7	
June 21	8.42	1.6	82	4.2	64	33	320	21	0.0	0.6	
June 25	7.75	2.1	108	4.8	84	42	430	26	0.6	0.8	
June 28	7.70	2.0	110	3.7	80	42	410	26	0.4	0.8	
June 30	7.84	1.8	90	4.4	77	41	360	28	0.1	0.7	240
July 2	7.85	1.6	99	2.9	69	37	350	28	0.1	0.5	
July 9	8.61	1.5	93	3.1	61	33	330	25	0.1	0.5	
July 11	7.64	1.2	89	7.6	59	29	250	20	0.0	0.4	
July 23	8.26	1.2	113	1.0	48	26	220	17	0.0	0.3	218
Aug. 13	8.13	1.0	74	4.0	55	28	170	18	0.0	0.2	
Aug. 31	8.17	1.0	58	0.4	59	31	140	13	0.0	0.2	124
Sept. 16	8.14	0.8	58	0.8	54	30	120	14	0.0	0.2	
Oct. 1	7.92	0.8	53	0.6	56	30	100	12	0.0	0.1	133
Oct. 22	7.77	0.7	41	0.8	45	23	80	10	0.0	0.1	81

LYSIMETER 9

Date	pH	E.C. (mmhos/cm)	C (μg/ml)	Si (μg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
Feb. 20	8.45	1.5	42	3.7	30	14	350	24	0.0	0.2	174
Feb. 23	8.25	1.8	69	3.7	42	19	420	25	0.0	0.4	236
Feb. 27	8.25	1.8	75	3.8	44	19	440	26	0.6	0.4	224
Feb. 28	8.00	1.8	60	3.8	44	19	420	26	0.1	0.4	232
Mar. 2	8.00	1.8	75	3.5	43	19	420	24	0.2	0.4	228
Mar. 15	8.00	1.8	78	3.2	42	19	470	24	0.2	0.4	158
Mar. 16	7.60	1.5	48	3.4	38	16	400	23	0.1	0.4	156
Mar. 16	7.90	1.4	52	3.4	34	16	330	22	0.2	0.4	126
Mar. 17	8.10	1.5	70	4.2	37	17	360	23	0.3	0.4	140
Mar. 19	7.90	1.5	63	3.8	38	15	350	23	0.1	0.4	140
Mar. 25	8.30	1.4	48	3.7	37	16	330	21	0.0	0.4	220
Apr. 9	8.40	1.5	45	5.0	34	16	420	21	0.1	0.4	
Apr. 23	8.40	1.4	45	5.6	27	15	380	18	0.4	0.1	
Apr. 30	8.30	1.3	34	6.4	30	13	390	18	0.0	0.2	190
May 7	8.40	1.2	54	5.7	29	13	350	18	0.3	0.2	
May 12	8.42	1.1	51	6.5	30	13	230	15	0.2	0.3	
May 17	8.28	1.1	48	5.6	33	13	230	15	0.3	0.2	
May 28	8.32	1.0	51	6.7	34	15	220	16	0.2	0.2	128
June 7	8.34	1.0	45	5.3	38	16	270	14	0.3	0.3	
June 15	8.53	1.0	51	6.0	39	18	230	15	0.2	0.4	
June 21	8.50	1.0	51	6.5	43	19	250	15	0.1	0.2	
June 23	8.00	1.0	48	6.2	53	25	210	16	0.2	0.4	
June 25	7.62	1.1	56	4.6	69	32	160	16	0.2	0.5	
June 28	7.70	1.1	56	6.0	81	38	190	18	0.2	0.7	
June 30	7.78	1.0	57	4.8	77	36	200	20	0.1	0.7	128
July 2	7.83	1.0	60	4.8	72	35	170	20	0.2	0.6	
July 9	8.57	1.0	51	6.0	69	34	190	20	0.0	0.6	
July 23	7.69	0.8	69	1.7	56	28	130	12	0.2	0.5	169
Aug. 13	8.35	0.8	50	3.4	53	25	120	11	0.0	0.4	
Aug. 31	8.13	0.8	41	1.6	51	26	100	11	0.1	0.4	90
Sept. 16	8.22	0.8	42	1.2	57	28	90	11	0.0	0.4	
Oct. 1	8.03	0.7	36	0.7	40	22	110	9	0.1	0.1	90

LYSIMETER 10

Date	pH	E.C. (mmhos/cm)	C (µg/ml)	Si (µg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO$_4$ (ppm)
May 5	8.00	2.6	121	4.4	83	40	630	34	0.0	0.8	
May 7	8.10	2.5	99	4.5	83	38	590	35	0.0	0.8	
May 14	8.28	2.3	123	4.5	99	50	430	31	0.0	0.9	
May 21	8.42	2.3	120	4.0	104	51	430	28	0.2	0.9	297
June 7	8.53	2.3	123	4.4	98	51	420	25	0.1	0.8	
June 15	8.52	2.3	120	4.9	100	52	430	24	0.1	0.9	
June 21	8.55	2.2	112	5.3	95	52	440	25	0.0	0.8	
June 25	7.84	2.0	110	5.0	87	46	390	22	0.8	0.7	
June 28	8.00	1.7	74	5.2	72	40	360	19	0.3	0.6	267
June 30	8.05	1.4	51	4.6	58	33	280	18	0.2	0.4	
July 2	8.05	1.4	71	4.1	62	36	290	20	0.0	0.4	
July 9	8.66	1.4	72	4.8	63	29	300	19	0.2	0.4	
July 23	8.33	1.2	58	5.4	60	35	220	12	0.1	0.4	215
Aug. 13	8.31	1.2	82	2.7	61	36	220	12	0.1	0.3	
Aug. 31	8.35	0.9	55	1.2	41	24	160	6	0.1	0.1	210
Sept. 16	8.12	0.8	93	0.7	42	23	110	7	0.1	0.1	
Oct. 1	8.05	0.7	36	0.7	40	22	110	9	0.1	0.1	58
Oct. 22	7.96	0.7	41	5.8	37	21	110	6	0.6	0.1	52

RAIN SAMPLES

Date	pH	E.C. (mmhos/cm)	C (µg/ml)	Si (µg/ml)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Fe (ppm)	Mn (ppm)	SO_4 (ppm)
June 15	6.25	0.02	0	1.9	0.9	0.1	0.8	0.4	0.0	0.0	-
June 21	6.46	0.02	0	3.3	0.7	0.1	1.0	0.7	0.0	0.0	-
June 25	5.88	0.01	0	2.2	0.1	0.02	0.3	0.2	0.0	0.0	-
June 28	5.68	0.09	0	1.6	0.03	0.04	0.3	0.1	0.0	0.0	-
July 9	5.68	0.02	0	1.2	0.6	0.2	0.6	0.3	0.0	0.0	-
July 23	6.72	0.08	0	2.2	1.2	0.4	0.6	0.8	0.0	0.1	0.7
Aug. 3	6.12	0.07	0	0.1	0.6	0.1	0.1	0.2	0.0	0.0	-
Aug. 13	5.05	0.03	0	0.1	0.6	0.2	0.1	0.2	0.0	0.0	0.0
Aug. 31	5.83	0.01	0	0.1	0.6	0.1	0.08	0.09	0.0	0.0	0.0
Sept. 10	5.92	0.07	0	0.3	0.6	0.1	0.07	0.1	0.0	0.0	0.8
Sept. 16	6.19	0.04	0	0.2	1.0	0.1	0.08	0.2	0.0	0.0	-

[1] Lysimeters 1 and 9 - No treatment

Lysimeters 2 and 8 - Till surface treatment

Lysimeters 3 and 6 - One subsurface till layer

Lysimeters 4 and 10 - Two subsurface till layers

Lysimeters 5 and 7 - Peat surface treatment

Lysimeters 1-5 are with, and 6-10 without, brome grass.

PART III. SULPHUR DEPOSITION AND ACIDIFICATION OF SOILS IN THE OIL SANDS AREA

S.K. TAKYI

M. NYBORG

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ABSTRACT

In the soil sub-project on the effects of sulphur dioxide evolution on soils of the Oil Sands area, the first full year was directed toward evaluation of potentially damaging situations in order to establish future monitoring and research needs. Sites were established around the sulphur dioxide emission source, some over 170 km away. Data collection devices were constructed at these sites for present and future field research needs.

Estimates were made of the amounts of sulphur deposited in the soils by various means (wet deposits, dry deposits, and deposits in snow) at the research sites in the Oil Sands area and at remote (control) sites. With only one Oil Sands processing plant presently in operation, sulphur deposits in the very close vicinity of the emission source, were relatively higher. Wet deposits (incident rain and intercepted rain) contained larger proportions of sulphur than particulate deposits or deposits in snow. The ranges in pH values of the 15-day samples of incident rains (straight rain) suggest that some rains were acid at some sites. The average pH value of the incident rains, however, was not acid.

Sulphur content increased and pH decreased in samples of bare soils and peat set out under rain shelters at the sites. Soil samples, mosses and lichen (which are an important component of the forest floors of the Oil Sands area) exposed to low concentrations of sulphur dioxide in the laboratory exhibited a similar trend. The implication, as indicated by the depressed pH values and increased sulphur content, is that the long-term effects of sulphur fall-out in the Oil Sands area could pose an environmental problem.

Microplots, aimed at long-term studies of acidification and other changes in the physicochemical properties of the native soils at the research sites, were laid out and sampled. Lysimeters with two soils from the Oil Sands area were set up at nine of the research sites to study sulphur movements through the soils and the leaching of plant nutrients resulting from soil acidification caused by acid rains.

1. INTRODUCTION

Associated with the present development of the Oil Sands and the possibility of more development in the near future is the increased production of industrial air pollutants that are harmful to the ecosystem of the Oil Sands area. An industrial air pollutant of major concern in the area is the sulphur dioxide gas emitted by the processing plants. The main hazard associated with this gas is the possible detrimental effects of acid precipitation on the entire ecosystem. Of particular concern in terrestrial systems is the possible effects of the sulphur dioxide gas itself on vegetation and of the associated acid precipitation on the growth of forest trees and other smaller plant species and on the production potential of the forest.

The soil eventually receives all this pollutant, including that deposited directly in rainfall, snow, and dry deposits and that initially intercepted by the vegetative cover. Resultant effects on the soil may eventually alter the growth and production potential of forest trees and the growth of the forest floor vegetation of the Oil Sands area. The main impact of the sulphur dioxide pollutant to be expected in the soils of the Oil Sands area involve changes in the chemistry and biology of the soils and peat lands. These changes may lead to increased leaching of plant nutrients and other elements and to lowering of pH and base saturation values; generally, the physicochemical properties of the soils are altered.

Presently, the main activities of the project are the estimation of the amounts of sulphur deposited in the soils of the Oil Sands area and the determination of changes in soil acidity levels and other physicochemical soil changes that may adversely affect plant growth, the production potential of forest trees, and the growth of forest floor vegetation. After evaluating potential damage to the soil-plant system in the Oil Sands area by the sulphur dioxide pollutant, the main objective of the project will be to initiate studies of countermeasures to prevent or minimize soil damage.

2. BRIEF REVIEW OF PRESENT KNOWLEDGE

Combustion of fossil fuel for energy for home and industry has led to increases in sulphur dioxide emissions, which have been the main cause of acid precipitation and dry deposits of some acid-bearing particulates. Soils generally can tolerate considerable amounts of sulphur deposits (for example, from the use of acid forming sulphate-bearing fertilizers such as ammonium sulphate) without much damage. However, continuous additions as pollutants in the native soil-plant systems such as in the Oil Sands area could lead to permanent changes in at least the vegetative cover. In agricultural soils, acidity caused by the use of sulphur-based fertilizers such as ammonium sulphate is readily corrected with lime. In the natural system, such as in forested areas, the task of rectifying damaged soils may be more difficult because of the more complex natural ecosystem involved.

Precipitation chemistry has indicated that acid rains are a major environmental concern in industrialized areas of the world. In the Scandinavian countries it has been emphasized that acidity in precipitation is increasing in recent years (Dovland *et al*, 1976). Most of the deposited sulphur in Norway is believed to have originated from industry elsewhere in western Europe; the mean pH of precipitation has been recorded in some areas of Norway to be as low as 4.3, and pH values as low as 3.5 have been recorded.

In forest throughfalls (Ulrich, 1968; Nihlgard, 1970; Horntvedt and Joranger, 1974; and many others), there is an enrichment of some elements as precipitation goes through the canopy, and concentrations of these elements increase as the acidity of the incident rain increases. Also, the incident rain washes off the dry deposits in the forest canopy, including sulphur. In stemflow studies, Carlisle *et al.* (1965) have indicated that concentrations of elements in stemflow water were relatively high. In lysimeter studies, Abrahamsen *et al.* (1976) observed that with increasing acidity of simulated acid rain the moss cover died out when the pH of the "rain" was lower than 3.

Soils have a substantial capacity for the sorption of sulphur dioxide gas (Smith *et al.*, 1973, and Bremner and Barnwart, 1976), and as such soil is an important natural sink for the gas and other gaseous atmospheric pollutants (Bremner and Barnwart, 1976). However, in the maintenance of the balance in the natural ecosystem sulphur dioxide gas is a major environmental hazard. Acid precipitation increases the loss of plant nutrients from soils, and although it may not be a serious problem in agricultural soils (Reuss, 1975) because of constant replacement of nutrients, in forest soils such losses are significant if they continue for any length of time (Reuss, 1975, and Overrein, 1972). Studies in Norway by Abrahamsen *et al.* (1976) with simulated acid rains showed that with increased acidity of the "rain" the pH, the exchangeable metal cations, and the base saturation in the top layer of a Podzol were lowered, and the pH of the leachates of the same soil from lysimeters were significantly lowered. In the same studies, it was found that when the pH of a mineral soil was lowered to 3.8 there was a great reduction (80%) in the establishment of Norway spruce seedlings.

In central Alberta, where approximately half of the sulphur processing plants in the province are located, Walker (1969) showed that only 2 to 4 kg of sulphur per hectare are deposited annually. This low deposition rate suggests a very wide distribution of the sulphur emission, perhaps even far outside Alberta. Also, Nyborg *et al.* (1973) have shown that little sulphur is deposited directly by rain and snow in Alberta; the implication is that the emissions affect large areas downwind from the source (Nyborg *et al.*, 1974) and that acidification of soils exposed under rain shelters has been due to sulphur emissions. Intercepted rains from forest canopies exposed to sulphur dioxide emissions were found to be acid, and the sulphur content generally is higher than in incident rain.

3. MATERIALS AND METHODS

3.1. SITES

Sites selected for the studies, and their relation to the sulphur dioxide emission source, are shown in Map 1. These sites are widely distributed, and except for the western sector they virtually encircle the sulphur dioxide emission source at the GCOS processing plant. The sites were built and equipped in May and June, 1976. Five sites were built not more than 25 km from the emission source, four between 25 and 50 km, three between 50 and 100 km, and four (remote or control sites) more than 100 km from the source (Table 1). After construction, each site was visited once every two weeks to maintain and service the experiments. At Site 3 (Supertest Hill), results obtained may not be reliable because of the heavy dust generated by nearby road construction activities and heavy traffic; results from this site therefore have been excluded from this report.

Every site, except Hangingstone River (Site 15), has a 3.7 m x 3.7 m x 1.8 m high link chain fence, equipped with a door, built in the open away from the forest canopy. Within the fence is a 1.2 m x 1.8 m rain shelter raised 0.9 m above ground level. Exposed to the air under this rain shelter were soils in canisters, potted mosses, distilled water, and sulphation discs. Within the fence at each site were a rain gauge and a rain collector, and at some sites there also were a Nipher gauge and a series of lysimeters. Under the forest canopy at each site, nine throughfall collectors and two stemflow collectors were erected; potted mosses also were set out in an unsheltered enclosure.

3.2. PRECIPITATION MEASUREMENTS

At each of the selected sites, a rain gauge was set up in the fenced area to interecpt and measure the amount of precipitation at the site for the duration of the field studies. Rainfall measurements were made covering the first and second halves of each month (approximately 15 days apart) from June through September 1976. About 10 ml of a light mineral oil was placed inside each rain gauge at the time it was set up and at every

MAP 1. Site locations in relation to the Sulphur dioxide emission source (1976) in the Alberta Oil Sands Area.

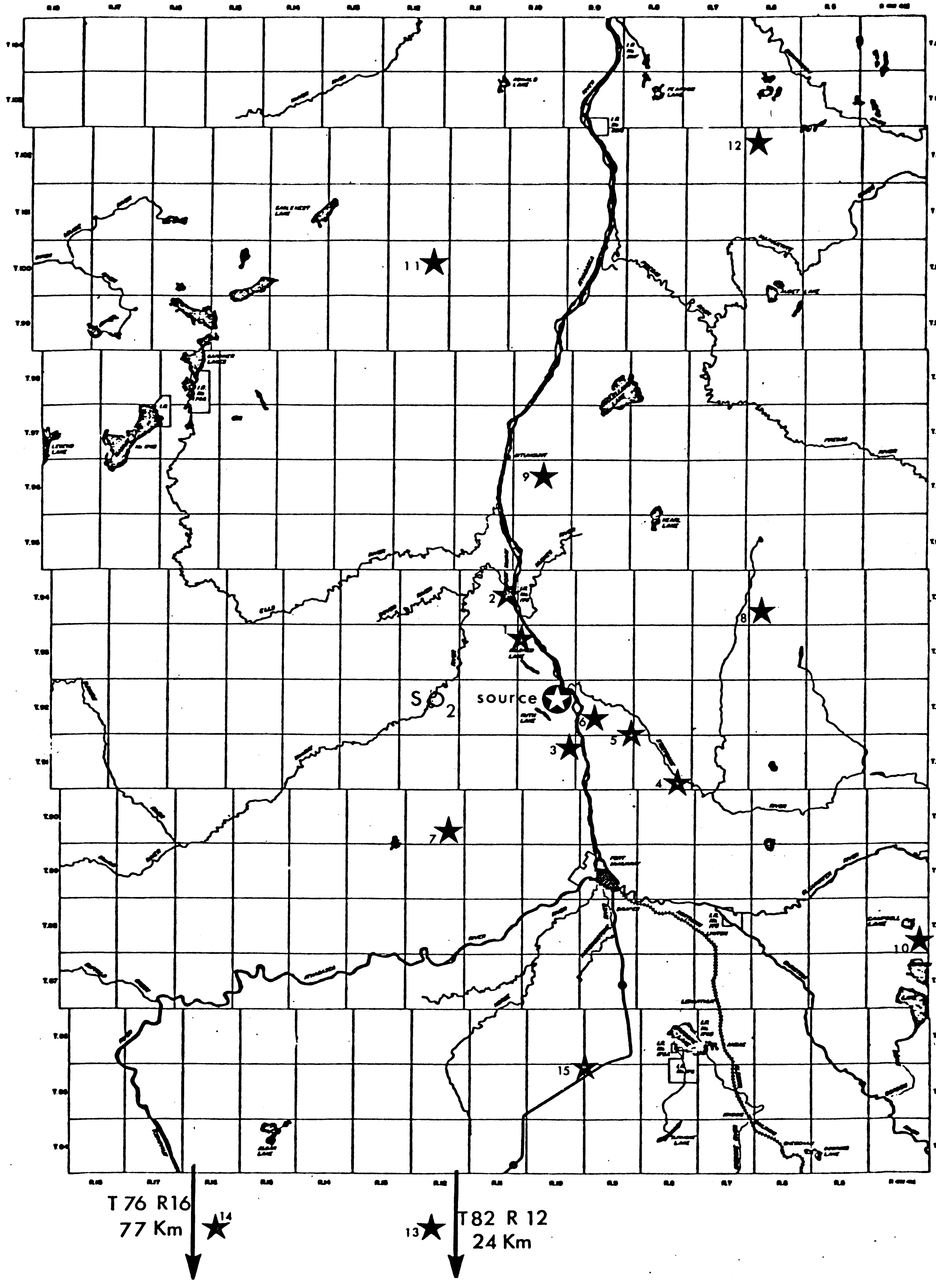

TABLE 1. Distances (km) and direction of the research sites from the sulphur dioxide emission source.

Site No.[1]	Site	Direction[2]	Distance (km) from emission source[2] 0 to 25	25 to 50	50 to 100	over 100
Northerly Sites:						
1	AOSERP Camp	NW	11	-	-	-
2	McKay River	NW	21	-	-	-
9	Bitumount	N	-	39	-	-
11	Birch Mountain	NNW	-	-	79	-
12	Richardson	NNE	-	-	-	102
Southerly Sites:						
3	Supertest Hill	S	7	-	-	-
7	Thickwood Hills	SW	-	31	-	-
15	Hangingstone River	S	-	-	67	-
13	Algar	SSW	-	-	-	101
14	May	SW	-	-	-	173
Easterly Sites:						
6	Steepbank Site #2	ESE	4	-	-	-
5	Steepbank Site #1	ESE	17	-	-	-
4	Steepbank Site A	SE	-	32	-	-
8	Muskeg Mountain	ENE	-	38	-	-
10	Gordon Lake	SE	-	-	75	-

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[1] See map showing site locations.
[2] In relation to emission source.

reading. The mineral oil formed a film over the rainwater collected in the rain gauge and prevented evaporation loss.

3.3. PRECIPITATION SAMPLING

Incident rain (straight rain) samples for laboratory analyses were collected in a 4.5 liter plastic container fitted with a 25 cm plastic funnel in turn fitted with a fine screen. The precipitation collector was placed adjacent to the rain gauge (see Section 3.2) at the same height above the ground as the rain gauge. Precipitation samples were collected each time the rain gauges were read. The volume of each sample collected for the 15-day period was measured in the field and a sub-sample taken in a 250 ml plastic bottle. The sample was kept cold in the field until it was sent to the laboratory, where it was frozen prior to analyses.

So far, rain samples have been analyzed for their acidity or alkalinity using a combination glass electrode on a Fisher Model 520 pH meter, both before and again after degassing with an ultrasonic device. Sulphur (in the sulphate form, SO_4-S) concentration in each sample was determined by the Johnson and Nishita (1952) method.

The amount of sulphur deposited (kg SO_4-S/ha/month) in soils by incident rain was calculated, using the sulphur concentration in the precipitation samples and the amount of precipitation recorded. (Other laboratory determinations, basic cations etc., on the rain samples still are being carried out.) The concentration levels of basic cations in a few randomly selected rain samples from 1975 were determined by atomic absorption (Black, Ed., 1965).

3.4. INTERCEPTED PRECIPITATION SAMPLING

3.4.1. Throughfall

Precipitation that eventually reaches the soil after penetrating the forest canopy (throughfall) also was sampled at each site in the same manner and frequency as the incident precipitation (see Section 3.3). At each site, throughfall through a dominant tree species was sampled; these species were jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), or white spruce (*Picea glauca*). For a mature stand, three trees were selected randomly and a collector (identical to incident precipitation collectors; see Section 3.3) was placed under each tree (a) up to 1 m from the trunk, (b) in the middle of the radius of the canopy, and (c) up to 1 m from the circumference of the canopy (Figure 1). For young or smaller tree stands, a collector was placed under each of nine trees (Figure 1).

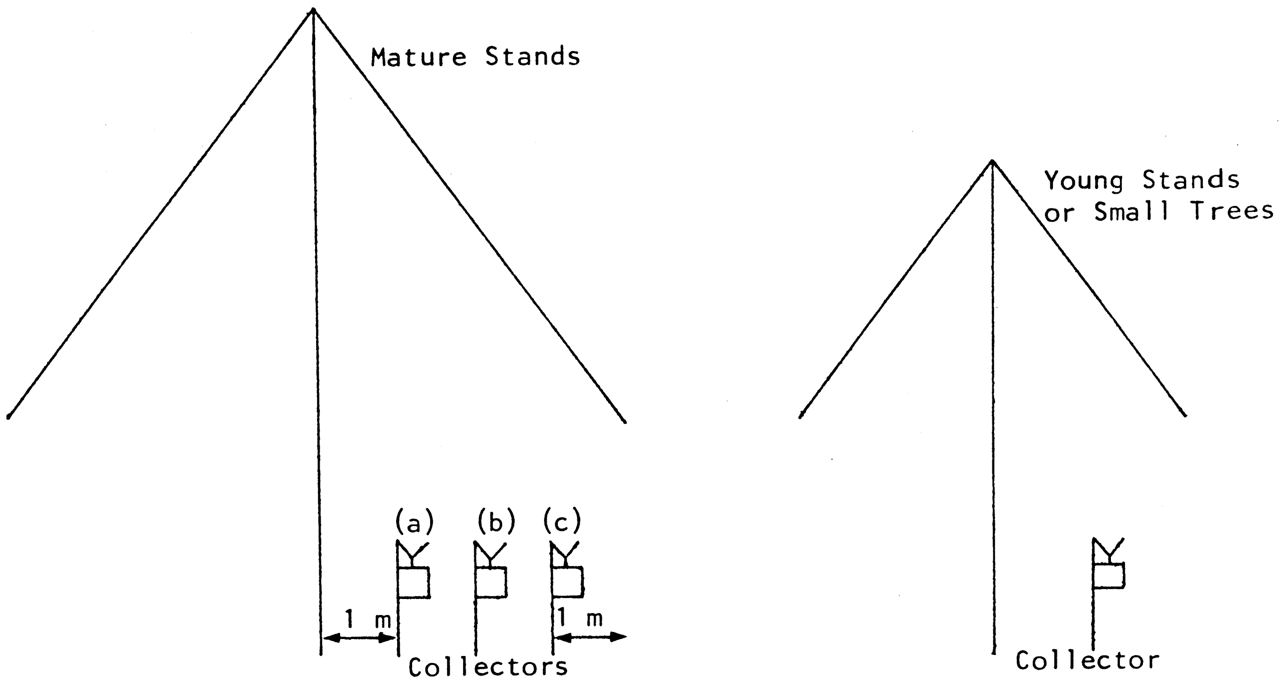

FIGURE 1. POSITION OF THROUGHFALL COLLECTORS

Sampling, handling of samples, and the chemical analyses so far completed are the same as for the incident precipitation samples (see Section 3.3). In estimating the amount of sulphur deposited in the soil per unit area, an efficiency factor was introduced in addition to considering the sulphur concentration of the throughfall samples and the amount of precipitation. The efficiency factor (expressed as a percentage of the measured rainfall in the open space) of a throughfall collector was based on the mean volume of the throughfall per collector in relation to the mean volume of the incident precipitation in the rain collector in the open (see Section 3.3) throughout the season. (This factor varies depending on location of throughfall collector (Figure 1)).

$$\text{Throughfall collector efficiency} = \frac{\text{Mean Volume of Throughfall Collector}}{\text{Mean Volume of Incident Rain Collector}}$$

3.4.2. Stemflow

Rainwater running down the trunks (stemflow) also was collected from two trees of the same species as that under which throughfall samples (see Section 3.4.1) were collected at each site. A collar consisting of a plastic water hose was fastened tightly around the trunk to intercept all water running down the trunk; the water was collected in 22.7 liter plastic containers.

Sampling frequency, field measurements, sample handling, and laboratory analyses so far accomplished were carried out in the same manner as for incident precipitation sampling (see Section 3.3).

Estimations of the amount of sulphur deposited in the soil were based on the volume of stemflow water collected per tree and its sulphur concentration. The estimates assumed a pure stand of trees and a given number of trees per unit area.

3.5. SULPHUR DEPOSITED IN SNOW

Accumulated snow samples were collected on March 17 and 18, 1976 at a few selected sites in the Oil Sands area. The duplicate samples were taken at each site. Snow volume per unit area was measured. The pH, sulphur concentrations, and basic cation content were determined (see Section 3.3) on the melted snow samples. Estimation of the amount of sulphur in the accumulated snow per unit area up until the sampling date was based on the sulphur concentration and the volume of snow (melted) for the sampled area.

3.6. ABSORPTION BY WATER AND SULPHATION DISCS

3.6.1. Absorption by water

Beakers filled with distilled water were exposed under the rain shelters at each site from June through September. The water level in the beaker was kept constant at all times and also was protected from contamination by insects and other foreign matter with fine screen which allowed for a minimum restriction of air movement. The entire content of each beaker was collected monthly to determine the sulphur concentration (see Section 3.3).

3.6.2. Absorption by sulphation discs

A pair of sulphation discs (Huey Plates or lead candles) 5 cm in diameter were exposed to the atmosphere under rain shelters at the sites from June through September. The discs were changed once every month. The sulphur absorbed by the discs was digested in Na_2CO_3 before being analyzed for sulphur concentration (see Section 3.3).

3.7. SULPHATE-BEARING PARTICULATES

A Nipher gauge setup was used for the collection of sulphate-bearing particulates in the air. The dust was collected on a glass filter (Gelman), and the filter was taken in every month for analyses. Deposits on the filter were washed off and the sulphur concentration was determined (see Section 3.3).

3.8. ACIDIFICATION OF MOSS

Two sets of two species of moss which commonly grow on the forest floors of the Oil Sands area, collected from areas far from the sulphur dioxide emission source, were potted and set out in mid-July at each of the sites (see Map 1). One set, in three replicates, was placed in a rain shelter and was watered with distilled water by weighing to a predetermined weight two times a month. The second set, in three replicates, was placed on the open forest floor inside a fence at each site in order to maintain as closely as possible the average condition of the undergrowth of the forest floor without collecting the throughfall of the forest canopy. These potted mosses were taken from the field in early October. (The objective of this experiment is to determine the comparative levels of acidification and sulphur absorption by these species of mosses at the widely separate sites. Analyses of the mosses as to their acidity levels and sulphur content are yet to be carried out.)

3.9. ACIDIFICATION OF BARE SOILS

Mineral soils and a peat passed through 2 mm sieve were set out in canisters at each site from June through September to establish the relative levels of acidification through sulphur absorption taking place at each site. These bare soils and peat were watered two times a month with distilled water by weighing to 10% above their predetermined field capacity moisture content. There were three replicates of each soil at all sites.

In the laboratory, the content of each canister was taken apart by layers (0-1 cm, 1-3 cm, 3-5 cm, and 5-12 cm). The pH levels and sulphur concentrations have so far been determined on some samples by methods referred to in Section 3.3. Sulphate-sulphur in the soils was extracted with 0.1 M $CaCl_2$ solution by shaking for 30 minutes, and aliquots of the filtrates were analyzed for sulphur. For the sulphate extractions, 10 g of mineral soil was used in 20 ml of the $CaCl_2$ solution, and 2 g of peat was used in 30 ml of the $CaCl_2$ solution. The ratios of soil to water and peat to water in pH determinations were, respectively, 20 g soil: 50 ml water and 2 g peat:50 ml water.

3.10 "PERMANENT" ACIDIFICATION PLOTS

Microplots (1 m by 2 m) were laid out in mid-August at each site (Map 1) for systematic long-term soil samplings for studies aimed at determining changes in soil chemical properties associated with any possible acidification of the native soils

Rep.1	Rep. 2	Rep. 3
(a)	1978	(a)
(a)	1976	(a)
1978	1980	(a)
1980	(a)	1978
(a)	(a)	1976
1976	(a)	1980
(a)	(a)	(a)
(a)	(a)	(a)
(a)	(a)	(a)

(a) = areas to be sampled after 1980

FIGURE 2. Plot plan, "permanent" acidification plots

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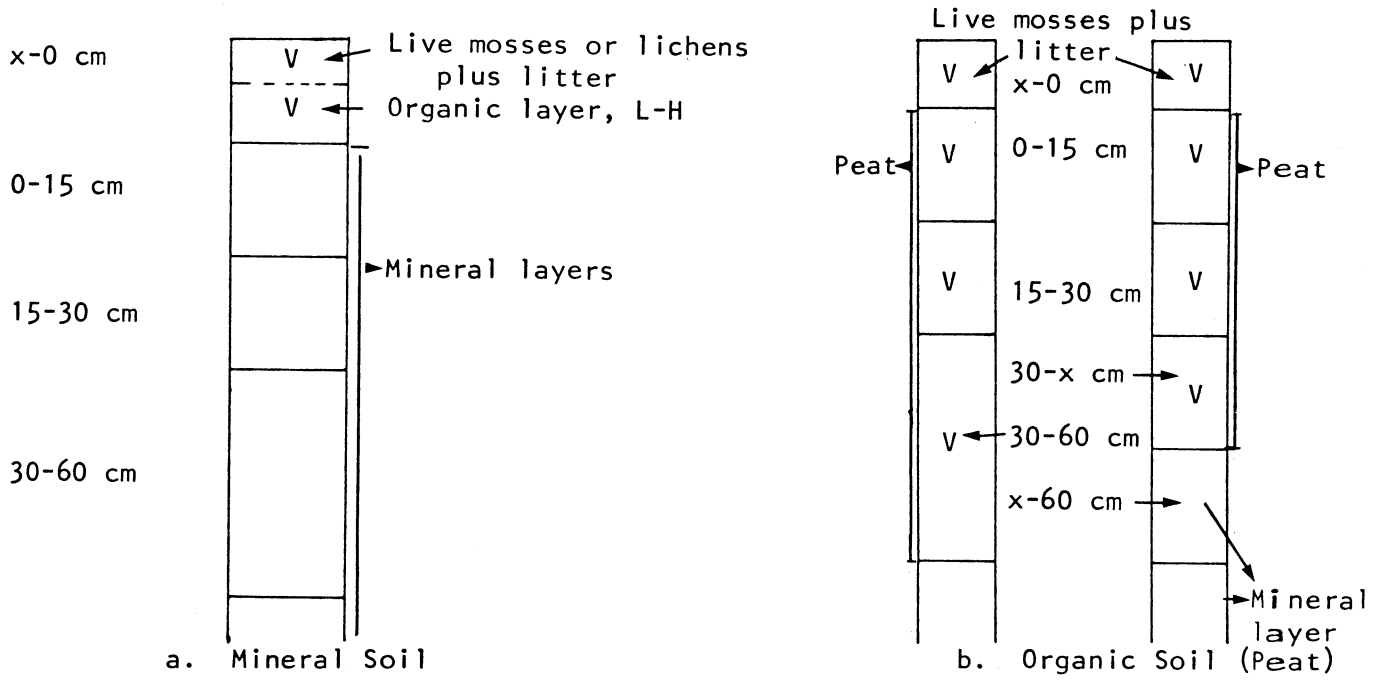
caused by acid rains at the selected sites. The plot plan (Figure 2) allowed for many years of sampling in three replicates at specified intervals.

Sampling is done according to soil depth, up to a maximum of 60 cm. Sampling was as illustrated in Figure 3. The live forest



a. Mineral Soil

b. Organic Soil (Peat)

V = volume sampling

FIGURE 3. SAMPLING OF "PERMANENT" ACIDIFICATION PLOTS

floor undergrowth, mosses and lichens, along with the mixed litter, also was sampled and the litter was later separated from the lichen or moss in the laboratory. The organic layer, if it occurred, was sampled separately. Sampling of the forest floor undergrowth, the litter, and the organic layers of the soils is considered important because any immediate changes in the sulphur levels in the soils probably will first be detected here. The soil samples, including the litter, live moss, and lichen all were air-dried; the soils were screened through a 2 mm screen and the litter and mosses were ground. The dried lichen simply was crumbled.

The soil samples taken in August 1976 are being held in an SO_2-free environment until after the second (1978) or third (1980) sampling, when the accumulated samples will be analyzed at one time. This will guard against any possible variability or inconsistency in analytical procedure.

3.11 SULPHUR MOVEMENT AND PLANT NUTRIENT LEACHING FROM SOILS

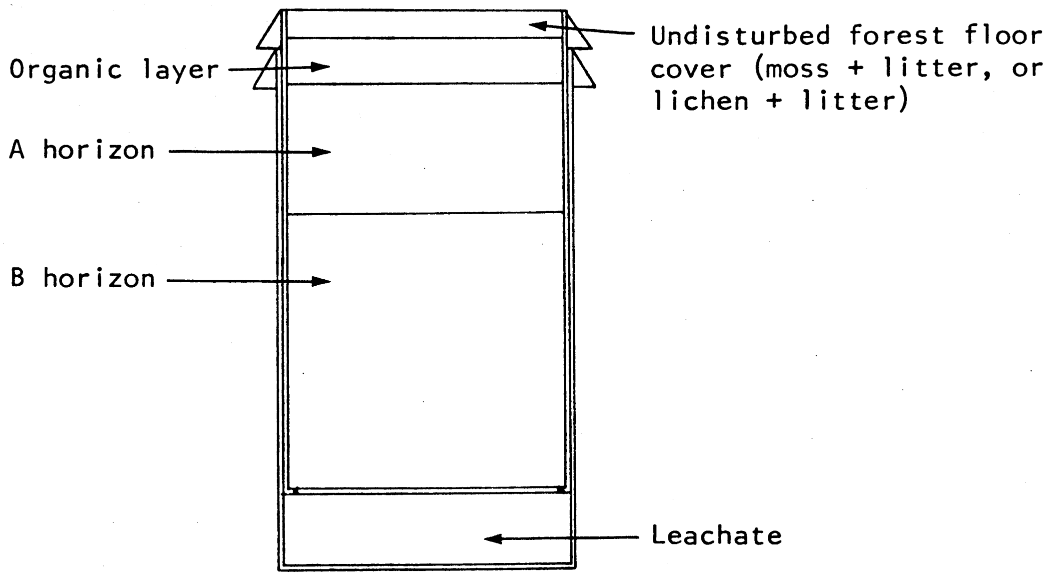


FIGURE 4. LYSIMETER DESIGN

Two soils sampled from the Oil Sands area, a sand and a sandy loam, were set up in lysimeters, as shown in Figure 4. The experiment, which was set up at nine sites in mid-summer, is aimed at determining sulphur movement through the soil profile and the extent of increased loss of plant nutrients, associated with acid precipitation, from soil profiles.

Leachate collections ended just before freezing. Handling of the leachate samples was the same as for incident rain samples (see Section 3.3). Leachate analyses for nutrient losses, acidity levels, and sulphur content are yet to be carried out.

3.12. EXPOSURE OF SOILS, MOSSES AND LICHENS, TREE TRUNKS AND SPRUCE SEEDLINGS TO SULPHUR DIOXIDE GAS

In the laboratory, two agricultural soils, two non-agricultural soils, peat, moss, lichen, spruce seedlings, and trunks of some tree species common to the Oil Sands area were exposed to sulphur dioxide gas under a controlled environment to determine the extent to which these materials would retain sulphur. Temperature, relative humidity, and sulphur dioxide concentration in the exposure chamber for the 30-day duration of each experiment were, respectively, 22°C, 30 or 60% R.H. and 66 or 70 ppb. All treatments were replicated three or more times. After the run of each experiment, sulphur levels were determined for each treatment; pH determinations were made on the soils, peat, lichen, and moss. Sulphur was extracted from the soils, peat, lichen, and moss as described in Section 3.9. With tree trunks and the spruce seedlings, extractions were made in distilled water for two minutes. Sulphur extracted and pH values were determined as described in Section 3.3.

4. RESULTS AND DISCUSSION

4.1. PRECIPITATION

The total precipitation, recorded approximately each 15 days from June through September at each of the field sites, is given in Table 2. In general, total summer precipitation was lower at sites close (25 km) to the sulphur dioxide emission source than at sites farther out (Table 3). Sites in the southern part of the study area received almost two times the amount of precipitation as those in the northern portions. The variation in precipitation at each site was considerable (Table 2).

The second half of September was dry in the entire Oil Sands area; only the two northernmost sites (Richardson and Birch Mountain) received substantial precipitation. Most of the sites north of the emission source were dry in the first half of August. During these dry periods, the forest canopies yielded very little or no throughfalls and no stemflows. (Continued recording of precipitation at these and any other sites in the Oil Sands area will in the long term establish any possible changes in the precipitation pattern as more Oil Sands processing plants are developed.)

4.2. ACIDITY AND SULPHUR CONTENT OF INCIDENT AND INTERCEPTED RAIN

4.2.1. Incident rain

Mean pH values of the incident rains at sites near the sulphur dioxide emission source were nearer neutrality than at sites over 100 km away (Table 4). The two sites to the northwest close to the sulphur dioxide source had higher pH values than any other site, including the remote sites over 100 km away. Some individual rain samples from some sites had pH values in the lower ranges (5.0 to 5.5), suggesting that some rains which could not be sampled individually were acid. It should be emphasized that as individual rains were not sampled, specific occurrences of acid rains could not be recorded. In samples where pH values were low it could be assumed that some rains during the 15-day intervals between samplings could have been acid. Removal of dissolved

TABLE 2. Total precipitation (mm) read approximately in the first and second halves of each month at the different sites from June to September, 1976.

Site No.[1]	Site	June		July		August		September				
		1st half	2nd half	1st half	2nd half	1st half	2nd half	1st half	2nd half	mean	s.d.	total
1	AOSERP Camp	9.0	21.6	41.8	20.8	3.8	29.2	94.5	0.2	27.6	30.3	220.9
2	McKay River	4.8	20.6	25.6	19.4	8.2	38.0	80.3	0	24.6	25.6	196.9
3	Supertest Hill	10.3	22.6	45.2	30.8	6.9	31.0	97.0	0	30.5	30.7	243.8
4	Steepbank Site A	8.0	26.2	48.8	25.8	17.1	21.2	101.2	0	31.0	31.8	248.3
5	Steepbank Site #1	14.2	19.5	50.1	28.4	3.6	19.6	91.4	0.2	28.4	29.8	227.0
6	Steepbank Site #2	16.2	22.2	63.4	26.6	4.0	21.0	93.0	0.1	30.8	31.6	246.5
7	Thickwood Hills	17.2	45.5	31.0	30.8	78.8	140.2	35.8	0.1	47.4	43.8	379.4
8	Muskeg Mountain	55.8	22.7	26.2	41.6	25.4	62.0	31.7	0.1	33.2	19.7	265.5
9	Bitumount	7.0	25.0	27.8	22.8	0.6	39.6	33.2	0.6	19.6	15.0	156.6
10	Gordon Lake	37.0	32.9	65.6	30.6	32.2	106.4	34.6	0	42.4	31.3	339.3
11	Birch Mountain	19.8	80.4	33.8	42.0	0	53.2	10.2	2.2	30.2	27.8	241.6
12	Richardson	8.8	34.5	32.2	57.8	2.4	40.8	20.0	1.6	24.8	20.0	198.1
13	Algar	52.0	69.9	47.6	21.0	25.4	137.0	49.5	0	50.3	41.3	402.4
14	May	23.8	121.3	47.5	22.2	22.1	102.0	48.2	0	48.4	42.3	387.1
15	Hangingstone River	32.0	66.1	60.0	19.4	52.4	129.3	57.2	0	52.1	38.6	416.4

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[1] See map showing site locations

TABLE 3. Total precipitation (mm) at the research sites from June through September, 1976.

Site No.[1]	Site	Direction[2]	Distance (km) from emission source 0 to 25	25 to 50	50 to 100	over 100
Northerly Sites:						
1	AOSERP Camp	NW	220.9	-	-	-
2	McKay River	NW	196.9	-	-	-
9	Bitumount	N	-	156.6	-	-
11	Birch Mountain	NNW	-	-	241.6	-
12	Richardson	NNE	-	-	-	198.1
				Mean 201.3		
Southerly Sites:						
3	Supertest Hill	S	243.8	-	-	-
7	Thickwood Hills	SW	-	379.4	-	-
15	Hangingstone River	S	-	-	416.4	-
13	Algar	SSW	-	-	-	402.4
14	May	SW	-	-	-	387.1
				Mean 358.6		
Easterly Sites:						
6	Steepbank Site #2	ESE	246.5	-	-	-
5	Steepbank Site #1	ESE	227.0	-	-	-
4	Steepbank Site A	SE	-	248.3	-	-
8	Muskeg Mountain	ENE	-	265.5	-	-
10	Gordon Lake	SE	-	-	339.3	-
				Mean 277.7		
		Mean	227.0	262.5	332.4	329.2

---

[1] See map showing site locations

[2] In relation to emission source

TABLE 4. pH values of rainfall samples from June through mid-September, 1976 (sampled in the first and second halves of the month).

Site No.[1]	Site	Direction[2]	Range	Distance (km) from emission source: 0 to 25 mean	0 to 25 s.d.	25 to 50 mean	25 to 50 s.d.	50 to 100 mean	50 to 100 s.d.	over 100 mean	over 100 s.d.
Northerly Sites:											
1	AOSERP Camp	NW	6.6 - 6.9	6.8	0.1	-	-	-	-	-	-
2	McKay River	NW	6.5 - 6.8	6.7	0.1	-	-	-	-	-	-
9	Bitumount	N	5.6 - 6.6	-	-	6.2	0.4	-	-	-	-
11	Birch Mountain	NNW	5.3 - 6.4	-	-	-	-	6.0	0.4	-	-
12	Richardson	NNE	5.8 - 6.4	-	-	-	-	-	-	6.1	0.2
Southerly Sites:											
7	Thickwood Hills	SW	5.2 - 6.5	-	-	6.2	0.4	-	-	-	-
15	Hangingstone River	S	5.9 - 7.0	-	-	-	-	6.5	0.4	-	-
13	Algar	SSW	5.6 - 6.4	-	-	-	-	-	-	6.1	0.3
14	May	SW	5.5 - 6.1	-	-	-	-	-	-	5.9	0.2
Easterly Sites:											
6	Steepbank Site #2	ESE	5.8 - 6.4	6.2	0.2	-	-	-	-	-	-
5	Steepbank Site #1	ESE	6.0 - 6.5	6.3	0.2	-	-	-	-	-	-
4	Steepbank Site A	SE	5.0 - 6.6	-	-	6.3	0.6	-	-	-	-
8	Muskeg Mountain	ENE	5.6 - 6.6	-	-	6.3	0.4	-	-	-	-
10	Gordon Lake	SE	5.5 - 6.5	-	-	-	-	6.1	0.3	-	-
			Mean	6.5	0.3	6.2	0.1	6.2	0.3	6.0	0.1

---

[1] See map showing site locations

[2] In relation to emission source

gases (Table 5) generally increased the pH values only very slightly, suggesting that dissolved gases had no significant effect on the pH values. Variability in pH values of samples was low for each site. It appears that with only one processing plant now in operation, the rains generally are not acid. (Dust generated from road construction at Supertest Hill (Site 3) affected the results of the experiments and therefore are not given in the tables and are excluded from all discussions.

Concentration of sulphur (Table 6) in the twice-monthly precipitation samples ranges from almost zero in some samples at the remote sites to 1.95 ppm in one sample taken directly across the river (Steepbank, Site 2) from the emission source. Samples taken on different dates from the same site were highly variable in concentration levels. In general, the mean sulphur concentration in the samples taken within 25 km of the emission source were about two times the concentrations found in samples from the remote sites over 100 km away.

The mean amount of sulphur deposited by rainfall, although low at each site, generally is higher nearer the emission source (Table 7) than at the remote sites. The two sites closest to the emission source received the highest sulphur deposits. Assuming the same amounts of precipitation were recorded for each site, the sites closer (25 km) to the emission source would have received on the average over two times the sulphur deposited at the remote sites over 100 km away. It therefore would appear that a site closer to the emission source may not necessarily have more sulphur deposited in precipitation than a site farther away. Amounts deposited near the emission source would appear to depend on the frequency and the duration of precipitation. If the emission source area generally is dry or the frequency of of precipitation is low, the emissions are likely to be distributed widely over large areas. The results of sulphur deposits in the Oil Sands area confirm the findings by Walker (1969) and Nyborg *et al.* (1973) that in Alberta amounts of sulphur deposited by rain are relatively small. In the Oil Sands area, however, sites very close to the source receive

TABLE 5. pH values of straight samples and degassed samples of rain, throughfall and stemflow.

Site	Tree Species	Sample Type	Straight Sample		Degassed Sample	
			mean	s.d.	mean	s.d.
Algar		Rain	6.1	.3	6.2	.4
	White Spruce	Throughfall	5.4	.6	5.5	.6
	White Spruce	Stemflow	4.3	.5	4.4	.6
May		Rain	5.9	.2	6.1	.3
	White Spruce	Throughfall	5.8	.3	6.0	.4
	White Spruce	Stemflow	4.7	.3	4.7	.3
McKay River		Rain	6.7	.1	6.8	.1
	White Spruce	Throughfall	5.7	.5	5.8	.5
	White Spruce	Stemflow	4.9	.4	4.9	.4
Steepbank Site A		Rain	6.2	.5	6.3	.6
	White Spruce	Throughfall	5.6	.8	5.6	.8
	White Spruce	Stemflow	4.4	.9	4.4	.9
Thickwood Hills		Rain	6.2	.4	6.3	.5
	White Spruce	Throughfall	6.5	.2	6.6	.2
	White Spruce	Stemflow	5.0	.8	5.0	.8
Steepbank Site #1		Rain	6.3	.2	6.5	.2
	Black Spruce (small)	Throughfall	5.5	.4	5.6	.5
	Black Spruce (small)	Stemflow	4.4	.6	4.4	.6
AOSERP Camp		Rain	6.8	.1	6.8	.2
	Jack Pine	Throughfall	6.5	.2	6.6	.2
	Jack Pine	Stemflow	3.7	.3	3.7	.3
Richardson		Rain	6.1	.2	6.2	.3
	Jack Pine	Throughfall	5.1	.1	5.2	.1
	Jack Pine	Stemflow	4.9	.6	4.9	.6

TABLE 6. Sulphur concentrations (ppm) in rainfall samples from June through mid-September, 1976 (sampled in the middle and end of the month).

Site No.[1]	Site	Direction[2]	Range	Distance (km) from emission source							
				0 to 25		25 to 50		50 to 100		over 100	
				mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Northerly Sites:											
1	AOSERP Camp	NW	.14 - 1.85	.59	.63	-	-	-	-	-	-
2	McKay River	NW	.10 - 1.30	.58	.44	-	-	-	-	-	-
9	Bitumount	N	.25 - .99	-	-	.45	.28	-	-	-	-
11	Birch Mountain	NNW	.10 - .90	-	-	-	-	.46	.26	-	-
12	Richardson	NNE	.10 - .95	-	-	-	-	-	-	.45	.36
Southerly Sites:											
7	Thickwood Hills	SW	.15 - 1.75	-	-	.70	.55	-	-	-	-
15	Hangingstone River	S	.10 - .85	-	-	-	-	.28	.26	-	-
13	Algar	SSW	.05 - .45	-	-	-	-	-	-	.24	.17
14	May	SW	.05 - .60	-	-	-	-	-	-	.27	.21
Easterly Sites											
6	Steepbank Site #2	ESE	.10 - 1.95	.81	.64	-	-	-	-	-	-
5	Steepbank Site #1	ESE	.10 - 1.00	.44	.31	-	-	-	-	-	-
4	Steepbank Site A	SE	.10 - 1.00	-	-	.37	.30	-	-	-	-
8	Muskeg Mountain	ENE	.10 - .50	-	-	.31	.15	-	-	-	-
10	Gordon Lake	SE	.10 - .50	-	-	-	-	.34	.18	-	-
			Mean	.61	.15	.46	.17	.36	.09	.31	.11

---

[1] See map showing site locations

[2] In relation to emission source

TABLE 7. Amounts of sulphur deposited by rainfall from June through mid-September, 1976 (kg/ha/month). Figures in brackets represent relative amounts deposited assuming each site received the same amount of precipitation.

Site No.[1]	Site	Direction[2]	Distance (km) from emission source			
			0 to 25	25 to 50	50 to 100	over 100
Northerly Sites:						
1	AOSERP Camp	NW	.47 (3.5)	-	-	-
2	McKay River	NW	.21 (1.8)	-	-	-
9	Bitumount	N	-	.16 (1.7)	-	-
11	Birch Mountain	NNW	-	-	.25 (1.7)	-
12	Richardson	NNE	-	-	-	.18 (1.5)
Southerly Sites:						
7	Thickwood Hills	SW	-	.56 (2.5)	-	-
15	Hangingstone River	S	-	-	.25 (1.0)	-
13	Algar	SSW	-	-	-	.25 (1.0)
14	May	SW	-	-	-	.26 (1.2)
Easterly Sites:						
6	Steepbank Site #2	ESE	.60 (4.0)	-	-	-
5	Steepbank Site #1	ESE	.19 (1.3)	-	-	-
4	Steepbank Site A	SE	-	.17 (1.2)	-	-
8	Muskeg Mountain	ENE	-	.29 (1.8)	-	-
10	Gordon Lake	SE	-	-	.25 (1.2)	-
		Mean	.37 (2.7)	.30 (1.8)	.25 (1.3)	.23 (1.2)

---

[1] See map showing site locations

[2] In relation to emission source

more wet sulphur deposits than sites farther from the emission source. It appears that with a greater precipitation frequency in the Oil Sands area wet deposits of S would be increased beyond the levels estimated here. The acidity levels of the rainfalls and the wet deposits of sulphur in the Oil Sands area are not of the same magnitude as in the Scandinavian countries (Dovland *et al.*, 1976).

Basic cation concentrations in a few selected 1975 summer precipitation samples from the Oil Sands area are given in Table 8, along with concentrations for a remote site. Near the sulphur dioxide emission source the net concentration (milliequivalents) of the basic cations and the sulphur (not sulphate) concentrations in the rainwater are almost equal. At the remote site, however, there is an excess of basic cations in the rain samples. The presence of basic cations in the samples (including those probably present but which were not determined) perhaps accounts for the relatively low acidity of the precipitation in the Oil Sands area.

4.2.2. Intercepted rain

4.2.2.1. Throughfall. The pH values of throughfall samples (Table 9) generally were similar to the incident rain values (Table 4) at approximately half of the sites. At the other sites, pH values of the throughfalls ranged between 0.5 and 1.0 below incident rain pH values. Mean pH values within 100 km distance of the emission source varied only slightly. There were several instances at many sites where the throughfalls were acid (pH less than 5). Differences in pH values probably are partly attributable to differences in species and age of the trees. Instances of high pH values of the throughfall samples have been attributed to nutrients (mostly basic cations) leached from the forest canopy (Ulrich, 1968; Nihlgard, 1970; Horntvedt and Joranger, 1974; and many others). Dissolved gases in the throughfall samples had hardly any influence on the pH values (Table 5).

Sulphur concentrations in the throughfall samples (Table 10) ranged from almost nil to as high as 20 ppm in some samples

TABLE 8. Basic cation concentrations in selected 1975 rain water samples from the Oil Sands area and a remote site.

Site	Date	pH	S ppm	Cations (ppm) K	Na	Mg	Ca	Excess Cations meq/ℓ
Exposed Sites:								
AOSERP Camp	July 31	6.8	0.60	0.56	0.40	0	0.22	.01
	Oct. 9	6.3	0.80	0.41	0.37	0	0.18	-.01
Syncrude Lower Camp	Oct. 9	6.3	1.20	0.73	0.35	0.06	0.62	-.01
Mildred Lake Air-Strip	Oct. 9	6.9	0.90	3.22	0.37	0.87	0.82	.16
Supertest Hill	July 25	5.2	0.85	0.37	0.12	0.05	0.06	-.03
	Aug. 8	6.8	0.65	0.41	0.14	0.18	0.30	.01
	Sept. 11	6.4	0.40	0.43	0.40	0.06	0.26	.02
Steepbank Site #3	July 28	6.3	1.05	0.41	0.62	0.14	0.34	0
	Aug. 11	6.0	1.85	0.62	0.11	0.21	0.38	-.06
	Aug. 21	6.5	2.10	0.62	3.70	0.64	0.98	.15
	Sept. 10	5.8	1.00	0.60	0.60	0	0.02	-.02
Steepbank Site #2	July 3	6.0	1.00	0.20	0.22	0	0.18	-.04
	Aug. 11	5.7	2.45	0	0.09	0.22	0.22	-.12
	Aug. 29	6.1	1.00	0	0.08	0.07	0	-.05
	Sept. 10	5.3	0.50	0.45	0.22	0	0	-.10
Hangingstone River	July 7	6.1	0.30	0.83	0.44	0.09	0.42	.05
Remote Site:								
Canwood, Sask.	June 19	6.4	0.20	0.47	0.75	0	0	.03
	June 25	6.9	0.20	0.43	0.98	0	0	.04
	Aug. 9	6.4	0.50	0.43	0.75	0.07	0.22	.03
	Sept. 1	6.7	0.15	0.45	0.86	0	0	.04

TABLE 9. pH values of throughfall samples (middle collectors) from July through mid-September, 1976 (sampled in the first and second halves of each month)

Site No.[1]	Site	Direction[2]	Tree species and Age	Range	Distance (km) from emission source							
					0 to 25		25 to 50		50 to 100		over 100	
					mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Northerly Sites:												
1	AOSERP Camp	NW	Jack Pine - mature	6.2-6.7	6.5	.2	-	-	-	-	-	-
2	McKay River	NW	White Spruce - mature	5.3-6.5	5.7	.5	-	-	-	-	-	-
9	Bitumount	N	White Spruce - mature	6.3-6.9	-	-	6.6	.3	-	-	-	-
11	Birch Mountain	NNW	Black Spruce - small	4.7-6.7	-	-	-	-	5.5	.7	-	-
12	Richardson	NNE	Jack Pine - mature	5.0-6.6	-	-	-	-	-	-	5.1	.1
Southerly Sites:												
7	Thickwood Hills	SW	White Spruce - mature	6.3-6.8	-	-	6.5	.2	-	-	-	-
15	Hangingstone River	S	White Spruce - mature	6.2-7.1	-	-	-	-	6.6	.3	-	-
13	Algar	SSW	White Spruce - mature	4.8-6.0	-	-	-	-	-	-	5.4	.6
14	May	SW	White Spruce - mature	5.6-6.5	-	-	-	-	-	-	5.9	.4
Easterly Sites:												
6	Steepbank Site #2	ESE	White Spruce - young	6.3-7.0	6.5	.2	-	-	-	-	-	-
5	Steepbank Site #1	ESE	Black Spruce - small	4.7-6.2	5.5	.4	-	-	-	-	-	-
4	Steepbank Site A	SE	White Spruce - mature	4.4-6.3	-	-	5.6	.8	-	-	-	-
8	Muskeg Hountain	ENE	White Spruce - young	4.4-6.4	-	-	5.5	.6	-	-	-	-
10	Gordon Lake	SE	White Spruce - mature	5.8-6.6	-	-	-	-	6.3	.3	-	-
				Mean	6.0	.6	6.0	.6	6.1	.5	5.5	.4

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[1] See map showing site locations

[2] In relation to emission source

TABLE 10. Sulphur concentration (ppm) in throughfall samples (middle collectors) from July through mid-September 1976. (Sampled in the middle and end of the month)

Site No.[1]	Site	Direction[2]	Tree Species and Age	Range	Distance (km) from emission source 0 to 25		25 to 50		50 to 100		over 100	
					mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Northerly Sites:												
1	AOSERP Camp	NW	Jack Pine - mature	1.70-5.50	3.20	1.63	-	-	-	-	-	-
2	McKay River	NW	White Spruce - mature	6.40-14.50	9.11	3.34	-	-	-	-	-	-
9	Bitumount	N	White Spruce - mature	0.55-3.05	-	-	1.33	0.88	-	-	-	-
11	Birch Mountain	NNW	Black Spruce - small	0.50-7.60	-	-	-	-	3.16	2.11	-	-
12	Richardson	NNE	Jack Pine - mature	0.35-2.15	-	-	-	-	-	-	0.76	0.41
Southerly Sites:												
7	Thickwood Hills	SW	White Spruce - mature	0.80-4.00	-	-	2.64	1.54	-	-	-	-
15	Hangingstone River	S	White Spruce - mature	1.70-8.60	-	-	-	-	4.84	3.04	-	-
13	Algar	SSW	White Spruce - mature	1.20-2.70	-	-	-	-	-	-	2.10	0.48
14	May	SW	White Spruce - mature	0.50-2.10	-	-	-	-	-	-	1.19	0.66
Easterly Sites:												
6	Steepbank Site #2	ESE	White Spruce - young	0.10-4.00	1.68	1.06	-	-	-	-	-	-
5	Steepbank Site #1	ESE	Black Spruce - small	0.35-8.50	2.70	2.30	-	-	-	-	-	-
4	Steepbank Site A	SE	White Spruce - mature	6.50-20.20	-	-	15.80	6.30	-	-	-	-
8	Muskeg Mountain	ENE	White Spruce - young	0.20-4.00	-	-	2.22	1.92	-	-	-	-
10	Gordon Lake	SE	White Spruce - mature	0.25-3.30	-	-	-	-	2.05	1.12	-	-
				Mean	4.17	3.40	5.50	6.89	3.35	1.40	1.35	0.68

---

[1] See map showing site locations

[2] In relation to emission source

close to the emission source. When the volume of throughfall was small, sulphur concentrations generally were higher than concentrations in large volumes. Sites closer to the emission source and those in a general easterly direction had higher sulphur concentrations. At approximately the same distance from the emission source, sulphur concentrations generally were lower in the younger trees than in mature trees of the same species, and differences between species also were evident.

Amounts of sulphur deposited (Table 11) in the soil by intercepted rain are much greater than the amounts deposited by incident rain at each site. Generally, amounts of sulphur deposited decreased with greater distance from the emission source. At sites where the mature trees have formed dense canopies, e.g. McKay River and Steepbank River Site A, deposits were much greater than at sites where the trees are smaller and sparsely spaced, e.g. Steepbank Site 1. Although the greater percentage of sulphur deposited is that contained in the incident rain and the dry deposits washed off the canopy, leaching of sulphur from the leaves of the canopy has a contributing influence. In the forest soils of the Oil Sands area, sulphur deposits by intercepted rain are larger than deposits by incident rain.

In collecting throughfall samples, placement of the collector under the tree has an effect on the efficiency of the collector (Table 12). Collectors placed close to the trunk where the canopy generally is thickest under spruce trees most often yielded the least throughfall; acidity levels and sulphur concentrations were the highest in this case. The edges of the canopy yielded the highest volume of throughfall and the acidity levels and sulphur concentrations were lowest there.

4.2.2.2. Stemflow. Stemflow was the most acid in comparison with incident rain and throughfall. There were instances where relatively large numbers of individual stemflow samples were strongly acid (pH less than 4) at several sites.

Sulphur concentrations in the stemflows were high (Table 13); these were much higher than concentrations in the throughfalls.

TABLE 11. Amounts of sulphur deposited by throughfalls from July through mid-September, 1976. (kg/ha/month)

Site No.[1]	Site	Direction[2]	Tree Species and Age	Distance (km) from emission source			
				0 to 25	25 to 50	50 to 100	over 100
Northerly Sites:							
1	AOSERP Camp	NW	Jack Pine - mature	1.32	-	-	-
2	McKay River	NW	White Spruce - mature	4.51	-	-	-
9	Bitumount	N	White Spruce - mature	-	1.04	-	-
11	Birch Mountain	NNW	Black Spruce - small	-	-	1.29	-
12	Richardson	NNE	Jack Pine - mature	-	-	-	0.37
Southerly Sites:							
7	Thickwood Hills	SW	White Spruce - mature	-	1.86	-	-
15	Hangingstone River	S	White Spruce - mature	-	-	2.20	-
13	Algar	SSW	White Spruce - mature	-	-	-	1.56
14	May	SW	White Spruce - mature	-	-	-	0.59
Easterly Sites:							
6	Steepbank Site #2	ESE	White Spruce - young	0.82	-	-	-
5	Steepbank Site #1	ESE	Black Spruce - small	1.47	-	-	-
4	Steepbank Site A	SE	White Spruce - mature	-	2.74	-	-
8	Muskeg Mountain	ENE	White Spruce - young	-	0.95	-	-
10	Gordon Lake	SE	White Spruce - mature	-	-	1.19	-
			Mean	2.03	1.65	1.56	0.84

---

[1] See map showing site locations

[2] In relation to emission source

TABLE 12. Influence of placement of throughfall collector on pH values, S concentration and the efficiency in collecting intercepted rain by a given tree. Gordon Lake, July through mid-September, 1976.

Collector placement		Collector efficiency (%)	pH	SO_4-S conc. (ppm)
Close to trunk	(A)[1]	43.3	6.24	2.47
Middle	(B)	59.2	6.26	2.05
Edge	(C)	90.6	6.43	0.88
Incident Rain		100.0	6.07	0.34

---

[1] See Figure 1.

TABLE 13. Concentration of sulphur (ppm) in stemflow samples from July through mid-September, 1976. (Sampled in the middle and end of the month.)

Site No.[1]	Site	Direction[2]	Tree Species and Age	Range	Distance (km) from emission source							
					0 to 25		25 to 50		50 to 100		over 100	
					mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Northerly Sites:												
1	AOSERP Camp	NW	Jack Pine - mature	5.05-35.00	16.11	11.56	-	-	-	-	-	-
2	McKay River	NW	White Spruce - mature	8.85-43.50	26.11	13.10	-	-	-	-	-	-
9	Bitumount	N	White Spruce - mature	4.00-36.00	-	-	13.49	12.27	-	-	-	-
11	Birch Mountain	NNW	Black Spruce - small	2.20-10.40	-	-	-	-	6.11	2.99	-	-
12	Richardson	NNE	Jack Pine - mature	3.50-16.50	-	-	-	-	-	-	8.06	4.40
Southerly Sites:												
7	Thickwood Hills	SW	White Spruce - mature	1.40-12.20	-	-	7.98	4.75	-	-	-	-
15	Hangingstone River	S	White Spruce - mature	3.35-30.00	-	-	-	-	15.06	9.11	-	-
13	Algar	SSW	White Spruce - mature	2.40-42.50	-	-	-	-	-	-	11.96	12.64
14	May	SW	White Spruce - mature	1.60- 9.50	-	-	-	-	-	-	5.84	2.82
Easterly Sites:												
6	Steepbank Site #2	ESE	White Spruce - young	1.85-35.00	27.86	43.77	-	-	-	-	-	-
5	Steepbank Site #1	ESE	Black Spruce - small	3.50-27.00	13.84	8.04	-	-	-	-	-	-
8	Muskeg Mountain	ENE	White Spruce - young	1.75-33.00	-	-	11.06	9.34	-	-	-	-
10	Gordon Lake	SE	White Spruce - mature	1.85-11.50	-	-	-	-	6.09	4.00	-	-
				Mean	20.98	7.03	10.84	2.76	9.09	5.17	8.62	3.10

---

[1] See map showing site locations

[2] In relation to emission source

Mean sulphur concentrations at sites closest to the emission source were higher than at sites beyond 25 km. Variability in concentrations between individual samples taken on different dates from the same site was high. The estimated amounts of sulphur deposited in soils by stemflows are given in Table 14, and these are low considering the generally high concentrations of sulphur found in the stemflow samples.

It has been reported for other areas that concentrations of elements in stemflow samples are relatively high (Carlisle *et al.*, 1965). The concentrations of sulphur in stemflow samples from the Oil Sands area also have been found to be high. It would seem that the low pH values and the high concentrations of sulphur in the stemflows would be a major concern in the acidification of forest soils in the Oil Sands area, but the estimated low amounts of the sulphur deposited through stemflows and the actual volumes of water deposited as stemflows suggest that soil acidification by stemflow is of a lower magnitude than by throughfalls.

4.3. ACIDITY AND SULPHUR CONTENT OF SNOW

Accumulated snow very close (Steepbank sites to the southeast) to the emission source in general was only slightly more acid than the accumulated snow from sites farther out (Table 15). Sulphur concentrations in the snow closer to the emission source, although low, averaged higher than concentrations in samples farther out. Basic cation contents of the snow at sites farther from the sulphur dioxide emission source were in excess of the sulphur (not sulphate) equivalents closer to the emission source; however, there essentially was a balance between the cations and the sulphur, except at one site (AOSERP Camp) where calcium concentration was high. Considering that the estimated amounts deposited by snow represent the totals deposited between the sampling date and the time snow started to accumulate permanently (about three and a half months), amounts of sulphur deposited in snow in the Oil Sands area are small. This same observation has been made in central Alberta (Nyborg *et al.*, 1973). Sulphur emissions from the plant therefore appear to be distributed widely beyond the Oil Sands area. Acidification of soils in forests of the Oil Sands area due to sulphur

TABLE 14. Estimates of amounts of sulphur deposited in soils by stemflow from July to mid-September, 1976. (kg/ha/month)[1,2]

Site No.[3]	Site	Direction[4]	Tree Species and Age	Distance (km) from emission source			
				0 to 25	25 to 50	50 to 100	over 100
Northerly Sites:							
1	AOSERP Camp	NW	Jack Pine - mature	.14[1]	-	-	-
2	McKay River	NW	White Spruce - mature	.16[1]	-	-	-
9	Bitumount	N	White Spruce - mature	-	.10[1]	-	-
11	Birch Mountain	NNW	Black Spruce - small	-	-	.01[2]	-
12	Richardson	NNE	Jack Pine - mature	-	-	-	.03[1]
Southerly Sites:							
7	Thickwood Hills	SW	White Spruce - mature	-	.13[1]	-	-
15	Hangingstone River	S	White Spruce - mature	-	-	.13[1]	-
13	Algar	SSW	White Spruce - mature	-	-	-	.06[1]
14	May	SW	White Spruce - mature	-	-	-	.05[1]
Easterly Sites:							
6	Steepbank Site #2	ESE	White Spruce - young	.19[2]	-	-	-
8	Muskeg Mountain	ENE	White Spruce - young	-	.19[2]	-	-
10	Gordon Lake	SE	White Spruce - mature	-	-	.01[1]	-
			Mean	.16	.14	.05	.05

---

[1] Assumes an even stand of 1250 mature trees per ha.

[2] Assumes an even stand of 3750 young/small trees per ha.

[3] See map showing site locations.

[4] In relation to emission source

TABLE 15. pH values, electrical conductivity, sulphur and basic cation concentrations in accumulated snow sampled on March 17 and 18, 1976.

Site[1]	Direction[2] and Distance (km)		Snow Depth (cm)	pH	Cond. µmho/cm	S (ppm)	Basic cations (ppm)				Excess Cations meq/ℓ	SO_4-S kg/ha
							Ca	Mg	Na	K		
May[3]	SW	172	38-43	5.6	6	0.28	0.32	0.08	0.51	0.32	0.03	0.30
Hangingstone River	S	67	33-38	6.0	6	0.40	0.29	0.12	0.50	0.40	0.03	0.34
Thickwood Hills	SW	31	38-41	5.6	7	0.25	0.27	0.08	0.28	0.67	0.03	0.26
AOSERP Camp	NW	11	30-41	6.3	7	0.52	0.75	0.21	0.20	0.22	0.05	0.54
Steepbank Site #1	ESE	17	38	5.1	6	0.32	0.26	0.06	0.23	0.15	0	0.32
Steepbank Site #2	ESE	4	41-43	5.4	7	0.40	0.31	0.11	0.23	0.17	0.01	0.44
Steepbank Site #3	ESE	2	38	5.5	8	0.53	0.31	0.10	0.23	0.23	0.01	0.52

---

[1] See map showing site locations

[2] In relation to emission source

[3] 6 km east of site shown on Map 1

deposited during the winter by snow may only be very slight.

4.4. SULPHUR DIOXIDE AND SULPHUR-BEARING PARTICULATES

4.4.1. Exposed distilled water

Amounts of sulphur absorbed at different sites by distilled water set out under rain shelters are given in Table 16. The actual sulphur concentrations detected in the distilled water were very low. Generally, the amounts of sulphur absorbed decreased with distance from the sulphur dioxide emission source. As sulphur dioxide gas would readily go into solution upon coming into contact with water, the amounts of sulphur detected in the water could be assumed to reflect the relative concentrations of the gas in the atmosphere at each site during the periods of exposure. (There was some restriction in air movement in the water exposure enclosure. The figures in the table should therefore be regarded only as rough indicators of sulphur dioxide concentration.) The results suggest that open water is also a mechanism for the deposition of sulphur.

4.4.2. Sulphur-bearing particulates

Amounts of sulphur deposited as particulates or in the form of dust were very low (Table 17) at all sites. Deposits at sites nearer the emission source were greater than deposits at sites more than 25 km away. The closest site (Steepbank, Site 2) received the largest dry deposits of sulphur. Dry depositions as observed here are rather insignificant as compared with wet depositions (Table 7); this also has been the observed elsewhere (Dovland *et al.*, 1976). Acidification of forest soils in the Oil Sands area through dry depositions of sulphur, with the probable exception of sites in the very close vicinity of the emission source, should be minimal in the short term.

4.5. SULPHATION DISCS

The amount of sulphur absorbed by the sulphation discs set out monthly in the summer is an indication of the relative concentration of sulphur dioxide gas present in the atmosphere at these sites (Table 18). Mean sulphur concentrations were higher

TABLE 16. Amounts of sulphur absorbed by distilled water set out monthly under rain shelters (µg/cm^2/month), June through September, 1976.

Site No.[1]	Site	Direction[2]	Distance (km) from emission source			
			0 to 25	25 to 50	50 to 100	over 100
Northerly Sites:						
1	AOSERP Camp	NW	1.3	-	-	-
2	McKay River	NW	1.4	-	-	-
9	Bitumount	N	-	2.8	-	-
11	Birch Mountain	NNW	-	-	1.0	-
12	Richardson	NNE	-	-	-	0.8
Southerly Sites:						
7	Thickwood Hills	SW	-	1.1	-	-
13	Algar	SSW	-	-	-	0.5
14	May	SW	-	-	-	0.4
Easterly Sites:						
6	Steepbank Site #2	ESE	3.6	-	-	-
5	Steepbank Site #1	ESE	1.6	-	-	-
4	Steepbank Site A	SE	-	0.9	-	-
8	Muskeg Mountain	ENE	-	6.2	-	-
10	Gordon Lake	SE	-	-	1.2	-
	Mean		2.0	2.7	1.1	0.6

---

[1] See map showing site locations

[2] In relation to emission source

TABLE 17. Amounts of sulphur in sulphur-bearing particulates deposited (kg/ha/mo). June through September, 1976.

Site No.[1]	Site	Direction[2]	Distance (km) from emission source			
			0 to 25	25 to 50	50 to 100	over 100
Northerly Sites:						
1	AOSERP Camp	NW	0.03	-	-	-
9	Bitumount	N	-	0.02	-	-
Southerly Sites:						
7	Thickwood Hills	SW	-	0.01	-	-
13	Algar	SSW	-	-	-	0.01
14	May	SW	-	-	-	0.01
Easterly Sites:						
6	Steepbank Site #2	ESE	0.07	-	-	-
10	Gordon Lake	SE	-	-	0.01	-
		Mean	0.05	0.02	0.01	0.01

---

[1] See map showing site locations

[2] In relation to emission source

TABLE 18. Sulphur absorbed by sulphation discs set out monthly from June through September, 1976 ($\mu g/cm^2$/month).

Site No.[1]	Site	Direction[2]	Distance (km) from emission source							
			0 to 25		25 to 50		50 to 100		over 100	
			mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Northerly Sites:										
1	AOSERP Camp	NW	12.6	6.1	-		-		-	
2	McKay River	NW	9.9	6.2	-		-		-	
9	Bitumount	N	-		7.9	6.8	-		-	
11	Birch Mountain	NNW	-		-		7.5	5.6	-	
12	Richardson	NNE	-		-		-		2.5	1.1
Southerly Sites:										
3	Supertest Hill	S	-		-		-		-	
7	Thickwood Hills	SW	-		2.3	1.2	-		-	
15	Hangingstone River	S	-		-		-		-	
13	Algar	SSW	-		-		-		2.4	1.0
14	May	SW	-		-		-		2.0	0.8
Easterly Sites:										
6	Steepbank Site #2	ESE	19.9	9.3	-		-		-	
5	Steepbank Site #1	ESE	7.2	3.3	-		-		-	
4	Steepbank Site A	SE	-		3.9	1.0	-		-	
8	Muskeg Mountain	ENE	-		15.9	14.8	-		-	
10	Gordon Lake	SE	-		-		3.6	1.3	-	
		Mean	12.4		7.5		5.5		2.3	

---

[1] See map showing site locations

[2] In relation to emission source

at sites closer to the sulphur dioxide emission source than at the sites much farther away. The monthly variability in concentration is high near the emission source, but relatively low at the remote (over 100 km) sites. At sites less than 100 km from the emission source, the monthly concentration levels appeared to be dependent on the total precipitation for the disc exposure period. When the first or second half of the month received particularly low total precipitation, the amounts of sulphur absorbed by the disc for that month usually were high.

4.6. ACIDIFICATION OF BARE SOILS EXPOSED IN THE FIELD

The pH values and sulphur concentrations in the top layers of samples of bare sandy soil and a bare mesic peat sampled from the Oil Sands area, contained in canisters and set out under rain shelters for four months, are given in Table 19. Mean pH values were lower nearer the sulphur dioxide emission source than at sites more than 50 km from the source. The pH value of the sandy soil at one site (Steepbank, Site 2) was particularly low in comparison with the values at all other sites.

The mean sulphur concentrations in the sandy soil and the peat were lower farther from the sulphur dioxide emission source, but concentrations were considerably higher closer to the emission source. Concentrations were particularly higher at two sites (Steepbank Site 2, and Muskeg Mountain) where sulphation disc concentrations also were high (Table 18), in the general easterly direction close to the emission source. The differences in acidity levels and sulphur concentrations in the bare soils set out were not so dramatic at the lower soil layers in the canisters. Length of exposure perhaps did not allow for small changes to be detected beyond the surface layer of the soils in the canisters. The sulphur as sulphate was the only form tested for in the soils in the canister; it is highly probable that some of the gas sorbed was sorbed in other forms which could not be recovered by the method employed in extracting the sulphur from the soil. It therefore is highly possible that these bare soils sorbed more sulphur than detected by the analytical method used for sulphur determination.

TABLE 19. pH values and sulphur levels (ppm) of a sandy soil and a mesic peat from the Oil Sands area set out under rain shelters from June through September, 1976. (Top 1 cm, means of three replications.)

Site No.[1]	Site	Direction[2]	Sandy Soil								Peat							
			Distance (km) from emission source								Distance (km) from emission source							
			0 to 25		25 to 50		50 to 100		over 100		0 to 25		25 to 50		50 to 100		over 100	
			pH	SO_4-S	pH	SO_4-S	pH	SO_4-S	pH	SO_4-S	pH	SO_4-S	pH	SO_4-S	pH	SO_4-S	pH	SO_4-S
Northerly Sites:																		
1	AOSERP Camp	NW	5.37	4.7	-	-	-	-	-	-	5.48	130.5	-	-	-	-	-	-
2	McKay River	NW	5.40	6.1	-	-	-	-	-	-	5.50	51.0	-	-	-	-	-	-
9	Bitumount	N	-	-	5.41	5.8	-	-	-	-	-	-	5.46	56.5	-	-	-	-
11	Birch Mountain	NNW	-	-	-	-	5.63	6.9	-	-	-	-	-	-	5.47	40.5	-	-
12	Richardson	NNE	-	-	-	-	-	-	5.45	1.7	-	-	-	-	-	-	5.58	59.0
Southerly Sites:																		
7	Thickwood Hills	SW	-	-	5.37	2.7	-	-	-	-	-	-	5.48	-	-	-	-	-
13	Algar	SSW	-	-	-	-	-	-	5.56	2.5	-	-	-	-	-	-	5.54	41.0
14	May	SW	-	-	-	-	-	-	5.61	2.1	-	-	-	-	-	-	5.55	63.0
Easterly Sites:																		
6	Steepbank Site #2	ESE	5.25	11.3	-	-	-	-	-	-	5.40	261.0	-	-	-	-	-	-
5	Steepbank Site #1	ESE	5.40	4.2	-	-	-	-	-	-	5.43	103.0	-	-	-	-	-	-
4	Steepbank Site A	SE	-	-	5.44	5.3	-	-	-	-	-	-	5.46	99.5	-	-	-	-
8	Muskeg Mountain	ENE	-	-	5.43	12.1	-	-	-	-	-	-	5.40	160.5	-	-	-	-
10	Gordon Lake	SE	-	-	-	-	5.50	3.2	-	-	-	-	-	-	5.53	46.5	-	-
		Mean	5.36	6.6	5.41	6.5	5.56	5.0	5.54	2.1	5.45	136.4	5.45	105.5	5.50	43.5	5.56	54.3

---

[1] See map showing site locations

[2] In relation to emission source

There may be other factors involved in the increased acidity levels and sulphur concentrations in the soils set out, but it would appear from the pattern established from site to site in relation to the sulphur dioxide emission source that the main cause of the changes observed is the amount of sulphur gas in the atmosphere at the site. It should, however, be stated that in natural forest the soils have surface litter or other plant cover and sorption of the sulphur dioxide gas would be much less than in the bare soils in canisters. Soils have great capacity for sorbing sulphur dioxide gas (Smith *et al.*, 1973, and Bremner and Barnwart, 1976). Sulphur dioxide gas in contact with the bare moist soils in the canisters at these sites therefore would be readily sorbed. Bare soils set out in the open under rain shelters elsewhere in Alberta (Nyborg *et al.*, 1974) have been shown to increase in acidity, a result attributed to sulphur emissions from gas plants.

4.7. SULPHUR DIOXIDE GAS SORPTION BY SOIL, PEAT, LICHEN, MOSS AND TRUNKS UNDER A CONTROLLED ENVIRONMENT

4.7.1. Soils and peat

Four mineral soils and a mesic peat which were exposed to low sulphur dioxide gas concentration under controlled laboratory conditions for 30 days sorbed the gas at various rates. These soils and peat showed depressions of varying degrees in pH value (Table 20). The two agricultural soils (Malmo and Studer) which are the finer textured of the four soils, decreased in pH value by essentially the same amount and sorbed the same amount of the sulphur dioxide gas. The pH of the coarse-textured unnamed non-agricultural mineral soils (Luvisols) decreased considerably although they actually sorbed less of the gas than the finer-textured agricultural soils. In terms of percentage increase over the levels in the controls, the amounts of sulphur dioxide gas sorbed were greater in the non-agricultural mineral soils from the Oil Sands area than in the agricultural soils. With the peat from the Oil Sands area, the depression in pH of 0.2 of a unit is considerable considering that peats normally are well buffered. The amount of the gas sorbed by the peat was considerably higher than the amounts sorbed by

TABLE 20. pH values and amounts of sulphur sorbed by soils after exposure to SO_2 gas under controlled conditions[1] (means of three replications).

	pH		SO_4-S (ppm)	
	Control	Exposed	Control	Exposed
Agricultural Soils:				
Malmo silt loam	5.89	5.81	8.5	61.3
Studer loam	6.43	6.30	5.9	61.7
Non-agricultural Soils:				
Pine Sand[2]	5.82	5.33	1.3	26.7
Loam[2]	6.15	5.85	2.9	40.1
Peat (mesic)	5.68	5.47	23.3	456.7

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[1] at 22°C, 70 ppb SO_2 and at 60% R.H. for 30 days

[2] un-named Luvisols which along with the peat were sampled from the Soil Sands area.

any of the mineral soils in both absolute amounts and in percentage increase over the controls. As discussed earlier for soils set out under rain shelters in the field, soils generally have a great capacity for sorption of sulphur dioxide gas. This again has been demonstrated under a controlled environment. Forest soils which have never been brought under cultivation also have been shown to be as capable of sorbing sulphur dioxide gas as cultivated soils, when exposed to the gas, and could become equally acidic. The peat exposed to the sulphur dioxide gas exhibited a very high capacity for sorbing the gas; as the Oil Sands area has wide expanses of moss-covered peatlands which are sources of many streams in the area, increased acidity of the peatlands also could affect many streams in the area in the long term.

4.7.2. Moss and lichen

Samples of potted lichen and moss, which are significant components of the forest floors in the Oil Sands area, when exposed to sulphur dioxide gas under control conditions changed in both pH value and in sulphur content (Table 21). The lichen and the moss underwent a considerable drop in pH value (by about the same amount)

TABLE 21. pH value changes and amounts of sulphur sorbed by potted Lichen and moss exposed to SO_2 gas under controlled conditions.[1]

	pH		SO_4-S (ppm)	
	Control	Exposed	Control	Exposed
Live moss[2]	4.57	4.36	488.0	597.0
Lichen[2]	5.14	4.90	10.5	88.5

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[1] at 22°C, 70 ppb SO_2 and 60% R.H. for 30 days

[2] includes the forest floor litter. Surface green portion of the moss.

after exposure to the sulphur dioxide gas, and also retained large amounts of the sulphur. Although numerical increase in the sulphur content of the moss was higher than that of the lichen, the percentage increase in the moss was only a small fraction of the percentage increase in the lichen.

In overwatered potted soils set out in the field under rain shelters in 1975, some moss growth occurred in some of the pots. Analysis of these growths of moss patches for sulphur (Table 22) showed that moss growths in pots near the sulphur dioxide emission source had higher sulphur concentrations. Although the mosses in the Oil Sands area are mostly growing in a near acid to acid environment, any increase in acidity probably would result in their dying off, as Abrahamsen *et al.* (1976) observed with high acidity of rain the moss cover in a lysimeter experiment died out.

4.7.3. Accumulation of sulphur in trunks

Exposure of pieces of trunks of some common tree species sampled from the Oil Sands area to sulphur dioxide gas under control laboratory conditions showed clearly that while all species tested would accumulate some sulphur on their bark (Table 23), there are differences between species. White spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) bark accumulated more of the sulphur than did white birch (*Betula papyrifera*) or trembling aspen (*Populus*

TABLE 22. Sulphur concentration in moss growth on some over-watered soils set out under rain shelters during the summer of 1975.

Site	Direction and distance (km) from SO_2 emission source		SO_4-S (ppm)	
			Malmo silty clay loam	Tiller loam
Syncrude Lower Camp	N	1.5	120.0	-
Steepbank Site #3	ESE	2	-	120.3
Steepbank Site #1	ESE	17	188.0	-
Thickwood Hills	SW	31	11.5	6.0

TABLE 23. Accumulated sulphur on the bark of portions of trunks on different tree species and white spruce seedlings exposed to SO_2 gas under controlled conditions[1].

Tree Species[2]	µg SO_4-S per cm^2		µg SO_4-S per g of needles (wet weight)	
	Control	Exposed	Control	Exposed
Trembling Aspen	0.41	0.64	-	-
Birch	0.29	0.48	-	-
White Spruce	0.69	1.10	-	-
Jack Pine	0.43	0.82	-	-
2.5-year-old white spruce seedling	-	-	23.6	31.4

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[1] 66 ppb SO_2, 25 to 30% R.H. at 22°C. Extracted with distilled water for 2 min.

[2] Trunks sampled from the Oil Sands area. Spruce seedlings obtained from the Provincial Tree Nursery, Edmonton.

tremuloides), which have comparatively smooth barks. Also, needles of young spruce plants accumulated sulphur when exposed to it. In forests of the Oil Sands area, soil acidification attributable to dry deposits on trunks, as demonstrated by the results of the experiment, would be expected to be more serious in jack pine forests (where the soils are mostly sands and subject to becoming acid with relatively low levels of sulphur additions) and spruce forests than in birch or poplar forests.

5. CONCLUSIONS AND RECOMMENDATION

The conclusions and recommendation given here are based on the results of the past year's research project and also draw heavily on research carried out in the Oil Sands area by the Department of Soil Science, University of Alberta prior to the inception of this project.

Precipitation in the Oil Sands area is no more acid than precipitation at remote (control) sites in northern Alberta. There are, however, occasions when the incident precipitation is acid near the sulphur dioxide emission source. Sulphur deposited by precipitation (incident and intercepted) and snow, however, is higher in areas close to the sulphur dioxide emission source than at sites farther out and at the remote sites. The Oil Sands area generally does not receive excessively large amounts of sulphur deposits at the present time. Sulphur deposited in throughfalls is several times higher than that deposited by the incident rain. The acidity of stemflows, especially of spruce, is high; however, because of the low volumes of stemflows the higher sulphur concentrations found in stemflow does not make it as important as throughfall in terms of the amounts of sulphur deposited.

Soils with surfaces kept bare, set out in the field under rain shelters during the warmer months of the year, have absorbed sulphur dioxide from the air as indicated by their slight increase in acidity and sulphate-sulphur concentrations in the surface layers. Moss and lichen exposed to the gas also have shown changes similar to those observed in the bare soils. Under natural conditions the native soils of the Oil Sands area which naturally are not bare will not become acid as fast as the bare soils under the same conditions. The native soils, however, also receive wet deposits of sulphur (incident and intercepted rain) which the field studies show to be much more important than dry deposits in amounts of sulphur deposited and which might be significant in acidification of soils. The implication here is that the amounts of sulphur estimated to be deposited by the various means in the soils of the Oil Sands area, although presently relatively low, could in the long term cause serious acidity problems at least on the sandy soils. The situation would be more serious with the development of more Oil Sands processing plants.

Soils have been demonstrated to be an important natural sink for gaseous industrial pollutants and to have a substantial capacity for sorption of sulphur dioxide, hydrogen sulphide, and methyl mercaptan, and are being considered as a vehicle for the purification of industrial emissions containing sulphur gases (Bremner and Barnwart, 1976, and Smith *et al.*, 1973). In exposing different soils and peat to sulphur dioxide gas in the laboratory, a major result of significance is the ability of the moist peat from the Oil Sands area to sorb very large quantities of the gas, over eight times the highest amounts sorbed by any soil (Table 20). Can peat then be used for reducing industrial sulphur dioxide emissions, e.g. from Oil Sands processing plants? Placement of moist peat "filters" in the emission stacks or above them, without igniting the peat, to sorb sulphur dioxide gas should significantly decrease the amount of sulphur dioxide emitted. If the sulphur sorbed by the peat could be recovered by another process and if it has a commercial value, the peat "filters" may be feasible for industrial use. An investigation of the engineering aspects of such a peat filtration process relative to other processes may be worthwhile.

6. NEED FOR FURTHER STUDY

The acidifying effects of sulphur dioxide on a soil are well known; presumably the same should be expected on the soils of the Oil Sands area. The rate at which the soils of the Oil Sands area may become acidic as a result of sulphur depositions resulting from the development of the processing plants may be difficult to predict accurately. Bare soils set out in the Oil Sands area have decreased slightly in pH values. Estimates of the amounts of sulphur deposited by various means with only one processing plant so far in operation suggest that the native soils of the area will become acidic more slowly with increased distance from the sulphur dioxide emission source; in the very close vicinity of the emission source the rate could be greater, especially on the sandy soils.

Some studies already initiated in this project and reported herein should be continued on a long-term basis. The "permanent" acidification experiment (Section 3.10) laid out on native soils should be continued throughout the life of the project to verify results so far obtained under artificial conditions. The physico-chemical changes observed in these plots represent actual changes in the natural soils of the area which may affect their ability to maintain the present vegetative cover. Estimation of the amounts of sulphur deposited in the soils by various means (Sections 3.3, 3.4, 3.5, and 3.7) should be continued on a very limited scale (less frequent sampling). Continuation, especially after the second processing plant goes on-stream, would further improve the accuracy of predictions of the rate of acidification of the soils. Studies of sulphur movement through the soil profile and the leaching of plant nutrients (Section 3.11, lysimeter studies) initiated this year at nine of the research sites should be continued for the life of the project. In the short term, however, the effects of simulated acid rains on some soils of the Oil Sands area should be initiated in lysimeter experiments to assist in predicting the long-term effects of sulphur deposits from the Oil Sands processing plants on the soils of the area. For the coming years, liming experiments should be established in the field on artificially acidified soils and unacidified soils to determine if soil acidification could be corrected or averted without damage to the forest undergrowth and trees.

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