S. K. Takyi, M. H. Rowell, W. B. McGill, M. Nyborg

Department of Soil Science
University of Alberta

ENVIRONMENTAL RESEARCH MONOGRAPH 1977-1
A Public Service of
Syncrude CANADA LTD.

RECLAMATION AND VEGETATION OF SURFACE MINED AREAS IN THE ATHABASCA TAR SANDS

RECLAMATION AND VEGETATION OF SURFACE MINED AREAS IN THE ATHABASCA TAR SANDS

S.K. Takyi
M.H. Rowell
W.B. McGill
M. Nyborg

Department of Soil Science

University of Alberta

Cover Photo by: S.J. Elliot

FOREWORD

Syncrude Canda Ltd. has commissioned a series of studies concerning the revegetation of disturbed areas in the Athabasca Tar Sands. The following report deals with experiments carried out on a dike on Great Canadian Oil Sands Ltd.'s Lease, and with experiments performed in a growth chamber by University of Alberta researchers.

It is Syncrude's policy to publish its environmental consultants' final reports as they are received, withholding only proprietary technical information or that of a financial nature. Because we do not necessarily base our decisions on just one consultant's opinion, recommendations found in the text should not be construed as commitments to action by Syncrude.

Syncrude Canada Ltd. welcomes public and scientific interest in its environmental activities. Please address any questions or comments to Syncrude Environmental Affairs, 9915 - 108 Street, EDMONTON, Alberta, T5K 2G8

ACKNOWLEDGEMENTS

The one-year research projects reported here were conducted by the University of Alberta (Department of Soil Science) for Syncrude Canada Limited under Contract No. 5-39619 Vol. 12.

We wish to acknowledge the co-operation and assistance of several people. Mr. Don Klym, Reclamation Officer, and Mr. Cliff Berry of Great Canadian Oil Sands Limited (GCOS), Fort McMurray, contributed substantially to the study, especially in providing background information on the vegetation program carried out on the tailings pond dike. Special acknowledgements go to Mr. Klym for his overall helpfulness to us during the time we spent in Fort McMurray.

We are also indebted to Dr. Herman Vaartnou and Mr. Jerry Wheeler of the Plant Industry Laboratory, Alberta Department of Agriculture, and to their technical staff, for providing us with the seeds of the native and cultivated grass and legume species which were used in our studies. We are especially grateful to Dr. Vaartnou for providing us with growth chamber facilities.

Mr. Robert Logan's heavy involvement in the project is gratefully acknowledged. The assistance of Mrs. Susan Putz, Mr. Nicholae Velcelean and Mr. Lawrence Jensen of the Department of Soil Science, University of Alberta, and of Mr. Lloyd Hodgins, Mrs. Shelley Eliuk and Mr. Roy Panasiuk of the Alberta Soil and Feed Testing Laboratory, Alberta Department of Agriculture, either in the field, laboratory or growth chamber, is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

INTRODUCTION

One of the major environmental problems which arises with surface mining of the oil sands in the Fort McMurray-Fort MacKay area of Alberta is the permanent loss of the natural vegetation and the drastic change in the soils that supported it. It has been estimated that with a production target of one million barrels of crude oil per day approximately two thousand acres of land will have to be cleared every year. Most of the disturbed areas eventually must be vegetated again; these include the overburden piles and the tailings sand. In vegetating such areas several problems such as salinity, oil, low fertility, erosion and unfavorable soil reaction have to be contended with. There has been some success in the general vegetation program on the Great Canadian Oil Sands Ltd. lease, but the problems listed above still have to be studied and solutions for them found. The following research projects were undertaken to solve some of these problems.

SUMMARY AND RECOMMENDATIONS

Surface mining of the Alberta oil sands requires the clearing of natural vegetation from thousands of acres of land. Under other circumstances these cleared areas should present few problems for revegetation programs, but major problems arise in mined areas and in areas where mine wastes are deposited. The wastes include tailings sand, overburden materials (which may contain oil-bearing materials and may present salinity and alkalinity problems), and coke and sulfur (by-products of the upgrading process which could damage vegetated areas through wind-blown dust deposits). A likely problem in the future is the damage that would be caused over wide areas to the soil and vegetation by the sulfur dioxide emissions from the processing plants. The only operating plant in the area, Great Canadian Oil Sands Ltd (GCOS), has embarked on a program to vegetate the tailings pond dike, whose outer shell consists of tailings sand, and also the overburden piles.

Investigations carried out over a one-year period examined some of the materials at hand and techniques available for solving some of the existing known problems in vegetating the mine wastes. A number of plant species, both cultivated and native, were grown in growth chambers on the waste materials to determine the performance of the species under different salinity, soil reaction, fertility, soil mix, and oil conditions. A second major study, a field trial on an already vegetated area on the GCOS tailings pond dike, was conducted to determine responses of the already established vegetative cover to different fertility levels, and to determine the fate of added fertilizer nutrients. The materials used in preparing various "soil mixes" were characterized chemically and biologically.

The problems outlined require long-term studies to come up with conclusive recommendations. The following main conclusions are based on the results obtained over a one-year period only, and must, therefore, be considered as tentative:

(1) *To vegetate areas where heavy oil sands may be present, it is recommended that the oil sand-bearing materials be mixed with fertilizer and a good soil material and left for a growing season before seeding, at which time fertilizers should again be applied.*

Several plant species, both native and cultivated, were demonstrated to grow well on the oil-bearing materials under a controlled growth chamber environment if suitable conditions such as proper fertilization and proper soil mixes are provided.

(2) *In areas where salinity levels are extreme, normal chemical means of reclaiming saline soils before sowing may be the only solution to this problem. Where salinity is low to moderate, tolerant plant species could be seeded without chemical reclamation.*

Salinity problems that may be encountered in such mining operations are of two types. The first is where already vegetated areas of the tailings pond dike progressively increase in salinity, as through water seepage, and the second is where high salinity levels exist before a vegetation program is initiated. This is mainly associated with saline overburden materials. (There are reports published elsewhere which outline chemical procedures for reclaiming salt-affected soils.) Several legume and grass species were tested under a controlled growth chamber environment at salinity levels which simulated those that would be encountered in the two types of salinity problems to be expected. One native grass species and one cultivated grass species were found to grow fairly well at relatively high salinity levels on a soil mix composed of mine waste materials mixed with peat.

(3) *In areas of high pH (about 10) it is recommended that acidification, and correction of salinity problems where they may also exist, be carried out before seeding.*

In the soil pH range that may be normally encountered (slightly acidic to slightly alkaline) in a vegetation program, any of the plant species could be grown successfully. Where very high pHs were artificially created, there was no germination of plant species seeded on the soil mix composed primarily of mine waste materials.

(4) *Although the advisability of using legumes during the initial phase of dike vegetation requires further study, they can be grown successfully if the mix is near neutral and the seeds are inoculated with proper inoculants, assuming plant nutrients are provided in the mixes.*

Nitrogen fixation in soil mixes, made up of mine waste materials and peat, apparently occurred in the legume species tested when conducive conditions were created or already existed in the soil mixes.

(5) *To ensure balanced stands of legumes and grasses it is recommended that seeding mixtures consist of species of grasses and legumes which would compete on an equal basis, or to use a larger percentage of legume seeds in the seeding mixture, and to ensure soil conditions favoring legumes in competition with grasses.*

Plant growth (legume and grass mixtures) was good on several soil mixes consisting of the mine wastes mixed with peat with adequate fertilization, although not nearly as good as growth obtained on a good agricultural soil (Malmo silty clay loam). In the few months that the legume-grass mixtures were grown, the grasses appeared to be more competitive as they gave higher yields than legumes. The presence of adequate mineral nitrogen supply in the soil favored grasses over legumes when they were grown together.

(6) *One fertilizer application per growing season may be all the fertilizer that would be required in a vegetation program. Initial fertilizer rates should not be less than 80 lb N, 40 lb P and 80 lb K per acre per year after the establishment of vegetation. Liming would be necessary if the soil became more acid, as from fertilization and sulfur dioxide emissions from the processing plant.*

Fertilizer losses through run-off water were apparently negligible where vegetative cover was adequate. Significant leaching losses of fertilizer nitrogen were not detected with normal rainfall intensity. Although a complete nitrogen balance has not been drawn, results to date indicate that most of the fertilizer nitrogen applied during the growing season can be expected to be utilized by the vegetative cover.

(7) *A seedbed allowing for deeper root penetration is of high priority in establishing greater slope stability.*

Root penetration of the dike was restricted almost exclusively to the surface peat layer. Although this was enough to maintain slope stability with normal surface run-off, serious erosion and washouts occurred with heavy surface run-off due to above average rainfalls.

(8) *Under appropriate management any of the tested species could be grown on several soil mixes composed of tailings sand, peat and overburden materials.*

(9) *The cultivated species grew at least as well as the native species in the short term experiments.*

(10) *The capacity of soils to withstand acidification will be an important consideration in revegetation in the area. Tailings sand, lean and heavy oil sands were extremely poorly buffered against acidity. Under the conditions likely to prevail near an extraction plant they could be expected to be acidified to levels at which plant growth would be eliminated with ten years exposure. When mixed with peat and overburden materials the buffering capacity of tailings sand could be improved to acceptable levels.*

(11) *The study of general microbial populations, specific types of organisms and enzyme activities provided a baseline of biological information and enabled an assessment of the potential of mine materials to cycle nutrients. No material was devoid of microbial activity. The high input of sulfur into the soils resulted in low aryl sulfatase activities and high populations of sulfate reducing organisms. Low phosphatase and protease enzyme activities linked with low levels of organic nitrogen indicated a limited ability of the tailings materials and overburdens to supply available nitrogen and phosphorus to plants. Natural levels of atmospheric nitrogen fixation by free-living micro-organisms was extremely low.*

PART I

ANALYTICAL METHODS

(a) Routine soil and plant analysis

Soil samples and other material collected from the mine leases were air dried and screened with a 2mm sieve before being analysed. Soil samples taken from the experimental plots on the G.C.O.S. tailings pond dike and those from pots in the growth chambers were similarly treated. The heavy oil sand was the only material that was maintained field-moist for all analyses.

The harvested plant materials from both the field and growth chamber experiments were dried in a forced-air oven at 70 C for 48 hrs. before dry weights were determined. Dried plant samples were ground to pass a 20-mesh sieve before they were chemically analysed.

Chemical and mechanical analyses of samples were carried out by standard methods as detailed in "Methods of Soil Analysis" (Agronomy Monograph No. 9 Parts I and II, 1965).

Mechanical analysis of soils and related materials were done by the hydrometer method. Soil pH was measured in a 2:5 soil/water paste with a glass electrode. Electrical conductivity was determined in a saturated paste extract. Total nitrogen contents of soils and plant samples were determined by micro-Kjeldahl wet oxidation. Mineral nitrogen was determined by steam distillation after extraction with potassium chloride. The organic carbon content of soils was estimated by the Walkley-Black wet digestion method. Sulfate-sulfur was measured by the Johnson-Nishita method. Cation exchange capacities were determined by ammonium saturation and exchangeable cations were measured by atomic absorption spectroscopy of the ammonium acetate leachate. Available phosphorus was extracted in an H_2SO_4/NH_4F extracting solution. Carbonates were determined by the acid neutralization method. Oil contents were measured gravimetrically by extraction in cellulose thimbles in a Soxhlet extractor using methylene chloride. Oil was weighed after the methylene chloride had been distilled off. Oil contents were expressed as a percentage of oven dry oil-free soil.

(b) Special methods

(i) Chemical

Total nitrogen was determined by the method of Bremner (1965a). The procedure for acid hydrolysis and subsequent analysis of different forms of nitrogen is similar to that described by Bremner (1965b).

The buffering characteristics of the soils were studied by measuring the change in soil pH after the addition of different amounts of alkali, as calcium hydroxide, or acid, as sulfuric acid. For increasing the soil pH, 30 ml of distilled water was added to small disposable cups containing 10g of dry soil, weighed amounts of $Ca(OH)_2$ were added and the soil paste stirred intermittantly over the next three days. The pH was checked until it reached a constant value. A similar procedure was followed to study pH reductions although here different volumes of 0.05N H_2SO_4 were added to the soil and the total volume of liquid added kept constant at 30 ml by addition of distilled water. From the results buffering curves were produced by plotting meq of H^+ or OH^- added against soil pH.

(ii) Microbial

Numbers of bacteria and fungi present in the soils and mixes were determined by plate count methods. Bacteria were counted on standard Plate Count

Agar (Difco). Fungi were counted on Rose Bengal Streptomycin Agar. Organisms capable of growth on fatty acids were counted on Ammonium Stearate Agar. The composition of each medium is given below.

Difco Plate Count Agar:

Ingredients/litre

Bacto Tryptone	5g
Bacto Yeast extract	2.5g
Bacto Dextrose	1g
Bacto Agar	15g

Rose Bengal Streptomycin Agar:

Glucose	10g
Peptone	5g
KH_2PO_4	1g
$MgSO_4.7H_2O$	0.5g
Agar	15g
Rose Bengal	33g
Water	1000ml

Medium was sterilized and when cooled, but not set, filter sterilized streptomycin was added to give a final concentration of 30 µg/ml.

Ammonium Stearate Agar:

Yeast extract	2.50g
Tryptone	2.00g
Sodium acetate	0.20g
Agar	15g
Water	1000ml

The pH was adjusted to 8.0. Ammonium stearate was added at a rate of 3g/L as an ultrasonified paste and the medium sterilized. Plates were poured very hot and allowed to rapidly cool.

The soils were incubated at field capacity for two weeks at 25 C before they were plated. Appropriate dilutions were made of each soil using sterile distilled water as the diluent. Two replicates of each soil or mix were used and 4 replicate plates at each of 3 dilutions were plated. A 0.1 ml aliquot of each dilution was spread per plate. After incubating the plates for 10 days at 20 C the number of bacterial and actinomycete colonies that had developed on the Plate Count Agar plates were counted. Rose Bengal and Ammonium Stearate plates were counted after 14 days.

Most probable number counting methods were used to study soil algal populations and sulfate reducing and nitrate reducing organisms.
In each case the soils or mixes were incubated for 2 weeks at field capacity prior to testing. A ten gram sample of each soil was taken in duplicate and soil dilutions were prepared using sterile distilled water as the diluent. The range used in each case was 1:10 to 1:100,000. The different liquid media used for each experiment is given below. A 1ml aliqot of each soil dilution was aseptically transferred to tubes containing 9 ml of the medium. Five replicate tubes of each dilution were used.

Sulfate Reduction Medium:

KH_2PO_4	0.5g
NH_4Cl	1.0g

Na_2SO_4	4.5g
$CaCl_2,6H_2O$	60mg
Yeast Extract	1.0g
$FeSO_4,7H_2O$	0.1g
Na citrate.$2H_2O$	0.3g

The pH was adjusted to 7.5 and the medium diluted to 1000 ml and sterilized. After dispensing into tubes one sterile nail was added to each.

Nitrate Reduction Medium:

$CaCl_2$	0.05g
K_2HPO_4	0.50g
NaCl	0.50g
$MgSO_4.7H_2O$	0.20g
$NaNO_3$	2.00g
Glucose	10.00g
Peptone	0.50g
Yeast Extract	1.00g

The pH was adjusted to 7.8, the medium diluted to 1000 ml and sterilized.

Algal Medium (Bristols)

$NaNO_3$	1.0g
KH_2PO_4	1.0g
$MgSO_4,7H_2O$	0.3g
$CaCl_2$	0.1g
NaCl	0.1g
$FeCl_3.6H_2O$	10mg

Make to 1000 ml and sterilize.

For counting algae, test tubes were incubated at 20 C for 6 weeks under fluorescent light illumination. After 6 weeks the tubes were examined and scored either positive or negative for algal growth by the presence or absence of green coloration within the tube. By reference to statistical tables (Cochran, 1950) the results can be converted into the most probable number of algal cells contained within each particular soil or soil mix.

The tubes of innoculated sulfate reducing medium were allowed to incubate for 6 weeks at 25 C. After this time the tubes were examined. The growth of sulfate reducers was indicated by a black deposit of iron sulfide on the mail. Using the same tables as were used for algae, the numbers of sulfate reducers could be determined.

Innoculated tubes of the nitrate reduction medium were allowed to incubate for 2 weeks at 25 C. Small samples of culture fluid were then removed from each tube and analyzed for the presence of nitrite and nitrate. A sulfanilic acid/ 1-naphthylamine reagent was used to semi-quantitatively detect nitrite while diphenylamine was used to detect nitrate. Statistical tables were again used to calculate the most probable number of these organisms present in the soil mixes.

The natural level of nitrogen fixation occurring in the soils and mixes was determined by acetylene reduction using a method similar to that described by Rice and Paul (1971). About 100g of each soil was incubated at 15.5 C for two weeks at field capacity. Duplicate 20g samples of each soil were weighed into small glass bottles with a capacity of 60 ml. Bottles were capped tightly with serum stoppers and 20 ml of air was removed with a syringe and replaced with a similar volume of pure acetylene. The bottles were incubated at 20 C for 90 minutes. A 1 ml gas sample was removed from each and the amount of ethylene produced determined by gas chromatography using a Beckman GC 4 instrument equipped with a hydrogen flame ionization detector. The column was packed with Poropak R and was run at 55 C with nitrogen carrier gas at a flow rate of 60 ml/min. Injection and detector ports were maintained at 80 C and 65 C respectively. Mixtures of N_2/ethylene were prepared to produce a standard curve to calibrate the machine.

To determine soil respiration, air dry soil (100g) was weighed into litre capacity glass containers and the soil moistened to field capacity. Samples were maintained moist and stirred daily for two weeks. After this preincubation period a small glass vial containing 2 ml of 0.48M NaOH and a filter paper wick was placed inside the flask on the soil surface. The containers were sealed and incubated at 15.5 C for 24 hours. The vials were removed, the sodium hydroxide carefully washed into a 125 ml erlenmeyer flask and an excess of barium chloride added. Sodium carbonate produced by the reaction of sodium hydroxide and the CO_2 produced by the soil is converted into insoluble barium carbonate. The amount of NaOH remaining was determined by titration against

0.1M HCl. Duplicate sets of each soil were used and measurements of CO_2 evolution continued until the values obtained were constant.

(iii) Enzyme assays

Sulphatase activity:

Soil that had been preincubated for at least two weeks was weighed out in amounts of 1-2g into screw capped tissue culture tubes. 1 ml of the substrate p-nitrophenyl sulphate was added together with 4 ml of 0.5M, pH 5.8 sodium acetate buffer. The culture tubes were incubated for 30-60 minutes at 35 C in a shaking water bath set at 120 oscillations per minute. The reaction was terminated by the addition of 1 ml of 0.5M $CaCl_2$ and 1 ml of 0.5M NaOH. A similar control set of tubes was prepared which received the same treatment with the exception that substrate was not added until the end of the incubation. Each reaction was carried out in triplicate. For the most active soils a more precise estimation of activity could be gained by using a range of substrate concentration (5×10^{-4}M to 6×10^{-3}M). Soils with low activity were tested at one substrate concentration of 10^{-2}M. After the addition of sodium hydroxide and calcium chloride the tubes were centrifuged and the absorbance of the supernatants measured at 400 nm. The amount of p-nitrophenol released from the substrate was determined by reference to a standard curve using p-nitrophenol solutions of different concentrations that had been given the same treatment as the soil. With the less active soils the velocity of reaction using 10^{-2}M concentration of substrate was assumed to approximate to the real maximum velocity.

Phosphatase:

A similar procedure was followed as for sulphatase activities. Amounts of soil varied from 0.5-2.0g and the tubes were incubated for 30-60 minutes at 25 C. The substrate used was disodium p-nitrophenol phosphate hexahydrate at the same concentrations that had been used for measurement of sulphatase activity. The buffer used was Modified University Buffer (pH 6.5) made up as follows:

Tris	3.025g
Maleic acid	2.900g
Citric acid	3.500g
Boric acid	1.570g

Dissolved in 100 ml distilled water, adjusted to pH 6.5 wit 1N NaOH and then diluted to 250 ml.

Protease:

Protease activity was determined by slight modification of the method of Ladd and Butler (1972). Soil was incubated at field capacity for two weeks and to a sample of 1-2g was added 1 ml of sodium caseinate (25 mg/ml) and 4 ml of 0.02M Tris-HCl buffer, pH 8.1. Duplicate sets of tubes were incubated at 50 C for 60 minutes and shaken lengthwise at 120 oscillations per minute. Enzyme activity was stopped by the addition of 1 ml 17.5 percent trichloracetic acid (TCA). After centrifugation, a 1 ml sample was rapidly mixed with 1.5 ml 2.8N Na_2CO_3 and 1 ml of a six-fold diluted Folin reagent (Fischer Scientific standard reagent). Absorbances were determined at 700 nm and related to those of similarly treated tyrosine standards. Control tubes were included in the assay to allow for any TCA-soluble material present in the substrate and soil. Activities were expressed in μM tyrosine equivalents produced/g oven dry soil/hr. No measurements of Km or Vmax are possible with this method.

PART II

FERTILIZER EXPERIMENT ON VEGETATED DIKE, GCOS TAILINGS POND - FORT MCMURRAY

SITE

The site chosen for the fertilizer experiment occupies the bottom part of the slope of the Great Canadian Oil Sands (GCOS) tailings pond dike, which is situated on the western bank of the Athabasca River approximately 22 miles north of Fort McMurray. The experimental site is on the eastern slope of the dike and ranges between a 23^{o} and 28^{o} inclination.

HISTORY

The site is one of the areas on the dike which first received tailings sand from the GCOS oil extraction plant. It therefore represents the oldest substantial accumulation of tailings sand from oil sands extraction. A vegetation program was first started in this area by GCOS. Peat was first moved onto the site in the winter of 1970-1971 and mixed with the tailings sand to depths generally ranging from two to six inches. The site (elevation 827 feet) was soil sampled in September 1969, after the sand had been accumulated for some time, the soil test results given in Table 1 were obtained.

The reaction of the tailings sand was alkaline but the sodium level was low and the electrical conductivity (salt) measurement indicated no potential problems of damage to plant growth by salt. Plant nutrient levels of nitrogen, phosphorous and potassium were very low.

Table 1. Pre-seeding nutrient levels (September, 1969) and nutrient levels in November, 1974 of a vegetated GCOS tailings pond dike.

	pH	Cond. (mmho/cm)	NH_4^+ (ppm)	NO_3^- (ppm)	Total mineral N (ppm)	% total N	P (ppm)	K (ppm)	Sulphate S (ppm)	Na (ppm)	% Organic C
Pre-seeding soil test[*] results (tailings sand), September 1969.											
0-12 in	8.5	0.5	--	0	--	--	3.5	12	--	low[+]	--
12-24 in	8.4	0.5	--	0	--	--	2.5	6	--	low[+]	--
24-36 in	8.5	0.5	--	0	--	--	3.0	8	--	low[+]	--
Nutrient levels of vegetated tailings (mixed with peat) pond dike, November 1975 sampling.											
0- 6 in	6.4	0.60	0.68	0.07	0.75	0.24	13.20	47.17	58.78	51.00	5.69
6-12 in	6.4	0.85	0.52	0.09	0.64	0.09	2.57	17.83	71.53	37.67	1.39
12-24 in	6.9	0.43	0.40	0.05	0.45	0.01	1.07	14.83	19.89	30.33	0.47

[*]Alberta Soil and Feed Testing Laboratory. Report No. B 19522, Lab. No. 1999

(Note: These figures represent nutrient levels of the tailings sand before mixing with peat.)

In the spring of 1971 the general area of the experimental site was seeded with a mixture having the following composition:

Seed mixture (percent by volume)

1.	Bromegrass (*Bromus inermis*)	33%
2.	Crested wheat grass (*Agropyron cristatum*)	24%
3.	Creeping red fescue (*Festuca rubra*)	15%
4.	Sweet clover (*Melilotus*)	14%
5.	Alsike (*Trifolium hybridum*)	14%

(Both legumes were inoculated with commercial inoculants.)

Seeding was accomplished by using a hydroseeder, at a seeding rate of 30 lb per acre.

In May 1971 the first fertilization was done, using a hydroseeder. Between May 1971 and July 1974 GCOS made six applications of commercial fertilizers on the vegetated area (Table 2).

EXPERIMENTAL OBJECTIVES AND PROCEDURES

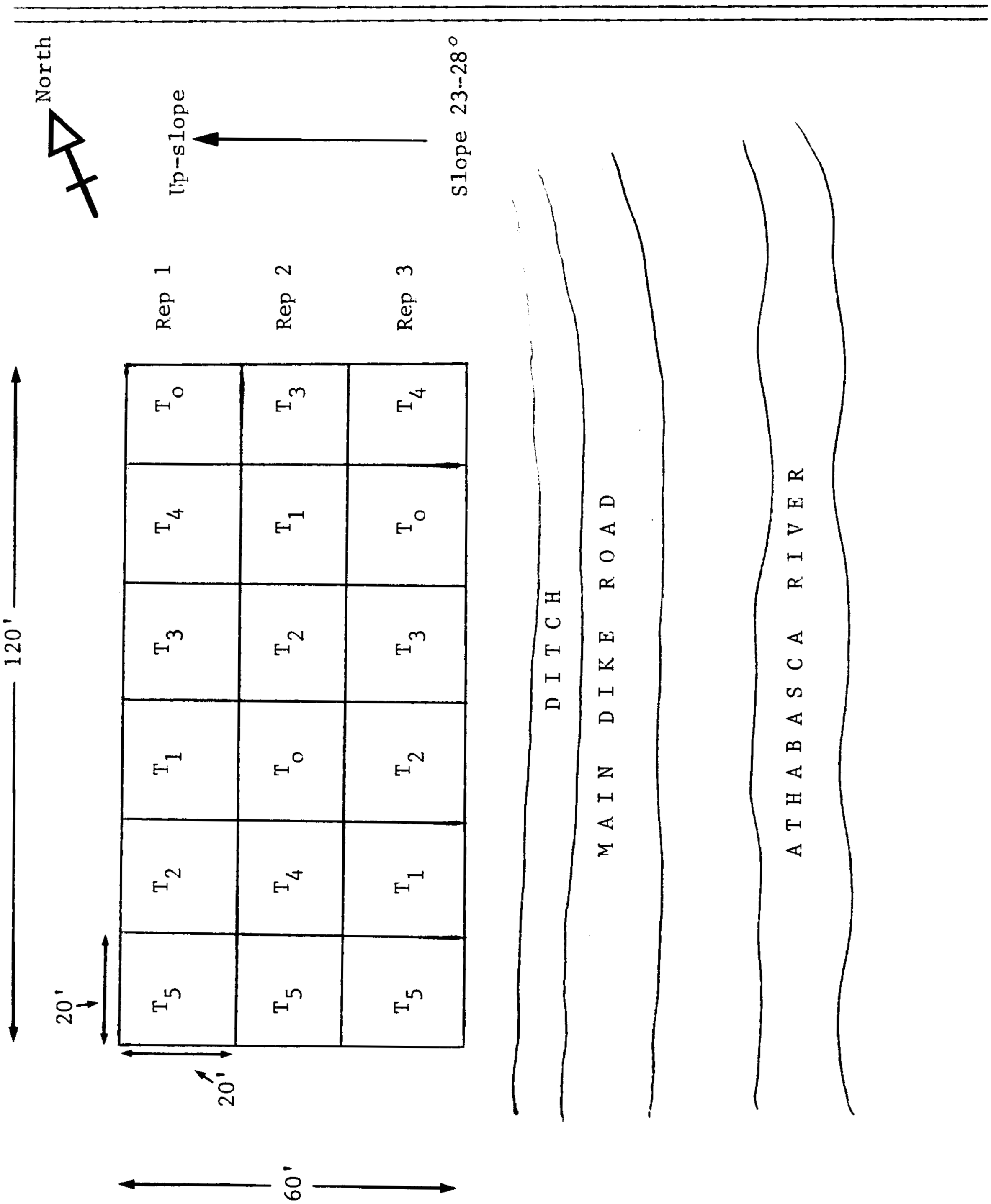
On November 14, 1974 the experiment was laid out in a randomized block design with each anticipated treatment replicated three times. Soil samples were taken at depths of 0 to 6 inches, 6 to 12 inches and 12 to 24 inches, from eight sampling cores from each anticipated treatment area, as indicated in the plan (Figure 1), excluding the GCOS treatment rate (T_5).

The objectives of the fertilizer experiment on the vegetated tailings pond dike were to determine (a) the fate of fertilizer nutrients applied on the dike by determining plant uptake, the extent of losses, and to find ways to minimize such losses, and (b) the type of fertilization program required after the initial establishment of grass cover (this is anticipated to help solve several existing problems).

Table 2. Fertilizer amounts applied and methods of application on a vegetated G.C.O.S. tailing pond dike between seeding in May 1971 and July 1974.

Date		Method of application	Nutrient ratios	Rate per acre (lb)	Nutrient equivalent, lbs. per acre		
			$N:P_2O_5:K_2O$		N	P	K
May	1971	hydroseeder	10:30:10	400	40	52.3	33.3
September	1971	broadcast	6-24-24	200	12	20.9	39.9
			33.5-0-0	200	67	-	-
June	1972	broadcast	6-24-24	100	6	10.5	20.0
			33.5-0-0	100	33.5	-	-
May	1973	broadcast	15-15-15	200	30	13.1	24.9
August	1973	broadcast	15-15-15	200	30	13.1	24.9
July	1974	broadcast	15-15-15	200	30	13.1	24.9
				TOTAL	248.5	123	167.9

Fig. 1. Original field plan of fertilizer experiment on a vegetated area of the GCOS tailings pond dike.



Cont'd

Fig. 1 (Cont'd.)

Fertilizer Treatments:

T_o = No fertilizer or lime (Nil).

T_1 = 80 lb. N, 20 lb. P, 80 lb. K and 8 lb. S per acre per year (NPKS).

T_2 = Same as T_1 plus 5 tons per acre of lime in the first year only (NPKS + lime).

T_3 = 160 lb. N, 40 lb. P, 160 lb. K and 16 lb. S per acre every other year ($N_2P_2K_2S_2$)

T_4 = Same as T_3 plus 5 tons per acre of lime in the first year only ($N_2P_2K_2S_2$ + lime)

T_5 = G.C.O.S. 1975 fertilizer rates (lb. per acre) (GCOS rate)

	Spring (June)	Summer (August)	Total
N =	13.5	24	37.5
P =	5.2	5.2	10.4
K =	10	10	20
S =	12	24	36

Sources: N = Ammonium nitrate
Ammonium phosphate
P = Ammonium phosphate
K = Potassium sulphate
Potassium chloride
S = Potassium sulphate
Lime = Finely ground agricultural lime

and for treatment T_5

N = Ammonium sulphate and 6:24:24
P & K = 6:24:24
S = Ammonium sulphate

It is anticipated that most of the answers to the stated objectives can be found in the data collected from these experiments in the next three to five years. Information on several additional aspects of objective (b) is also expected including (i) times (dates) of fertilizer application, (ii) intervals between fertilizations (yearly, etc.), (iii) best nutrient ratios, (iv) liming program under a system that may become progressively more acid with time, (v) ensuring a good stand of mixed species under a special fertilization program, and (vi) the establishment of self-sustaining plant cover on the dike.

SITE CONDITIONS

The soil samples taken in November 1974 were analyzed to establish the nutrient status of the area. A summary of the soil chemical properties is given in Table 1. The reactions of the three sampling depths were neutral to slightly acid. No lime has ever been applied to this site; it would thus appear that the peat used in vegetating this site was a near neutral peat.

At the time of soil sampling in November 1974 a visual survey of the plots was made. Each plot had almost 100 percent grass cover, with an estimated composition of 90 percent creeping red fescue, 9 percent bromegrass and 1 percent others. There were virtually no legumes, either seeded or voluntary, present in the plots. The total disappearance of the legumes four years after seeding could therefore not be due to an unfavorably low pH; it most likely is due to the greater competition from the very vigorous creeping red fescue, which has also virtually eliminated the crested wheat grass and diminished the percentage of the bromegrass stands. Nitrogen fertilization has probably reduced the competitive ability of the legumes with this fescue.

Salinity levels in the surface 12 inches are higher than those of any other tailings sand or peats encountered in the plots. The high salinity is perhaps due to the fertilizers that have been applied. Sulphate sulphur, which accumulates in the 6 to 12 inch depth, is most probably the main cause of the higher salinity level observed at this depth. The level of phosphorus in the surface falls within the moderate range of crop requirement but is still much lower than should normally result from the total amount applied, taking into account that which was probably taken up by the seeded plants at the site.

EXPERIMENTAL DESIGN AND PROCEDURES

In June 1975, when fertilizer treatments were to be imposed on the plots, an additional treatment was added to the 1974 treatments. This treatment represented the fertilizer rate GCOS was to use on the surrounding vegetated areas of the dike in 1975. The plots were sampled again and analyzed for mineral nitrogen content in June 1975, just prior to fertilizer treatments. Results of the soil analyses (Table 3) indicated that at the time of fertilizer treatments in June the mineral nitrogen levels at the sampled depths had increased somewhat as compared with levels in November 1974 (see Table 1), but the levels still remained very low.

Each plot was boarded off at the top to prevent any downslope movement of fertilizer in the run-off water from the upper plots to the lower plots (see Figure 2 and Plate 1). In addition, collection points were set up to collect run-off water from treatments T_0, T_2, T_4 and T_5 (Figures 1 and 2) and from an adjacent area where fertilizers were applied by GCOS personnel using a helicopter (Figure 3).

The objective of the water collection was to measure surface run-off and fertilizer nutrient losses in the surface run-off water. Run-off water collections were made on July 18 and August 17, 1975.

A first crop was harvested on August 17, 1975, at which time the plots were sampled at four different depths, 0-6 inches, 6-12 inches, 12-18 inches and 18-24 inches. Soils were analyzed for mineral nitrogen, pH and electrical conductivity. Yields of the plant materials were recorded and plant samples

Table 3. Mineral nitrogen levels on the dike at time of fertilizer treatments on June 19, 1975.

Depth	NH_4^+ ppm	NO_3^- ppm	NH_4^+ plus NO_3^- ppm
0 - 6 in.	1.58	1.40	2.98
6 - 12 in.	0.35	1.22	1.57
12 - 24 in.	0.52	0.35	0.87
24 - 36 in.	0	0	0

Fig. 2. Surface run-off collection set-up for the various treatments.

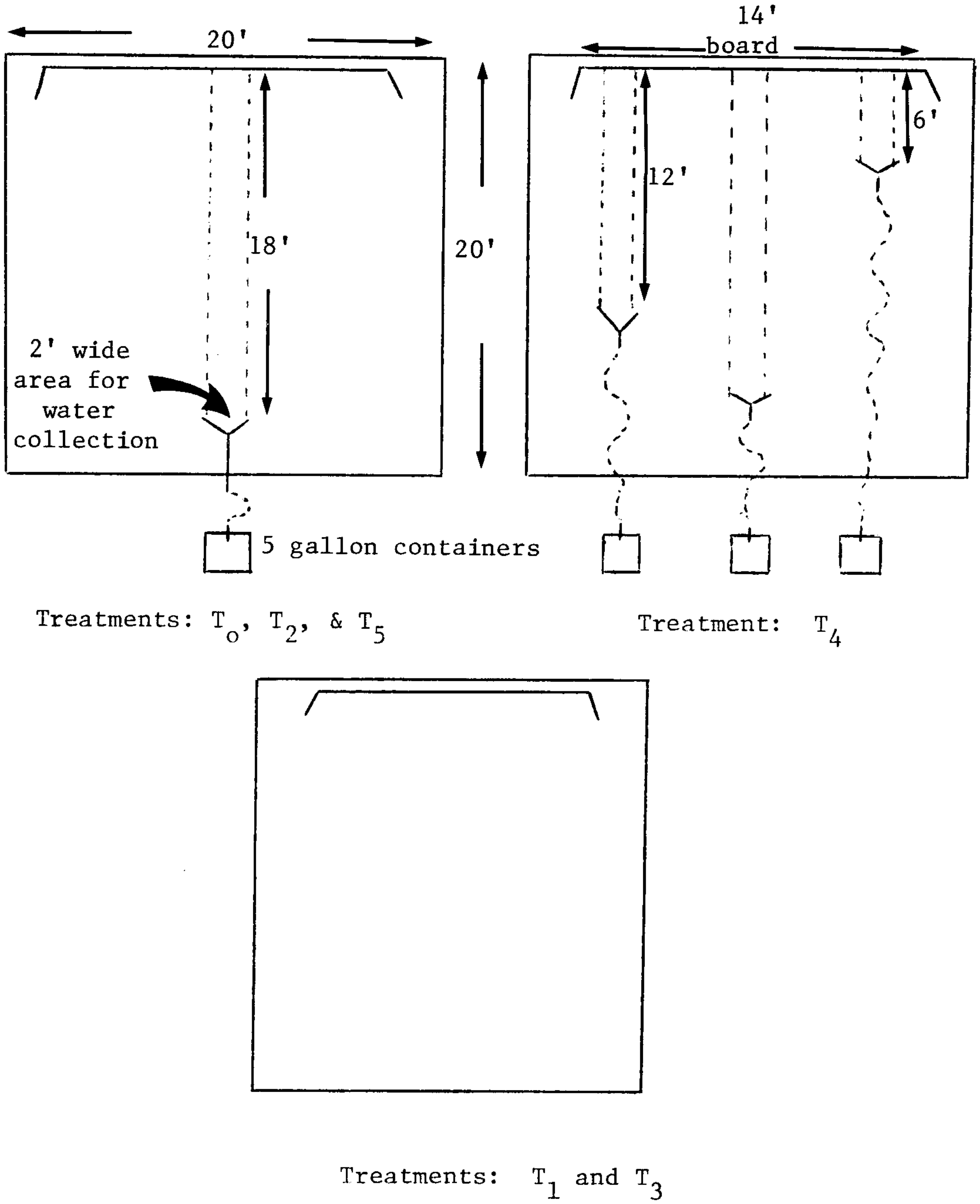


Fig. 3. Surface water run-off collecting points from areas fertilized by GCOS personnel with the aid of helicopters relative to fertilizer experiment area.

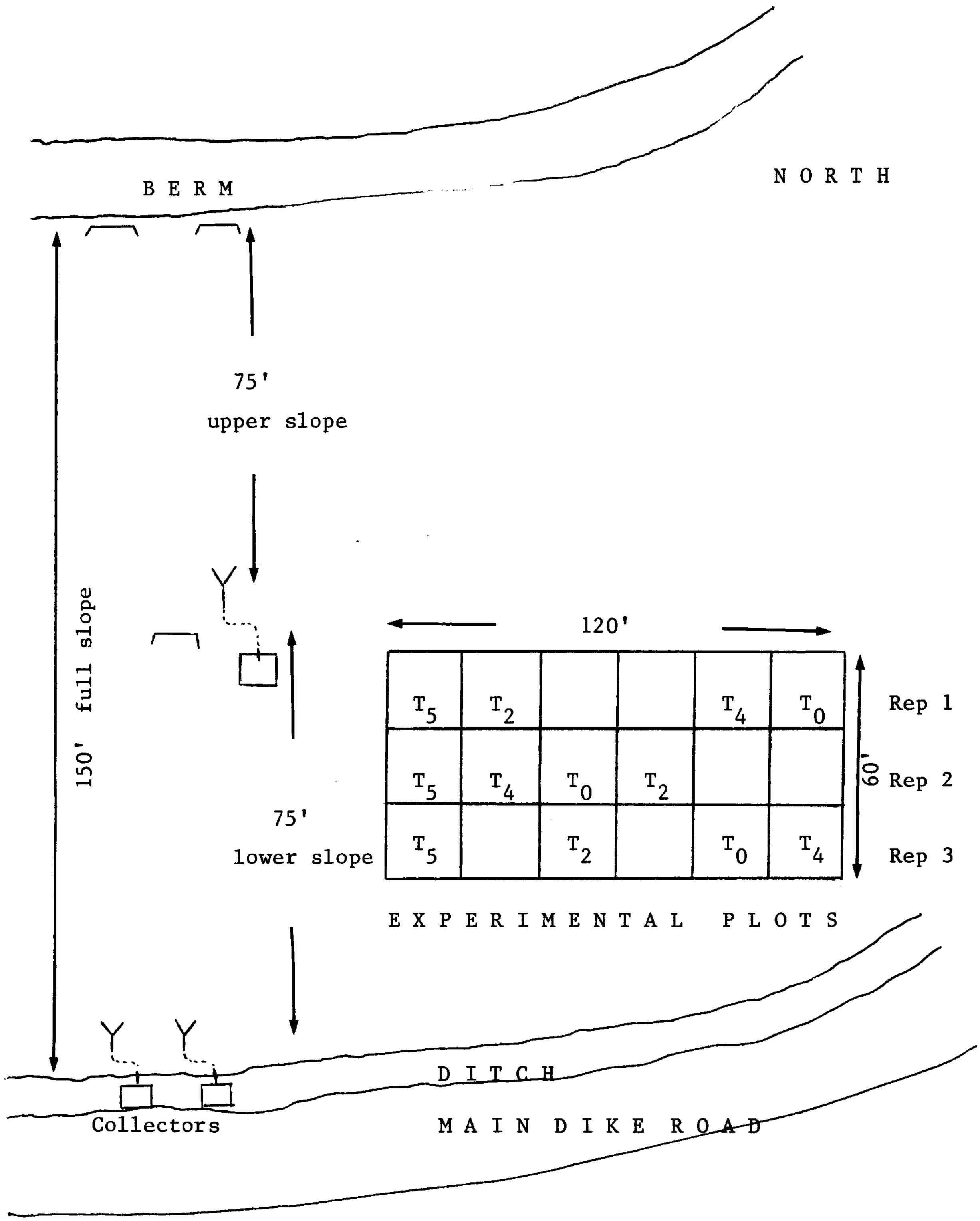
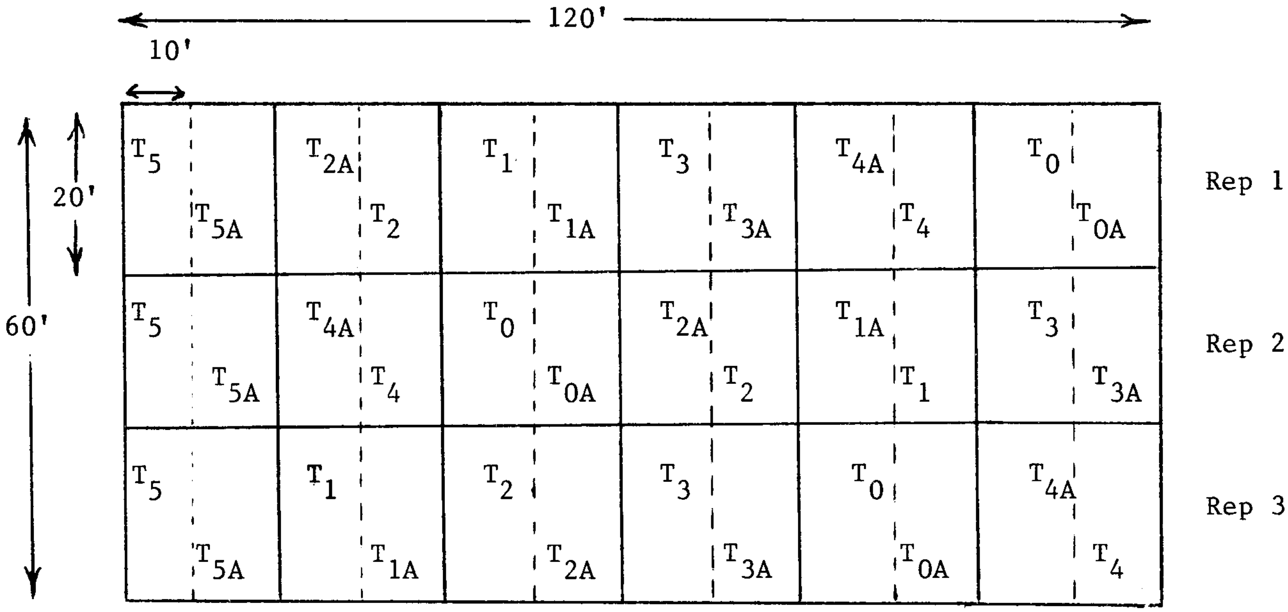


Fig. 4. Modified field plan of fertilizer experiment on a vegetated tailings pond dike -- as of August 17, 1975.



<u>Fertilizer Treatments</u>

T_o = No fertilizer or lime (Nil).

T_{oA} = 80 lb. N and 8 lb. S per acre applied in August (17th).

T_1 = NPKS (see Fig. 1) in June (19th).

T_{1A} = Same as T_1 plus 80 lb. N and 8 lb. S per acre applied in August (17th).

T_2 = NPKS + lime (see Fig.1) on June (19th).

T_{2A} = Same as T_2 plus 80 lb. N and 8 lb.S per acre applied in August (17th).

T_3 = $N_2P_2K_2S_2$ (see Fig.1) on June (19th).

T_{3A} = Same as T_3 plus 160 lb. N and 16 lb. S per acre applied in August(17th).

T_4 = $N_2P_2K_2S_2$ + lime (see Fig.1) on June (19th).

T_{4A} = Same as T_4 plus 160 lb. N and 16 lb. S per acre applied in August(17th).

T_5 = GCOS rate (see Fig.1) -- Summer application made (August 17th).

T_{5A} = Same as T_5 plus extra N added to bring total N for spring and summer applications to 80 lb. N per acre (extra N was in the form of ammonium nitrate).

analyzed for nitrogen content. Field observations indicated apparent N deficiency symptoms in all the treatments less than two months after fertilizers were applied. Therefore the experimental plan was modified. This involved further applications of nitrogen and sulphur, which were added as sub-treatments within the existing plots (see Figure 4 for the modified field plan and fertilizer treatment designations). A second crop was harvested on October 7, 1975, and soil samples were also taken at that time. Yields of the second crop are included in this report.

OBSERVATIONS AND RESULTS

Surface Water Run-Off

Total rainfall for the period June 19, 1975 to August 19, 1975 was 6.75 inches (171.4 mm). Run-off water collected on the grass-covered vegetated tailings pond varied considerably from almost nothing in some plots to over 24 liters in others (Table 4).

Almost all of the run-off water for each collecting area was the result of a 24-hour period (July 13) when 3.50 inches (88.9 mm) was recorded. Earlier field observations indicated absolutely no run-off water was being collected from the moderate amounts of rainfall observed prior to the heavy downpour on July 13.

An overall inspection of the plots on July 18 showed clearly that in the heavy downpour micro-channelling occurred in the plots and this probably explained the overall uneven run-off and the heavier run-off observed in some plots.

Slope lengths did not seem to bear any relation to the amounts of run-off water collected (Table 4). This again indicates that the amount of run-off would depend considerably on the amount of channelling into the collecting areas, which in turn is dependent on rainfall intensity.

Table 4. Quantity of run-off water collected and mineral nitrogen content of run-off water for the period June 19th - August 19th, 1975 on a vegetated portion of the GCOS tailings pond dike. Slope: 23° to 28°.

		Slope Length (ft.)	Collecting Area (Sq.Ft.)	Total Water Collected			NH_4^+ and NH_3^- Collected	
				litres	gal.	gal/a	ug/ml	lb./a
T_o	Nil	18	36	4.057	0.89	1,081	0.32	0.003
T_2	NPKS + lime (80 lb.N/a)	18	36	4.620	1.02	1,231	0.88	0.011
T_4	$N_2P_2K_2S_2$ + lime (160 lb.N/a)	6	12	1.852	0.41	1,481	0.53	0.008
		12	24	18.338	4.04	7,331	3.48	0.255
		18	36	8.010	1.76	2,135	2.34	0.050
T_5	GCOS Rate, Spring - (13.5 lb.N/a)	18	36	7.760	1.71	2,068	0.08	0.002
	Upper Slope, Spring- (13.5 lb.N/a)	75	150	0.575	0.13	37	1.64	0.001
	Lower Slope, Spring- (13.5 lb.N/a)	75	150	22.970	5.06	1,469	0.178	0.003
	Full Slope, Spring - (13.5 lb.N/a)	150	300	23.335	5.14	746	0.25	0.002

Infiltration measurements in the plots showed the infiltration rate in the dike to be very high (Table 5). Thus, under normal rainfall intensities the vegetative cover and the peat on the surface would allow for very little run-off even on the steep slope (23^o to 28^o) of the plots. Surface run-off on the vegetated dike under a rainfall intensity normal for the Fort McMurray region should not be a major problem as long as there is good grass cover on the peat which is spread over the tailings sand. Under heavy rainfall intensities, where run-off water collects on the berms of the dike where channels collect together substantial increases in water flow through channels leaving each berm occur. The erosion hazard is greatly increased and erosion damage becomes expensive and dangerous (see section on erosion).

Loss of Fertilizer Nitrogen through Run-off Water

Fertilizer nitrogen applied to the plots ranged from 13.5 lb N per acre (GCOS spring rate T_5) to 160 lb N per acre (T_4). Total mineral nitrogen content of the run-off water collected for any of the treatments was, however, small (Table 4) in relation to the amount applied. Although the amounts of run-off water collected were highly variable, the nitrogen concentration was low and even if our estimate of the run-off water is low by a factor of 10, losses by surface run-off would not appear to exceed 2-3 lb/acre. This suggests that most fertilizer nitrogen removal on the vegetated dike occurs by means other than run-off water.

Field observations showed that the pellets of nitrogen fertilizer were no longer visible on the plots 48 hours after application, as it dissolved in the morning dews on the grasses and had soaked into the surface litter and peat. It may therefore be safely assumed that, with moderate rainfalls, fertilizer nitrogen losses in run-off water on vegetated dikes of this slope will likely be

Table 5. Infiltration rate and bulk density of the vegetated G.C.O.S. tailings pond dike (experimental area).

Infiltration rate* (cm/h)		Area		
		Bulk Density (Db)		
1 min.	-	0 - 3 in.	(0 - 7.5 cm)	N.D.***
6 min.	32.85	3 - 6 in.	(7.5 - 15 cm)	0.85 to 1.29**
11 min.	25.50	6 - 9 in.	(15 - 23 cm)	1.43
21 min.	21.70	9 - 12 in.	(23 - 30 cm)	1.46
31 min.	20.55	15 - 18 in.	(38 - 45.7 cm)	1.47
46 min.	19.76	21 - 24 in.	(53 - 60 cm)	1.52
61 min.	19.56	33 - 36 in.	(84 - 91 cm)	1.52
76 min.	19.14	45 - 48 in.	(114 - 122 cm)	1.56
91 min.	18.84			
121 min.	18.72			
136 min.	18.72			
151 min.	18.72			

* Percent moisture at infiltration rate determinations.

0 - 6 in.	(0 - 15 cm)	38.9
6 - 12 in.	(15 - 30 cm)	8.5
12 - 24 in.	(30 - 60 cm)	6.5
24 - 36 in.	(60 - 91 cm)	7.7

** Bulk density is variable depending on the thickness of the surface peat.

*** The density and content of the peat was too variable to make measurements possible.

minimal. The losses would be significant only if applications of fertilizer nitrogen are immediately followed by a heavy rainfall. These losses would be dependent on the degree of channelling taking place. Visual observations of the growth of the grasses on the plots clearly showed minimal downslope movement of the fertilizers.

Loss of Fertilizer Nitrogen through Leaching

A dike built of tailings sand has a very high infiltration rate and it would be expected that leaching losses of fertilizer nitrogen applied to such a dike may be large. Once the nitrogen gets below the surface peat layer into the tailings sand it would be expected to move quickly beyond the rooting zone of the grass cover. Mineral nitrogen level at the four depths sampled two months after fertilization (Table 6) indicated that the greatest amount of fertilizer nitrogen remained in the surface 0 to 6 inch layer, although there was very little still to be detected.

For the nil treatments and the 160 lb N per acre treatments, soil samples taken at different times between fertilization in mid-June and in mid-August (table 6) indicated some increase in nitrogen levels in depths below the surface 0 to 6 inches twenty days (July 9) after fertilizer was applied and after a total rainfall of 1.70 inches (43.2mm). Fertilizer nitrogen levels in another sampling nine days later (July 18), which was one month after the initial nitrogen application, showed marked declines especially in the surface 0 to 6 inches. The nitrogen level, although low in the three lower depths of the fertilized plots, was still higher than in the nil plots.

The total rainfall from fertilization to sampling was 6.75 inches (171.4 mm). This included the 3.50 inches (88.9mm) recorded on the dike on July 13. The rapid decline in the nitrogen content of the vegetated dike does not necessarily indicate heavy leaching losses, as the lowest sampling depth did

Table 6. Mineral (ammonium and nitrate) nitrogen (ppm) levels at different depths on nil and fertilized plots at different soil sampling dates on a vegetated G.C.O.S. tailings pond dike.

	Fertilizers applied June 19, 1975			July 9, 1975			July 18, 1975			Harvest date August 14, 1975		
	Nil (To)	80 ppm N (T_3)*	Mineral N due to fertilizer	Nil (To)	80 ppm N (T_3)*	Mineral N due to fertilizer	Nil (To)	80 ppm N (T_3)*	Mineral N due to fertilizer	Nil (To)	80 ppm N (T_3)*	Mineral N due to fertilizer
0 - 6 in.	2.98	-	80.00	4.90	44.63	39.73	1.22	13.36	12.14	2.32	5.20	2.88
6 - 24 in.	1.57	-	-	1.57	8.06	6.49	0.69	4.02	3.33	1.36	2.15	0.79
12 - 24 in.	0.87	-	-	0.70	5.61	4.91	0.35	1.27	0.92	0.79	0.46	0
24 - 36 in.	0	-	-	0	1.97	1.97	0	0.47	0.47	1.35	0.62	0.73
Cumulative precipitation on dike	0 in. (0 mm)			1.70 in. (43.2 mm)			6.75 in. (171.4 mm)			7.88 in. (200.2 mm)		

T_3* = 160 lb. N, 40 lb. P, 160 lb. K and 16 lb. S per acre not show marked increases in the nitrogen level in any of the previous soil samplings. The last sampling (August 14) showed some further decline in nitrogen levels in the three upper sampling depths. The additional rainfall of 1.13 inches (28.7 mm) between samplings is hardly enough to explain the decline as being due to leaching losses. The higher amounts of mineral nitrogen detected in the surface 6 inches on all sampling dates suggest that although there may be some leaching losses the greater part of fertilizer nitrogen was used up by the grass cover.

Fertilizer Effects on Growth of the Grass Cover at First Harvest

At the time of fertilizer treatments of the plots on June 19, 1975 spring growth of the cover was poor and was dominated by creeping red fescue with patches of brome-grass. Nitrogen and phosphorus deficiency symptoms were clearly evident on both grasses. Three weeks after fertilizer treatments there was a marked improvement in the growth of the fertilized plots as compared to the nil plots (Plate 1). No marked differences were observed between the higher ($N_2P_2K_2S_2$) and lower (NPKS) fertilizer rates. There was no visual difference in growth between the limed and unlimed plots (Plate 1). Brome-grass appeared to be showing up more vigorously than before fertilizer treatments. The growth on the GCOS spring rate treatment was poor and was only marginally better than the nil treatment.

New growth of the brome-grass on the plots and in surrounding areas appeared to have received moderately severe damage, perhaps from the SO_2 emissions from the plant. This may be expected to happen anytime the dew is heavy and SO_2 concentration above the dike is high. However, no visible damage was observed on the creeping red fescue.

Field observations made one month after fertilizer treatments were imposed indicated that the higher ($N_2P_2K_2S_2$) fertilizer rates had improved growth more than the lower (NPKS) rates, but that no difference existed between the limed and unlimed plots. The GCOS spring rate was only marginally better in growth than the nil plots. By August 1, plant growth on the lower fertilizer rate plus lime (NPKS + lime) appeared to be better than the same fertilizer rate without lime (NPKS). The bromegrass and creeping red fescue were beginning to show nitrogen deficiency symptoms on the lower fertilizer rate plots and did not show as vigorous growth as for the higher rates ($N_2P_2K_2S_2$). Grass growth for the higher rates was the same on the limed and unlimed plots, and nitrogen deficiency symptoms were to some extent evident in the bromegrass, especially in the treatment including lime.

At harvest, two months after fertilizers were applied, nitrogen deficiency was marked in the lower fertilizer rates, with and without lime, on both creeping red fescue and bromegrass, and the bromegrass was showing phosphorus deficiency symptoms on both limed and unlimed plots. In the plots with higher fertilizer rates there had been no marked change from earlier observation except for new symptoms of nitrogen deficiency in the creeping red fescue. Phosphorus deficiency was becoming evident in the bromegrass on both limed and unlimed plots. Growth on the GCOS spring rate and the nil treatments was poor and both nitrogen and phosphorus deficiency symptoms were strongly evident in both grasses.

Dry Matter Yields at First Harvest

Dry matter yields of the grasses for the first harvest, two months after the fertilizers were applied, are summarized in Table 7. Yields were separated into bromegrass and creeping red fescue, and the old grass (pre-1975 growth, 1971 to 1974) was separated from the new (1975) growth. Two 6 by 20 foot strips were harvested per plot.

Table 7. Dry matter yields of bromegrass and creeping red fescue in the first harvest in August, 1975, as affected by fertilizer and lime treatments on a vegetated GCOS tailings pond dike.

	Yield (tons/acre) Average of 3 replicates		
	Bromegrass	Creeping Red Fescue	Bromegrass + C. R. Fescue
T_o, Nil	0.06	0.43	0.49
T_1, NPKS	0.11	1.41	1.52
T_2, NPKS + lime	0.11	1.88	1.99
T_3, $N_2P_2K_2S_2$	0.21	2.10	2.31
T_4, $N_2P_2K_2S_2$ + lime	0.13	1.91	2.04
T_5, GCOS Rate (Spring)	0.05	0.60	0.65
Mean	0.11	1.39	1.50

Pre-1975 growth = 2.13 tons/acre

Pre-1975 dry matter yield averaged 2.13 tons per acre; visual examination of the material suggested that probably most of the grass growth produced between 1971 and 1974 still remained.

Bromegrass yield for all treatments average 0.11 ton per acre, and creeping red fescue yield for all treatments average 1.39 tons per acre. Percent bromegrass within the harvested areas varied, so that any effect of fertilizers on the composition of the grasses in the first harvest could not be accurately assessed, although fertilizers, with the exception of the GCOS spring rate (T_5), greatly increased bromegrass yields. In each of the fertilizer treatments, creeping red fescue yields averaged nearly three or more times higher than the nil treatment, with the exception of the GCOS spring rate (T_5).

The combined yields of the grasses showed a remarkable effect from the fertilizer treatments. The higher fertilizer rates (T_3 and T_4) gave a greater yield increase than the lower rates (T_1 and T_2). Yield increase with the GCOS spring rate (T_5) was minimal. The treatments including lime (T_2 and T_4) were not much higher in average yield than the plots with the same treatments without lime (T_1 and T_3). Lime was beneficial at the lower fertilizer rate, but gave an apparent depressive effect at the higher fertilizer rate.

Nitrogen Content of Grass Tops at First Harvest

Percent nitrogen in the bromegrass was higher in all treatments than it was in the creeping red fescue (Table 8). Fertilizer increased the percent nitrogen of the bromegrass, and the higher rates gave higher percent nitrogen than the lower rates. Lime tended to lower the percent nitrogen at both low and high fertilizer rates. The creeping red fescue followed essentially the same pattern as the bromegrass with respect to percent nitrogen, except that lime increased the percentage at the higher fertilizer rate.

Table 8. Percent nitrogen contents of bromegrass and creeping red fescue as affected by fertilizer and lime treatments on a vegetated G.C.O.S. tailings pond dike -- first harvest.

	% N in harvested plant material		
	Brome grass	Creeping Red Fescue	Brome grass + C. R. Fescue
To, Nil	1.41	1.02	1.07
T_1, NPKS	1.90	1.79	1.80
T_2, NPKS + Lime	1.64	1.61	1.61
T_3, $N_2P_2K_2S_2$	2.84	2.11	2.18
T_4, $N_2P_2K_2S_2$ + Lime	2.58	2.28	2.30
T_5, G.C.O.S. Rate (Spring)	1.51	1.19	1.21
MEAN	1.98	1.67	1.70

Pre - 1975 growth = 1.39% N

Total nitrogen content of the tops of the grasses averaged higher in the brome-grass than in the creeping red fescue, considering their percent yield compositions in the harvested areas (Table 9). In the brome-grass total nitrogen content of the nil treatment was very low. Total nitrogen content was higher as the fertilizer rate increased. Lime, especially at the higher fertilizer rate, depressed the total nitrogen content of the crops. In the creeping red fescue and the combined brome-grass and creeping red fescue, the higher fertilizer rates gave higher total nitrogen content than the lower rates.

Lime increased the nitrogen content at the lower nitrogen rate but it had no effect at the higher rate. In the combined grasses the amounts of fertilizer nitrogen recovered in the tops were relatively high. Grasses at the lower fertilizer rates (T_1 and T_2) contained a slightly higher percentage of the nitrogen applied than was contained in the grasses at the higher fertilizer rates (T_3 and T_4). Grass on the GCOS spring rate (T_5) contained an even lower percentage of the fertilizer nitrogen in the tops; however, the applied rate was very low.

Fertilizer Effects on Growth of the Grass Cover at Second Harvest

After the first harvest the experimental plan was modified so that the plots received an additional nitrogen and sulphur application (see Figure 4). One of the two 6 x 2 foot areas of first harvest within each plot received the additional nitrogen and sulphur and the other area received nothing. These areas were again harvested seven weeks (October 7) after the additional nitrogen and sulfur were applied. In the case of the GCOS rate (T_5) a second fertilizer application (summer) was made, according to plans laid out by GCOS personnel, to one area and the other area received the same GCOS fertilizer rates plus additional nitrogen to raise the total to 80 lb N per acre. One nil treatment area received only nitrogen and sulphur at the lower rates, the same as applied in treatments T_1 and T_2 (see Plate 2).

Table 9. Total nitrogen contents per acre of bromegrass and creeping red fescue tops as affected by fertilizer and lime treatments on a vegetated G.C.O.S. tailings pond dike -- first harvest, lb./a.

		Bromegrass		Creeping Red Fescue		Bromegrass + C. R. Fescue	
		Total N	Increase*	Total N	Increase*	Total N	Increase*
To	Nil	1.69	-	8.77	-	10.46	-
T_1	NPKS	4.18	2.49	50.48	41.71	54.66	44.20
T_2	NPKS + Lime	3.61	1.92	60.53	51.76	64.14	53.68
T_3	$N_2P_2K_2S_2$	11.93	10.24	88.62	79.85	100.55	90.09
T_4	$N_2P_2K_2S_2$ + Lime	6.71	5.02	87.10	78.33	93.81	83.35
T_5	G.C.O.S. Rate (Spring)	1.51	-0.18	14.28	5.51	15.79	5.33
MEAN		4.94	3.90	51.63	51.43	56.57	55.33

Pre - 1975 growth = 59.21 lb/a

* OR nitrogen from fertilizer

Field observations at harvest time, seven weeks after the nitrogen and sulphur applications were made, showed very poor regrowth in the nil treatments (T_0), especially of the bromegrass. Growth in unharvested areas in the nil treatment continued to look poor and earlier growth appeared to be dying. Nitrogen and phosphorus deficiency symptoms were very evident throughout the plots. Areas in the nil treatments receiving only nitrogen and sulfur in August (T_{0A}) had good regrowths in the first harvest areas, and there appeared to be no major nutrient deficiency symptoms - not even of phosphorus. In the unharvested areas growth was good, especially of the creeping red fescue; phosphorus deficiency was evident in the bromegrass; and there was little evidence of the 1975 growth dying.

The lower fertilizer rate treatment (T_1) in the unharvested areas which received no additional nitrogen and sulfur in August, showed marked nitrogen deficiency symptoms in both grasses, and phosphorus deficiency symptoms in the bromegrass. Regrowth in the first harvest areas was only fair, and the grasses lacked nitrogen. In the treatment (T_{1A}) receiving additional nitrogen and sulfur in August, regrowth in the first harvest areas was good and no marked nutrient deficiencies were observed on the regrowth. Growth in the unharvested areas continued to be good and the grass showed very slight nitrogen deficiency symptoms in only one of the replications.

In the unharvested areas, growth in the lower fertilizer rate treatments, which also received five tons of lime per acre (T_2), indicated a need for nitrogen in both grasses and a need for phosphorus in the bromegrass. Regrowth in the first harvested areas was fair and both grasses indicated a need for both nitrogen and phosphorus. The treatment (T_{2A}) receiving additional nitrogen and sulfur in August continued to give good growth, but phosphorus deficiency symptoms had appeared on the bromegrass. In the first harvest areas, regrowth was good and there appeared to be no need for any nutrient.

In the unharvested areas, in the higher fertilizer rate treatment which received no additional nitrogen and sulfur in August (T_3), there was an additional need for nitrogen by both grasses and an additional need for phosphorus by bromegrass. The first harvest areas had a moderate regrowth and the grasses also showed a need for additional nitrogen. In the unharvested areas, in the treatment that received additional nitrogen and sulfur in August (T_{3A}), the grasses continued to make good growth. Regrowth in the first harvested areas was good and there appeared to be no need for additional nitrogen.

In the unharvested areas, the limed plots of the higher fertilizer rate treatments which received no additional nitrogen and sulfur in August (T_4) had developed a need for additional nitrogen, as indicated by the growths of both grasses, and also a need for additional phosphorus in the bromegrass. In the first harvest areas regrowth was fair to good and some need for nitrogen was evident in both grasses; the bromegrass also exhibited some need for phosphorus. Growth in the unharvested areas in the treatment receiving additional nitrogen and sulfur in August (T_{4A}) continued to be good and no marked need for nutrients was evident. In the first harvest areas regrowth was good and both grasses exhibited no need for additional nutrients.

In the GCOS rate treatment (T_5) plots which had received both spring and summer fertilizer applications, the grasses showed a need for additional nitrogen in the unharvested areas. The bromegrass growth also indicated a need for phosphorus. Regrowth in the first harvest areas was fair and a need for nitrogen was exhibited by the grasses. The GCOS rate treatment in which additional nitrogen was applied to bring the total for spring and summer applications to 80 lb N per acre (T_{5A}) have fair growth in the unharvested areas and the grasses continued to exhibit some need for additional nitrogen. A need for phosphorus was observed in the bromegrass. In the first harvest areas regrowth was good and both grasses indicated no need for additional nutrients.

Dry Matter Yields at Second Harvest

Bromegrass yields of the regrowths were higher with additional nitrogen and sulfur treatments than without additional nitrogen and sulfur (Table 10). Yields were also higher at the higher additional nitrogen and sulfur rates than at the lower additional rates. Lime gave lower yields in both fertilizer rates with the additional nitrogen and phosphorus. Treatments receiving no additional nitrogen and sulfur gave no improvement in yields of regrowths with liming. The bromegrass regrowth in the nil treatment (T_0) was essentially non-existent, suggesting that with continued low soil fertility the bromegrass may die out.

Regrowth of the creeping red fescue was achieved in each treatment, and yields were higher in treatments receiving additional nitrogen and sulfur than in treatments where no additional applications were made. Yields from the additional higher nitrogen and sulfur rate treatments were essentially the same. This was probably because of the cooler temperatures and the relatively short time between harvests. With additional nitrogen and sulfur the presence of lime improved yields of the regrowths at both low and high nitrogen and sulfur rates. Raising the GCOS nitrogen rate to 80 lb N per acre (T_{5A}) almost doubled the yield of the creeping red fescue as compared with the standard GCOS rate (T_5) for 1975. Regrowth yields of treatments receiving no fertilizer at any time were very much lower than when only nitrogen and sulfur were applied in August. The higher fertilizer rate treatment in the plots that received no additional nitrogen and phosphorus gave higher regrowth yields than the lower rate treatment, and liming had no influence on the yields of the regrowths. The combined bromegrass and creeping red fescue regrowth yields were essentially of the same pattern as those of creeping red fescue, discussed above.

Table 10. Dry matter yields of bromegrass and creeping red fescue regrowths as affected by fertilizer and lime treatments plus additional nitrogen and sulphur treatments on a vegetated G.C.O.S. tailings pond dike -- second harvest, tons per acre.

		Bromegrass	Creeping Red Fescue	Bromegrass + C. R. Fescue
To	Nil	0	0.04	0.04
To_{-A}	Nil + NS	0.03	0.46	0.49
T_1	NPKS	0.01	0.18	0.19
T_{1-A}	NPKS + NS	0.05	0.49	0.54
T_2	NPKS + Lime	0.01	0.13	0.14
T_{2-A}	NPKS + Lime + NS	0.04	0.55	0.59
T_3	$N_2P_2K_2S_2$	0.02	0.22	0.24
T_{3-A}	$N_2P_2K_2S_2 + N_2S_2$	0.15	0.38	0.53
T_4	$N_2P_2K_2S_2$ + Lime	0.02	0.24	0.26
T_{4-A}	$N_2P_2K_2S_2$ + Lime + N_2S_2	0.08	0.50	0.58
T_5	G.C.O.S. Rate (Spring & Summer)	0.01	0.25	0.26
T_{5-A}	G.C.O.S. Rate (Spring & Summer) + N	0.02	0.48	0.50

Soil Nutrient Levels at First Harvest

Analyses of the soil samples taken from the plots at harvest of the grasses (two months after fertilizers were applied) are given in Table 11. Soil pH of the nil treatment remained unchanged from the sampling of November 1974; the 0 to 24 inch depths also remained unchanged. In all treatments the 24 to 36 inch depth approached neutrality. The additions of fertilizer did not appear to have changed the pH much in the four sampling depths. Liming raised the pH level of the surface 0 to 6 inches only very slightly. An examination of the limed plots indicated that the lime had not moved deeper than the surface 0 to ½ inch depth. Salt (electrical conductivity) levels in the nil treatment remained at a safe level as was observed in the November 1974 sampling. The 1974 sampling had indicated a slightly elevated salt level at the 6 to 12 inch depth; although this was still the case in 1975 it was not as high as in 1974. Fertilizers, especially lime, very slightly raised the salt levels in the surface 0 to 6 inch depth but they remained at very safe levels.

Mineral nitrogen levels on the nil treatment remained very low at all times of sampling for all depths sampled (Tables 6 and 11). Fertilizer nitrogen was largely accounted for in the soil in the first three weeks after application (Table 6) but it disappeared very rapidly afterwards, until after two months very little of it was to be detected in the mineral form. Nitrogen levels in the soil, regardless of the rate of application, with or without lime (Table 11) had dropped close to the levels of the nil treatment in the final soil analyses for nitrogen.

Soil samplings at different dates of treatment T_3 (Table 6), analyses of the run-off water collected (Table 4), and total nitrogen contents of the tops of the creeping red fescue and bromegrass (Table 9) indicated that most of the nitrogen applied was absorbed by the bromegrass and creeping red fescue. It could safely be assumed that most of the applied fertilizer nitrogen not

Table 11. pH, electrical conductivity (salinity) and mineral nitrogen levels in soil samples taken two months after fertilizers and lime were applied on a vegetated GCOS tailings pond dike.

	pH	Cond. (mmho/cm)	NH_4^+ (ppm)	NO_3^- (ppm)	NH_4 plus NO_3 (ppm)
T_o, Nil					
0- 6	6.4	0.51	2.0	0.3	2.32
6-12	6.4	0.58	0.9	0.5	1.36
12-24	6.7	0.36	0.5	0.3	0.79
24-36	7.0	0.44	0.7	0.6	1.35
T_1, NPKS					
0- 6	6.3	0.58	3.0	1.0	3.95
6-12	6.6	0.54	0.7	1.1	1.81
12-24	6.8	0.42	1.1	1.1	2.20
24-36	6.9	0.39	0.3	1.1	1.35
T_2, NPKS + Lime					
0- 6	6.7	0.83	3.1	0.5	3.50
6-12	6.7	0.67	1.2	0.7	1.97
12-24	6.9	0.47	1.0	0	0.96
24-36	7.4	0.46	1.1	0.1	1.13
T_3, $N_2P_2K_2S_2$					
0- 6	6.2	0.58	4.1	1.1	5.20
6-12	6.4	0.69	1.9	0.2	2.15
12-24	6.7	0.52	0.2	0.2	0.46
24-36	6.8	0.42	0.2	0.5	0.62
T_4, $N_2P_2K_2S_2$ + Lime					
0- 6	6.7	0.76	5.6	1.2	6.83
6-12	6.4	0.71	1.0	0	0.96
12-24	6.9	0.39	0.5	0.5	0.96
24-36	7.4	0.42	0.2	0.5	0.74
T_5, GCOS Rate					
0- 6	6.5	0.53	2.0	0.6	2.65
6-12	6.6	0.63	0.6	0.5	0.74
12-24	7.6	0.55	0.2	0.6	0.79
24-36	7.9	0.54	0	0	0.28

accounted for in the run-off water, soil samples and contents of the grass tops is tied up in the roots of the grasses.

Fertilizer Effects on the Entire Season's Growth in the Single Harvest

The dry matter yields of a single harvest of the entire growing season, for both bromegrass and creeping red fescue receiving the initial fertilizers and lime treatments in June and the additional nitrogen and sulfur treatments in August, are summarized in Table 12. The harvest was carried out on October 7 and each harvested area measured 2 by 2 feet.

Bromegrass yields were generally higher with fertilization, but this probably was greatly influenced by the initial bromegrass compositions in the harvested areas. Yields of the creeping red fescue, and the combined bromegrass and creeping red fescue, give more closely the overall yields as affected by the fertilizer and lime treatments. The application of 80 lb N and 8 lb S alone (T_{0A}) as late as mid-August more than doubled the dry matter yield of the combined grasses. Both higher and lower fertilizer rates in the limed and unlimed treatments gave about the same yields of combined grasses. The slightly higher yields in some treatments make little difference in the ground cover thus provided. Yield obtained by applying only 80 lb N and 8 lb S per acre (T_{0A}) even in mid-summer provided almost as much yield or ground cover as the entire GCOS rate for 1975 (T_5), applied once in June and once in August. Additional nitrogen, raising the 1975 GCOS nitrogen rate to 80 lb N per acre, gave an 11 percent higher yield than the original GCOS rate. In comparison with the combined total yields of the first and second harvests (Table 13) the single harvest at the end of the growing season gave consistently lower yields for the same treatments, except for the nil and the unlimed lower fertilizer

Table 12. Dry matter yields (for entire growing season) of bromegrass and creeping red fescue as affected by fertilizer and lime treatments on a vegetated tailings pond dike.

		Bromegrass	C. R. Fescue*	Bromegrass + C. R. Fescue
		(Yield (tons/ac.) Ave. 3 replicates)		
T_o	Nil	0.01	0.54	0.55
T_{oA}	Nil plus NS	0.08	1.29	1.37
T_{1A}	NPKS plus NS	0.08	1.98	2.06
T_{2A}	NPKS + lime plus NS	0.05	2.30	2.35
T_{3A}	$N_2P_2K_2S_2$ plus N_2S_2	0.34	1.93	2.27
T_{4A}	$N_2P_2K_2S_2$ + lime plus N_2S_2	0.08	2.07	2.15
T_5	GCOS Rate (spring and summer)	0.08	1.42	1.50
T_{5A}	GCOS Rate (spring & summer)plus N	0.05	1.62	1.67

*Pre-1975 growth = 2.13 tons per acre (Table 6)

Pre-1975 growth and dead 1975 growth = 2.51 tons per acre. The difference of 0.38 tons per acre is included in the yield of the creeping red fescue -- this represents dead 1975 growth accumulating between the first and second harvests.

Table 13. A comparison of grass tops in the 1975 growing season.

		Yield (tons/acre)			
		First Harvest (August)	Second Harvest (October)	Total 1st & 2nd Harvests	One Growing Season Harvest
T_o	Nil	0.49	0.04	0.53	0.55
T_{1A}	NPKS plus NS	1.52	0.54	2.06	2.06
T_{2A}	NPKS + lime plus NS	1.99	0.59	2.58	2.35
T_{3A}	$N_2P_2K_2S_2$ plus N_2S_2	2.31	0.53	2.84	2.27
T_{4A}	$N_2P_2K_2S_2$+ lime plus N_2S_2	2.04	0.58	2.62	2.15

Table 14. Changes in percent bromegrass and creeping red fescue composition between two harvests in August and October under different fertilizer and lime treatments.

		% distribution (by weight)			
		Bromegrass		Creeping Red Fescue	
		First Harvest	Second Harvest	First Harvest	Second Harvest
T_o	Nil	10.9	0	89.1	100.0
T_{oA}	Nil plus NS	15.1	6.1	84.9	93.9
T_1	NPKS	6.7	5.3	93.3	94.7
T_{1A}	NPKS plus NS	7.7	9.3	92.3	90.7
T_2	NPKS + lime	8.2	7.1	91.8	92.9
T_{2A}	NPKS + lime plus NS	3.5	6.8	96.5	93.2
T_3	$N_2P_2K_2S_2$	8.5	8.3	91.5	91.7
T_{3A}	$N_2P_2K_2S_2$ plus N_2S_2	9.6	28.3	90.4	71.7
T_4	$N_2P_2K_2S_2$ + lime	8.8	7.7	91.2	92.3
T_{4A}	$N_2P_2K_2S_2$ + lime plus N_2S_2	4.2	13.8	95.8	86.2
T_5	GCOS rate (spring & summer)	13.0	3.8	87.0	96.2
T_{5A}	GCOS rate (spring & summer) + N	6.0	4.0	94.0	96.0

rate treatments. A danger of major erosion may, perhaps, be a deterrent to taking a hay crop, as the only cover providing assurance against run-off would be temporarily removed.

Relationship of Fertilization and Grass Composition in the First and Second Harvest Areas

Percent compositions of the bromegrass and the creeping red fescue for the two harvests in each of the 2 by 6 foot areas in August and October seemed to have changed depending on the fertility level of the soil. In the nil treatment the bromegrass regrowth was essentially nil as compared with nearly 11 percent in the first harvest (Table 14). The decline was only partial where only nitrogen and sulfur were applied in mid-August (T_{0A}). In all other treatments where fertilizers and lime were applied in June and no additional nitrogen and sulfur were applied in August, the percent composition of bromegrass declined somewhat. The additional nitrogen and sulfur applied in August either maintained the same percent bromegrass composition or increased it. In the GCOS rates (T_5 and T_{5A}) percent bromegrass declined. This perhaps was due to the generally lower fertilizer rates, especially of nitrogen. It appears that with declining fertility the bromegrass will probably die out and the creeping red fescue may eventually be the sole species remaining.

OBSERVATIONS RELATING TO FUTURE VEGETATION PROGRAMS ON DIKES

Erosion

The tailings sand is very easily eroded by water and is readily dispersed by small wind gusts. Erosion is clearly evident, even after a rainfall as low as 0.1 inch (2.54 mm), if the surface of the sand is bare. Although the infiltration rate of the sand is expected to be high, the dry surface tends to wet slowly and water tends to move downslope very readily, starting erosion channels. With a slightly heavier rainfall erosion becomes severe and becomes serious with high intensity rainfalls of 1 inch (25.4 mm) or more. With peat spread on the sand or mixed in with the sand, surface water run-off is greatly reduced, as is the erosion hazard. In a more recently vegetated area where there are areas with little surface peat, erosion channels exist and with time they could become major problems.

With higher rainfall intensity, such as occurred on July 13 -- 3.50 inches on the dike within 24 hours -- surface water run-off with accompanying erosion becomes a major problem, even on the vegetated areas on the dike (Plate 3). Run-off water and seepage water (Plate 4) tend to collect on the berms and the water either channels downslope (Plate 3) or moves as a tailings sand bearing sheet over wide areas, flattening the vegetative cover and burying it under sand. Severe erosion may occur on the slopes and deep erosion channels may form on the berms. In most instances such downslope movement of the water results in washouts often more than 15 feet deep at the foot of the dike (Plate 3). Repair of the erosion damage caused could be very expensive as these channels have to be refilled, peat moved onto the site and the site fertilized and reseeded. As the tailings pond dike is supposed to be a permanent structure the design of such future dikes, especially the engineering of the berms, should probably be reconsidered to minimize seepage and massive downslope movement of water from the berms, as considerable damage or severe environmental degradation could result from a high intensity rainfall.

Coke was employed to stabilize the lower part of the toe of the dike. The coke has been highly susceptible to erosion and attempts to vegetate the areas have met with little success.

Erosion on the overburden piles exists on both unvegetated and vegetated areas. Seepage in some areas could result in slumping which could damage service roads and set back a vegetation program.

Presence of Salts

Evidence from a site on the dike where the tailings sand was probably over two years old at sampling, indicates (Table 15) some downward movement of salts. Salinity, pH and sodium levels all increase with depth; for pH the significant increase appears to be at the 12-inch depth, while for sodium and salinity the significant increase is at the 36-inch depth.

Salt levels in the surface 0 to 36 inch layer on the tailings pond dike are no problem as far as the grasses growing on it are concerned (Table 11). The toe of the dike, however, shows some evidence of salt concentrations which may in the future be a problem so long as water continues to seep on the dike. Along the toe of the dike evidence of high salt concentrations is to be found, a result of seepage water finding its way into drainage water (Plate 6) in the ditch. Estimated average depth of the concentration of salts at the toe of the dike is about 30 to 36 inches and is concentrated in the wetter zones (Plate 7).

On the overburden piles several areas have high salt concentrations which could hinder what should normally be a relatively easier vegetation program (Plate 5). While some of the soil on the surface may initially be slightly high in salt, the main problem is that the salt is continuously being brought to the surface by seeping water. With continuous seepage from the piles, the salt concentration on the surface may progressively increase, thus posing a continuous problem. Vegetation already established on the piles may eventually die off as the salt concentration continues to increase.

Table 15. Electrical conductivity, pH and sodium levels of a tailings pond at different depths within an unvegetated area of the GCOS tailings pond dike.

Depth (in)	Conductivity (mmho/cm)	pH	Na (ppm)
0-6	0.203	7.65	5.0
6-12	0.178	8.10	5.0
12-18	0.225	8.65	5.0
18-24	0.243	8.75	20.0
24-36	0.269	8.95	15.0
36-48	0.377	8.95	40.0
48-60	0.708	8.90	50.0
60-72	0.608	8.85	50.0

Lean Oil Sand Areas

Several areas on the overburden piles have small accumulations of lean oil sand material. These areas, although they may be considered problem areas, could be readily vegetated with the proper soil mixes and fertilization program (see section on the Bitumen Experiment, Part III).

Rooting Depth

Rooting of the grasses on the vegetated tailings pond dike is confined almost exclusively to the surface (Table 16 and Plate 7). About 86 percent (by weight) of the roots are concentrated in the peat layer. Perhaps a greater percentage and a deeper penetration into the sand may improve upon the stability of the dike, thus minimizing washouts (Plate 3). A study aimed at improving upon the shallow rooting on the dike may be the only answer to the problem.

Range of Temperatures at Different Depths of Overburden and Dike

On November 24, 1974 thermistors were planted at different depths on an unvegetated area on the southern crest of the GCOS tailings pond dike and at several locations on unvegetated overburden pile No. 7 to determine temperature changes over the seasons. On both the dike and the overburden pile the holes were backfilled with tailings sand and on the overburden pile bentonite was used to seal off the surface to precent the percolation of water through the sand. Temperatures were read on about two days during each week.

Temperature readings for one day in each month between January and October 1975 are summarized in Table 17. In general, the dike stayed warmer than the overburden pile, down to the greatest depth for which temperature measurements were taken on the dike. On the overburden pile the temperatures on the southwest facing slope averaged almost two full degrees higher than those taken

Table 16. Root distribution on a vegetated area on the tailings pond dike*

Depth (in)	Root** Dry wt.(g)	Percent
0-6	11.80	86.0
6-12	0.60	4.4
12-18	0.60	4.4
18-24	0.50	3.6
24-30	0.20	1.5
30-36+	0.02	0.1

*The area had a complete grass cover and was dominated by creeping red fescue (about 98 percent). Depth of the peat varied between 0 and 5.5 inches.

** For a 2" x 2" soil core

Table 17. Mean soil temperature (C) at different depths on given days from December to October on unvegetated overburden pile No. 7 and unvegetated site on the tailings pond dike.

	Depth cm	Dec. 19	Jan. 22	Feb. 24	March 20	April 21	May 15	June 18	July 23	Aug. 19	Sept. 29	Oct. 21
Overburden Pile No.7												
N.E. facing slope (sites 4 and 7)	15	-1.5	- 8.0	-4.1	- 0.5	1.5	3.5	10.5	14.2	13.0	11.2	5.6
	30	-0.5	- 7.0	-4.9	- 0.7	- 0.4	2.4	8.9	13.2	12.5	11.4	6.2
	60	1.5	- 5.0	-4.4	0	- 0.8	0.2	6.6	11.3	11.4	10.9	7.0
	90	2.5	- 2.3	-3.3	1.1	- 0.9	0	2.6	8.3	9.5	10.1	6.8
	230	4.0	1.3	-0.2	3.1	0	0	4.5	4.5	7.0	8.9	7.0
	460	5.7	3.6	2.5	5.0	1.7	1.2	4.6	2.1	3.0	6.5	5.5
	900	5.3	4.1	3.5	7.0	3.9	2.5	6.2	5.7	7.0	9.0	8.2
Crest (site 1)	15	-3.9	- 8.4	-3.0	- 4.0	- 2.1	7.0	9.8	17.0	15.0	8.8	5.0
	30	-2.1	- 3.0	-3.4	- 2.3	0.2	6.5	11.1	18.1	14.5	13.8	5.1
	60	-1.6	- 1.9	-4.1	- 4.2	- 0.5	5.6	9.8	15.2	13.2	9.6	5.3
	90	-0.3	- 5.2	-4.5	- 3.8	- 0.9	3.1	7.9	13.7	12.9	9.8	5.8
	230	2.1	0.8	-0.6	- 0.3	- 0.8	- 0.2	0.1	5.9	7.9	8.0	6.4
S.W. facing slope (sites 2 and 3)	15	0.5	- 2.5	-1.8	- 0.7	0	6.5	12.2	16.9	15.6	11.8	7.1
	30	0.8	- 1.7	-1.8	- 0.5	0	5.4	11.2	17.8	15.4	12.0	7.3
	60	1.6	- 0.5	-1.2	0.4	0	2.7	9.6	15.2	14.6	12.1	7.6
	90	2.8	1.1	0.1	2.0	0.2	0.5	7.5	13.1	13.0	11.7	8.3
	230	5.0	3.2	2.1	4.0	1.4	1.0	5.5	9.5	10.6	10.5	8.9
	460	7.0	7.2	4.7	6.4	3.7	3.1	4.3	5.0	6.3	7.9	7.9
	900	6.7	6.4	6.0	8.0	5.5	5.0	5.6	4.8	4.5	5.8	5.6
Tailings Pond Dike												
Crest	10	-8.6	-10.3	0.6	- 1.2	7.9	17.0	18.5	23.0	20.0	11.0	5.9
	30	-5.9	-10.0	-0.4	- 3.6	3.4	12.9	15.5	20.5	21.1	--	6.8
	90	2.0	- 4.2	-0.6	- 1.8	0.2	12.3	15.0	20.0	17.5	--	9.0
	180	7.2	3.8	0.9	2.2	3.2	9.9	13.9	--	--	13.4	11.9
Air Temperature (GCOS Top Gate Site)	Max.	--	- 7.8	3.3	1.1	13.3	12.2	17.8	25.0	--	10.6	--
	Min.	--	-17.2	-0.6	-20.0	- 7.2	- 1.7	8.3	9.4	8.3	3.9	--

on the northeast-facing slope in the 0 to 230 cm depth.

Soil temperatures remained above freezing at all depths on the southwest-facing slope as late as December 19, while freezing temperatures had been encountered as deep as the 90 cm depth in other areas on the overburden pile. On the dike freezing was limited to the surface 90 cm; on the overburden pile freezing occurred as deep as 230 cm on the crest and northeast-facing slope, while on the southwest-facing slope freezing was limited to the surface 90 cm, as on the dike. During the colder months (December to April) snow cover ranged between 0 and 15 cm.

At this time the dike was colder at the 30-cm depth, and considerably warmer at the 90-cm depth (Table 18). The northeast-facing slope and the crest of the overburden pile were colder than the southwest-facing slope at both depths. In the warmer months (May to August; Table 18 and Figure 5), when plant growth is greatest, the dike was the warmest. The southwest-facing slope and the crest of the overburden pile were of about the same temperature and the northeast-facing slope remained colder. Between August and October, when temperatures normally begin to fall in the region, temperature readings (Table 17) at 30-cm depths indicate that the surface of the dike crest cools faster than the crest of the overburden pile surface. Temperature drops over the same period in the overburden pile in depths of up to 30-cm also indicate that the northeast-facing slope cools off more slowly than the crest or the southwest-facing slope.

In a vegetation program the dike could be seeded about mid-May (Table 17), when sand temperature at the 30-cm depth is expected to be above 5^{o} C, even though the minimum air temperature may be slightly below freezing, assuming that the six inches of peat spread on top warms up just as fast as the sand. The exception to this is perhaps the north-facing slopes, where temperatures may remain lower past this date. On the overburden piles, with the exception of the north-facing slopes, temperatures at the 30-cm depth are also high

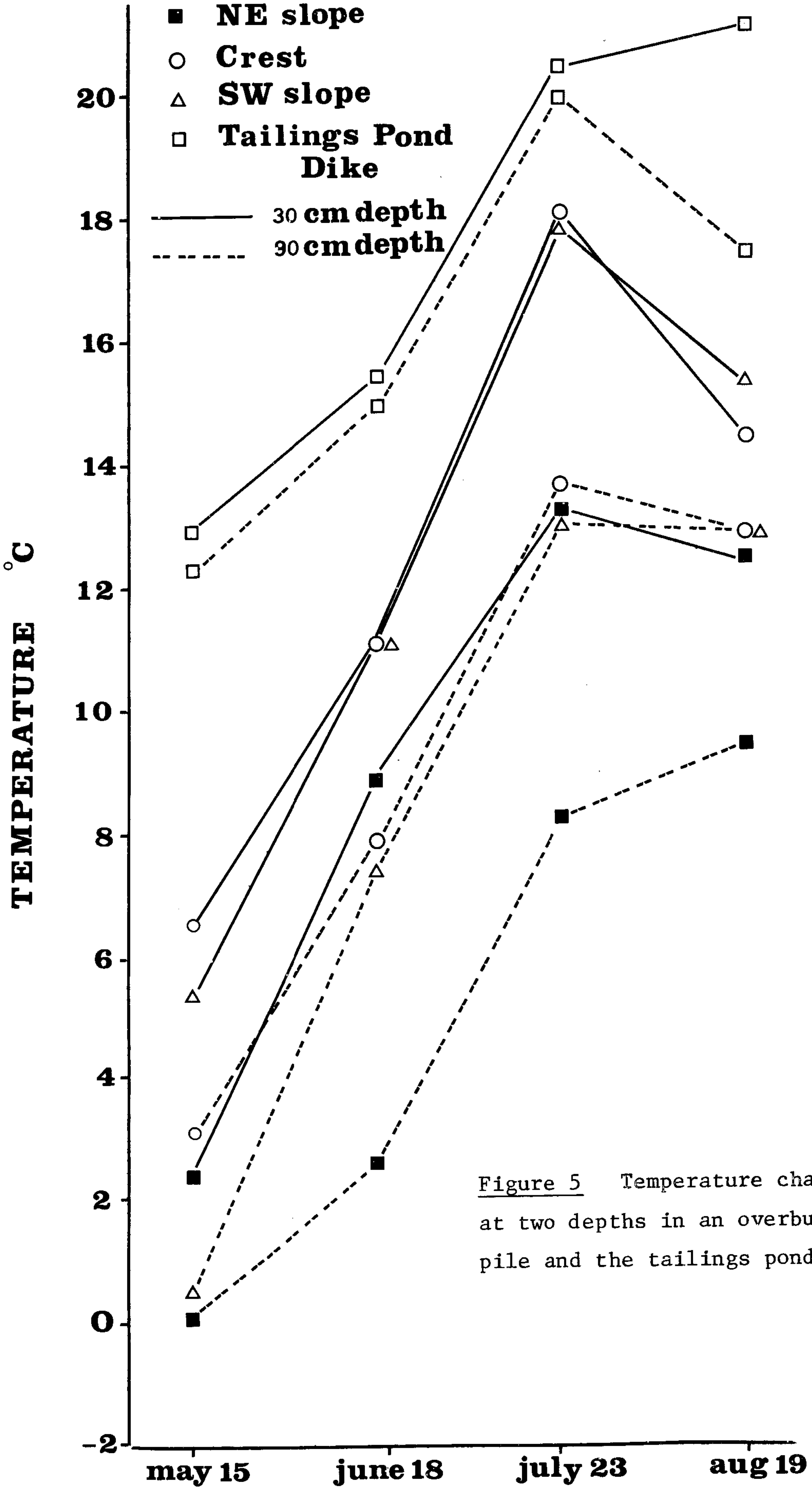


Figure 5 Temperature changes at two depths in an overburden pile and the tailings pond dike.

Table 18. Comparison of soil temperatures (C) at two critical depths during the colder months (December to April) and the warmer growing season months (May to August) on unvegetated overburden pile No. 7 and unvegetated tailings pond dike.

	Average Temperatures (C)		
	Colder months (Dec. to April)	Warmer months (May to Aug.)	Cooling-off months (Sept.-Oct.)
Overburden Pile No. 7			
N.E. facing slope (sites 4 and 7)			
30 cm depth	- 2.5	9.3	8.8
90 cm depth	- 2.7	5.1	8.4
Crest (site 1)			
30 cm depth	- 2.1	12.6	9.4
90 cm depth	- 2.9	9.4	7.8
S.W. facing slope (sites 2 and 3)			
30 cm depth	- 0.6	12.5	9.6
90 cm depth	1.2	8.5	10.0
Tailings Pond Dike			
Crest			
30 cm depth	- 3.3	17.5	6.8[a]
90 cm depth	- 0.9	16.2	9.0[a]
Air temperature[c]			
Maximum	2.5	18.3	10.6[b]
Minimum	-11.3	6.1	3.9[b]
Snow cover	0 to 15 cm	nil	nil

[a]October 21 reading only

[b]September 29 reading only

[c]GCOS Top Gate

enough for seeding to be started as early as mid-May. On the north-facing slopes seeding may have to be delayed until June.

TENTATIVE PRACTICAL IMPLICATIONS

(1) It would appear that good vegetative cover can be maintained on the dike if the fertilizers are applied at not less than 80 lb N, 40 lb P and 80 lb K per acre per year.

(2) One fertilizer application in June may be sufficient in view of the short growing season of the area. However, two fertilizer applications appeared to be more effective than one.

(3) Lime is presently not required, but the possibility exists of the dike becoming acid over the years as a result of SO_2 emissions from the extraction plant and sulfur dust; the pH of the dike should be monitored yearly.

(4) Removal of the grasses as hay crop is possible, as regrowth generally was good, but would appear to be quite undesirable as removal of a crop means that even higher amounts of fertilizer nutrients would be required. A hay crop removal also carries with it the increased danger of erosion as the grass cover which minimizes run-off is temporarily removed.

(5) Our results indicate that soil nutrient status has an important effect on plant species distribution. Bromegrass was favored over creeping red fescue by high fertilizer applications.

(6) The vegetative cover presently on the experimental site appears to be capable of preventing erosion if large-scale channelling of run-off water could be prevented.

(7) Root penetration of the dike is very shallow. Roots are confined almost exclusively to the peat layer, which is generally not deeper than 6 inches. A study is required to determine ways of improving rooting depth to beyond the peat layer. This may considerably improve slope stability.

(8) Little of the fertilizer nitrogen was lost in the small surface run-off water collected. There was little evidence to suggest that leaching losses of the fertilizer nitrogen was a problem.

(9) There was no evidence that any of the native plants in the area had voluntarily established themselves on the experimental plot. The seeded cultivated species form the entire cover. Efforts should be made to eventually develop a stable native cover on these slops and to determine the most appropriate time during the revegetation program to introduce native plant species.

Plate 1. Boards separate plots to prevent fertilizer movement downslope from one plot to the next.
Foreground: Nil plot in Rep. 1; shows the run-off water collection point in the plot centre.
Centre: Treatment T_3 ($N_2P_2K_2S_2$) in Rep. 2
Background: Treatment T_4 ($N_2P_2K_2S_2$ + lime)
Picture was taken three weeks after June 19 fertilizer applications.

Plate 2. Increased fertilizer application on right (nil treatment with 80 lb N and 8 lb S) demonstrates improved growth of vegetation over that on left (nil treatment T_0). See Fig. 4 for treatments. Picture taken 3 weeks before harvest.

Plate 3. Once surface layer of organic matter is broken, erosion is difficult to control. Plate shows washout developing upslope from toe of G.C.O.S. dyke. Channel erosion and new dike construction are visible in upper portion of picture. Stabilization of upper slopes is crucial to protect vegetation on lower slopes.

Plate 4. Tailings sand has a high infiltration capacity and permeability. Berms on G.C.O.S. dike influence surface and underground water movements, reducing channel erosion but contributing to seepage washouts such as this one.

Plate 5. Overburden is stored pending its use during mine reclamation. Evaporation of leachate results in continuous accumulation of salts. Salt concentrations may reach levels harmful to established vegetation.

Plate 6. Penetration by roots of the grass cover on the dike shows that a very great percentage of the roots are concentrated within the peat layer at the surface. While this helps prevent erosion at the surface, washout of the dike is possible with heavy precipitation.

PART III

GROWTH CHAMBER EXPERIMENTS

MATERIALS

Overburden materials, tailings sand, peat and heavy and lean tar sand materials collected from the Syncrude and GCOS leases were used in a series of growth chamber studies. These experiments were conducted between December 1974 and September 1975. Some chemical and physical properties of these materials are given in Table 19. The materials, whose properties vary widely, are described below.

Tailings Sand

This material, which was stored in the open from six to twelve months after passing through the oil extraction plant, was near neutral and non-saline in spite of the fact that NaOH is used in the bitumen extraction process. The electrical conductivity is similar to that of the Malmo soil and the sodium content on a weight basis is slightly lower. Sodium, however, dominates the exchangeable cation sites in the sand to a much greater extent than in the high yielding Malmo soil. Fresh tailings are to be expected to be much higher in sodium. Levels of major plant nutrients, however, are extremely low and the tailings would require heavy fertilization in order to support any vegetation. The sulfate sulfur level is high, and the higher level in an older sample of tailings indicates that extraction plant emissions increase sulfate levels with time. No carbonates are present but bicarbonates are. The cation exchange

Table 19. Properties of soils and other related materials from Syncrude and G.C.O.S. leases at Fort McMurray, used in the growth chamber studies.

Materials	pH	Cond. mmho per cm	NH_4^+ ppm	NO_3^- ppm	Total mineral N ppm	Org. C %	Organic matter %	P ppm	K ppm	Na ppm	Ca ppm	$CaCO_3$ equiv. %	Total N %	Sulfate S ppm	Exchange complex, me/100 g: CEC	Exchange complex, me/100 g: K	Exchange complex, me/100 g: Ca	Exchange complex, me/100 g: Na	Exchange complex, me/100 g: Mg	Particle size distribution, %: Sand	Particle size distribution, %: Silt	Particle size distribution, %: Clay	% moisture at field capacity (1/3 bar.)	Oil [illegible] (O.D. soil)
Tailings sand	7.89	0.55	1.06	0.53	1.59	0.20	-	3.5	12.5	75	75	-	0.005	11.4	2.9	0.26	0.25	0.43	0.48	96.6	1.0	2.4	14	1.4
Syncrude overburden	7.40	2.46	0.18	trace	0.18	1.24	-	3.5	32.5	65	1870	4.48	0.019	278.4	3.9	0.64	12.00	0.43	1.70	64.8	18.4	16.8	18	9.6
GCOS overburden	7.75	1.51	trace	trace	trace	1.89	-	3.5	60.0	75	1555	3.53	0.024	232.0	3.9	1.30	13.25	0.43	2.80	59.9	21.0	19.1	18	10.5
Agricultural soil (Malmo)	6.05	0.52	3.37	15.96	19.33	6.37	10.96	11.5	150.0	85	4950	-	0.450	9.5	37.8	3.80	31.75	0.43	4.80	38.4	45.2	16.4	30	-
Heavy oil sand (GCOS mine site)	5.70	0.19	trace	trace	trace	10.70	-	2.5	12.5	80	90	-	0.049	48.0	2.9	0.64	0.25	0.43	0.48	68.0	30.4	1.6	14*	141.4
Lean oil sand (air-dried)	6.75	0.15	trace	trace	trace	6.12	-	2.0	7.5	45	145	-	0.037	6.3	2.9	0.26	5.00	0.22	0.35	96.2	0.6	3.2	14	79.3
Peat (GCOS, drained)	4.10	0.16	trace	trace	trace	56.75	97.60	4.0	130.0	230	3250	-	0.863	460.0	127.1	3.80	33.25	0.65	9.04	-	-	-	250**	-

* 5% field moist

** on an air dry basis

capacity is that to be expected for a sand, and the dominant cation is sodium. Residue of oil in the sieved (2 mm) sample is low (0.15 percent). The tailings sand, once air-dry, does not re-wet readily and evenly without manual mixing; on the other hand, when wet it tends to hold more water than would be expected of any material whose sand fraction is nearly 97 percent of the particle size distribution.

Overburden Materials, Syncrude and GCOS

The overburden piles would be expected to vary in their properties because of differences in the materials comprising each pile. The two piles sampled, however, did not exhibit wide differences in their properties. Their reaction is slightly above neutrality, and although the salinity level is higher than in most agricultural soils the level as is would have hardly any detrimental effect on most crops. Movement of these salts and their accumulation at the soil surface or in localized spots within the pile will cause some problems if the pile is to be vegetated or used in vegetating mined sand. Major plant nutrient levels are low, and therefore fertilizers would be required to ensure rapid plant growth. Sulfate sulfur levels are high, and the piles are slightly calcareous. The low cation exchange capacities are due to the high sand content and relatively low organic carbon content. The high level of calcium in the exchange complex again emphasizes the presence of some free carbonates (soluble in 1N ammonium acetate). Bitumen content is about one percent in these two samples; however, this level (which is safe in terms of plant growth) is exceeded in several small areas within all overburden piles, in which areas they could be classified essentially as lean oil sand.

Heavy and Lean Oil Sands

These two sandy materials were found to be high in crude bitumen content and generally low in plant nutrients; either of these conditions would constitute a major problem in vegetating these materials. Soil reaction and salinity levels, as measured in the presence of bitumen, are within acceptable ranges for plant growth. The sulfate sulfur level is high in the heavy oil sand.. The bitumen content is high in the heavy oil sand, so that the material when used as a growth medium would probably be detrimental to the growth of a wide range of plants, including many plants adapted to the ecological environment of the oil sands area.

Peats

Peat samples taken within the Syncrude and GCOS leases range in reaction from very acid to near neutral. A drained sample (whose properties are given in Table 19) from the GCOS mining area has a pH of about 4.1 and a low salinity level. Plant nutrient levels are low compared with a mineral soil equivalent. It is a low-lime and high-organic peat. As a medium for crop production this peat would rate as very poor.

Agricultural Soil (Malmo)

Samples of this soil were obtained from the Department of Soil Science farm at Ellerslie. It has a silty clay loam surface texture and is considered to be a very productive soil. Samples of this soil were included in the experiments as a standard soil for comparison with the materials collected from the mine areas at Fort McMurray.

GROWTH OF A RANGE OF PLANT SPECIES ON BITUMEN CONTAINING MATERIALS

Introduction

Mined areas which are high in bitumen content and which become exposed would have to be vegetated. The overburden piles also have scattered areas on the surface which may range in oil content from traces to lean oil sands levels, and may in some areas approach heavy oil sands. In several places in the Syncrude and GCOS leases at Fort McMurray some native species have been found naturally established in areas high in oil sand content; however, observations have indicated that with mining activities, which disturb the established system, it becomes very difficult for voluntary native species to re-establish.

The objective of this experiment was to measure the amount of growth of both native and cultivated grasses and legumes on lean and heavy oil sand materials in the growth chamber. The growth of these species on the lean and heavy oil sand was compared to the growth on the agricultural soil (Malmo) to determine the effect of bitumen on each species.

Experimental Procedure

The experiment in the growth chamber was set up in a randomized block design with each treatment replicated two times. Plant species grown and soil material mixes used (treatments) are as follows:

(1) Soil mixes:

(a) Malmo (agricultural soil): 1,200 g per pot. Limed with dolomitic limestone (ratio of 10:1, $CaCO_3$:$MgCO_3$) at a rate of 2 g per pot.

(b) Malmo-heavy oil sand mix: 1,300 g per pot. Limed with dolomitic limestone at a rate of 1 g per pot (700 g of air-dry Malmo and 600 g of fresh heavy oil sand; 3:2 ratio by volume).

(c) Lean oil sand: 1,500 g per pot. Limed with dolomitic limestone at a rate of 0.5 g per pot. The material had been exposed for several years and therefore was probably different in composition from a fresh lean oil sand.

(2) Species:

(a) Saximontana fescue *(Festuca saximontana)*

(b) Slender wheat grass *(Agropyron trachycaulum)*

(c) Bromegrass *(Bromus inermis)*

(d) Alkali grass *(Puccinellia nuttalliana)*

(e) Hairy wild rye *(Elymus innovatus)*

(f) Creeping red fescue *(Festuca rubra)*

(g) Cicer milk vetch *(Astragalus cicer)*

(h) Sainfoin *(Onobrychis sp.)*

(i) Alfalfa *(Medicago sp.)*

(3) Replications: two.

The growth chamber environment was set to duplicate as closely as possible the summer conditions at Fort McMurray. Daytime temperature was set at 20^{o} C and nighttime temperature was set at 10^{o} C. Day length was 16 hours. Control of the humidity was somewhat limited in the building in which the growth chamber was located. Humidity in the building was always set at 55 percent. The humidity during the growth of the plants, therefore, was never less than 55 percent.

Two crops were grown, the first from December 30, 1974 to May 18, 1975 and the second from May 29 to September 27, 1975.

Each treatment received fertilizers at seeding. In the first seeding the fertilizer, which was applied in a solution, was placed two inches below the surface; in the second seeding it was added to the top of the soil. At the seeding of the first crop 20 lb N, 40 lb P, 68 lb K and 7.5 lb S per acre on an area basis were applied as NH_4NO_3, KH_2PO_4 and K_2SO_4. Micronutrients were also applied two months later, at the same time that an additional 40 lb N, 10 lb P, 49 lb K and 15 lb S per acre were applied. An additional 40 lb N was applied on April 24, bringing the total nutrients applied to the first crop to 100 lb N, 50 lb P, 118 lb K and 22.5 lb S per acre plus nicro-nutrients. The same micro-nutrient solution was used in all the growth chamber studies. Its composition is given below.

Micronutrient solution:

(a) Iron solution

6.71 g Ferric citrate

8.43 g EDTA

Dissolved in 250 ml distilled water and autoclaved for 20 minutes.

(b)

1.0 g NaCl

1.0 g $CaSO_4.2H_2O$

1.0 g $MgSO_4.7H_2O$

0.05 g H_3BO_3

0.154 g $MnSO_4.H_2O$

0.088 g $ZnSO_4,7H_2O$

0.100 g $Na_2MoO4.2H_2O$

0.001 g $CuSO_4,5H_2O$

0.002 g $CoCl_2,6H_2O$

Dissolved in 1500 ml distilled water, 50 ml of solution (a) added and made to 2000 ml Micronutrient solution applied at the rate of 4 ml per pot.

In the second seeding in May, 40 lb N, 10 lb P, 49 lb K and 15 lb S per acre plus micro-nutrients were applied at seeding. An additional 60 lb N, 20 lb P and 50 lb K were applied two months later, bringing the total nutrients applied to 100 lb N, 30 lb P, 99 lb K and 15 lb S per acre plus one application of micro-nutrients.

The percent moisture content for each soil mix at field capacity was determined and each pot was watered to field capacity by weighing in the first two months of growth. Plants in each pot were thinned to a maximum of five plants per pot at the appropriate times.

Observations and Results

Growth of the Different Plant Species

Germination on all three soil mixes was achieved in both seedings and some form of growth was maintained on all treatments throughout the duration of the experiments. In the first seeding, growth of each species on the Malmo silty clay loam was good, and growth on the lean oil sand was only about half as good as on the Malmo. Growth of each species on the Malmo-heavy oil sand mix was poor throughout the first seeding. With the exception of the Creeping Red Fescue, growth did not advance beyond the level achieved in the first few days after germination. About three months after seeding, individual plants were dying out. On the lean oil sand the plants initially grew well but at about the beginning of the fourth month after seeding growth seemed to have slowed down in the brome-grass, alkali grass, sainfoin and hairy wild rye, and the alfalfa and sainfoin started to die. Germination of the cicer milk vetch was very uneven. Germination dates for all species ranged between four and six weeks after seeding; this caused a delay in the early establishment of plants and thus growth even on the Malmo appeared to be delayed considerably.

In the second seeding on May 29, growth of each species was achieved on all three soil mixes. On the Malmo, germination of each species was very good, including cicer milk vetch. Growth of each species was much better than in the first seeding on the lean oil sand, except for the saximontana fescue of which, although it showed very good growth in the first three months, several plants died out in both replications and those remaining probably would also have died within another two months. The growth of each species in the Malmo-heavy oil sand mix was considerably improved over the growth obtained in the first seeding. None of the species appeared to be dying at harvest.

Nodulation by Legumes

An examination of the legumes at the harvest of both seedings showed no nodulation in any of the three legumes in the Malmo-heavy oil sand mix, and root distribution was only partial in the pots. In the lean oil sand, nodulation was absent in the first seeding but a few tiny nodules were produced by all three legumes in the second crop. The colors of the nodules were creamy to white and it is thus doubtful if much nitrogen were being fixed. Relatively large amounts of fertilizer nitrogen may have had an influence on this. On the Malmo each legume produced nodules but the color of the nodules again indicated little if any likelihood of nitrogen fixation. In the second seeding each legume also produced nodules, but their color indicated no clear indication of nitrogen fixation.

Root Distribution

Root distribution in the pots was restricted with the Malmo-heavy oil sand mix in all the legumes and grasses except the creeping red fescue, which had its roots distributed throughout the entire pot. In the Malmo and lean oil sand the roots were distributed throughout the entire pots, the only exception being the alkali grass grown on the lean oil sand. In the second seeding the roots of each species were distributed throughout the entire pot for the malmo and lean oil sand. On the Malmo-heavy oil sand mix the slender wheat grass, bromegrass, hairy wild rye and creeping red fescue roots were distributed throughout the mix; the distribution of the roots of the other grasses and legumes in the mix was fairly restricted. On washing the roots it was found that roots of nearly all the species had penetrated the lumps of the heavy oil sands in the Malmo-heavy oil sand mix. This did not occur in the first seeding where the few roots produced were confined to the pockets of Malmo in the mix.

Dry Matter Production

Tops

In the first seeding (Table 20) each of the species gave its best yield on the Malmo silty clay loam, which averaged three times as great as on the lean oil sand and about seventy times as great as on the Malmo-heavy oil sand mix. With the exception of the saximontana fescue, which gave a higher yield on the Malmo-heavy oil sand mix than on the lean oil sand, the same general yield patterns were observed in the second seeding (Table 21) as in the first. Yield on the Malmo-heavy oil sand mix, however, averaged 22 times greater in the second seeding than in the first, whereas yield on the Malmo soil remained relatively constant.

In lean oil sand areas all the species grown with the exception of Saximontana Fescue could be expected to survive in a vegetation program (Table 21). From the above results it would appear that where heavy oil sands

Table 20. Yields of tops and roots of the species grown on two oil sand-bearing materials as compared with yields on a good agricultural soil (Malmo), first seeding (grams per pot).

	TOPS			ROOTS			TOPS AND ROOTS		
	Malmo	Malmo + heavy oil sand	Lean oil sand	Malmo[2]	Malmo + heavy oil sand	Lean oil sand	Malmo[2]	Malmo + heavy oil sand	Lean oil sand
Saximontana fescue	4.98	0.03	2.66	1.40	*	1.68	6.38	*	4.34
Slender wheat grass	6.08	0.05	1.91	4.84	0.03	2.01	10.92	0.08	3.92
Bromegrass[1]	4.97	0.10	1.60	4.10	0.09	1.43	9.07	0.19	3.03
Alkali grass[1]	3.78	0.01	0.29	1.21	*	0.14	4.99	*	0.43
Hairy wild rye	4.24	0.07	1.42	2.08	0.03	0.79	6.32	0.10	2.21
Creeping red fescue	11.01	0.27	3.66	5.63	0.24	2.68	16.64	0.51	6.34
Cicer milk vetch[1]	1.56	0.01	0.92	0.95	*	0.99	2.51	*	1.91
Sainfoin[1]	3.99	0.05	0.77	1.69	0.04	0.55	5.68	0.09	1.32
Alfalfa	5.40	0.06	1.22	6.30	0.01	1.65	11.70	0.07	2.87

* Root yields were too low to recover

1 Reseeded 23 days after the others

2 A considerable percentage of the fine roots could not be recovered in the Malmo

Table 21. Yields of tops and roots of the species grown on two oil sand-bearing materials as compared with yields on a good agricultural soil (Malmo), second seeding (grams per pot).

	TOPS			ROOTS			TOPS AND ROOTS		
	Malmo	Malmo + heavy oil sand	Lean oil sand	Malmo[1]	Malmo + heavy oil sand	Lean oil sand	Malmo[1]	Malmo + heavy oil sand	Lean oil sand
Saximontana fescue	4.85	0.84	0.43	1.70	0.39	0.46	6.55	1.23	0.89
Slender wheat grass	5.75	2.83	3.58	6.10	1.88	6.30	11.85	4.71	9.88
Bromegrass	6.33	2.45	4.85	8.55	2.24	4.64	14.88	4.69	9.49
Alkali grass	5.78	0.48	4.20	2.52	0.12	3.55	8.30	0.60	7.75
Hairy wild rye	4.31	1.85	2.93	3.23	1.33	2.34	7.54	3.18	5.27
Creeping red fescue	11.75	4.16	6.77	7.53	3.07	8.69	19.28	7.23	15.46
Cicer milk vetch	4.14	0.06	2.89	4.79	0.07	3.53	8.93	0.13	6.42
Sainfoin	6.36	0.48	2.22	5.23	0.17	2.93	11.59	0.65	5.15
Alfalfa	6.02	0.44	3.96	8.60	0.22	4.53	14.62	0.66	8.49

[1] A considerable percentage of the fine roots could not be recovered in the Malmo.

Table 22. Root yields in relation to top yields of the species grown on lean oil sand and Malmo-heavy oil sand mix in the second seeding (roots/tops).

	Malmo + Heavy oil sand	Lean oil sand
Saximontana fescue	0.46	1.07
Slender wheat grass	0.66	1.76
Bromegrass	0.91	0.96
Alkali grass	0.25	0.85
Hairy wild rye	0.72	0.80
Creeping red fescue	0.74	1.28
Cicer milk vetch	1.17	1.22
Sainfoin	0.35	1.32
Alfalfa	0.50	1.14

may be exposed, the mixing of a good soil (such as Malmo) with the heavy oil sand, to achieve at least a 1:1 mixture in the surface four to six inches, would enhance the establishment of a surface cover. The first seeding (Table 20) indicated that none of the species tested could provide a quick surface cover. A waiting period of at least four to five months with warm temperatures is required between mixing of the heavy oil sand with a good soil and seeding, before a good vegetative cover could be successfully established with any of the tested species. Further work is needed to determine if the other overburden materials can be mixed with heavy oil sands to produce similar results. Slender Wheat Grass, Bromegrass, Hairy Wild Rye and Creeping Red Fescue (Table 21) appear to grow reasonably well in the growth chamber. Although the legumes tested were successfully grown, excluding cicer milk vetch (Table 21) the covers provided could not be considered adequate. From the work on the biological aspects of this material, it appears that the addition of a soil innoculum to a heavy oil sand markedly enhances the biological activity within the oil sand.

There were evidences of a probable non-nutritional toxic condition existing in the oil sand materials, the source of which requires further research to establish. The lean oil sand contained more oil per weight basis than the oil sand-Malmo mix.[1] It therefore appears that some components not present in the lean oil sand but present in the heavy oil sand may in the case of the heavy oil sand be adding to the already existing toxicity of these materials. The lean oil sand had been exposed for several years prior to sampling and was not typical of any freshly exposed lean oil sand; it was air-

---

[1]On a pot volume basis the lean oil sand contained 19.91 percent more oil than the heavy oil sand. On a weight basis it contained 38.36 percent more oil.

dried before potting. The heavy oil sand had little exposure; it came from the GCOS bucketwheels at the mine site and was mixed without air-drying with the air-dry Malmo. Pretreatment of the sample is expected to have had an effect on the results.

The better growth obtained with each species in the second seeding on the Malmo-heavy oil sand mix suggested a major decline in the toxic components in the heavy oil sand material in the period between the first and second seedings. Micro-organism breakdown of the oil in the fertilized Malmo-heavy oil sand mix may have reduced the content of toxic components of the fresh heavy oil sand. In the lean oil sand the improved yields of the species in the second seeding also suggested some decline in the toxic component or decline in readily decomposable components which lead to nitrogen immobilization. Volatilization may have been important in ameliorating the apparent "toxic" conditions in the heavy oil sand but not in the lean oil sand. Since the lean oil sand had been exposed several years prior to sampling, the mechanism for improvement in growth conditions in this material is expected to be biological.

Roots. Root yields in the soil mixes varied with the species. In general, root production on the Malmo was higher than the Malmo-heavy oil sand mix or the lean oil sand. A considerable percentage of the finer roots in the Malmo were lost in separating the roots from the soil and therefore cannot be fairly compared with the roots recovered from the other two soil mixes. In the first seeding (Table 20) root yields, as with the yields of the tops, were very poor in the Malmo-heavy oil sand mix for each of the species. In the lean oil sand, root yields were relatively high in all grasses except alkali grass and hairy wild rye. Of the three legumes only alfalfa gave a substantial root yield. In the second seeding root yields (Table 21), as with the tops, were higher on the Malmo-heavy oil sand mix and lean oil sand than in the first seeding, the only exception being the saximontana fescue. The same general explanations given for the differences between the yields of the first and second harvests of the tops also apply for the yields of the roots. Generally those species giving good root yields would be expected to improve slope stability on overburden piles on which these bitumen-bearing materials would be encountered. Total yields of the tops and roots (Table 21) and the yields of the roots in relation to the yields of the tops (Table 22) from the second seeding indicate that on the lean oil sands any of the species tested in the growth chamber would be possible candidate species for field tests. They may prove practical for improving slope stability in bitumen-rich material since they will grow in these materials. In areas where bitumen levels on overburden piles are high enough to approach levels found in heavy oil sand material, mixing the material with a good soil and seeding to slender wheat grass, bromegrass, hairy wild rye or creeping red fescue would warrant further field testing of their use in improving slope stability.

Oil Content of the Soil Mixes

Bitumen contents of the soil mixes are shown in Table 23. Fresh heavy oil sand had an oil content of 14.14 percent (141 mg per gram of oven dry soil). Oil content of the lean oil sand at seeding was 7.83 percent.

In nine months of cropping of the lean oil sand in pots, the bitumen content had declined by less than 8 percent. Bitumen loss from the heavy oil sand was, however, more rapid and about 25 percent of the bitumen had been lost over the nine-month period, when it was mixed with Malmo silty clay loam. Individual heavy oil sand lumps were still recognizable after the two seedings,

Table 23. Oil content of lean and heavy oil sands before and after two seedings (December 30, 1974 to September 28, 1975).

	Original Bitumen Content(%)	Amount of Original Oil Decomposed(%)
Pre-seeding (Dec. 30, 1974)		
Fresh heavy oil sand	14.14	--
Lean oil sand	7.83	--
Malmo-fresh heavy oil sand mix	6.53	--
After two seedings (Sept. 28, 1975)		
Lean oil sand	7.22	7.79
Malmo-fresh heavy oil sand mix	4.80	26.49
Decomposing heavy oil sand[1]	10.67	24.54
Equivalent of original heavy oil sand remaining[2]	10.40	26.45

[1]Lumps still recognizable as heavy oil sand in the mix with Malmo.

[2]Based on 4.80% oil left in the Malmo-heavy oil sand mix in relation to the pre-seeding bitumen content of the fresh heavy oil sand.

but their oil content had decreased by approximately 25 percent. Mixing of good soil with the lean oil sand would probably have contributed further towards a more rapid decomposition of the lean oil sand.

<u>Tentative Conclusions</u>

(1) As compared with a good agricultural soil (Malmo), growth of the species on the oil sand-bearing materials was poor. Growth on the air-dry lean oil sand material was better than on the Malmo-heavy oil sand mix.

(2) Fertilization and incubation at warm temperatures for at least four months improved growth of several species on the Malmo-heavy oil sand mix. It appears that some time is required for the attenuation of the "toxic" condition in the heavy oil sand. The processes by which growth conditions in the oil sand improved appeared to have been physical and biological.

(3) Rate of bitumen loss was very slow in the lean oil sand as compared with the Malmo-heavy oil sand over the nine-month period of the experiment. Mixing the lean oil sand with a good soil will probably accelerate decomposition of the bitumen. Field tests using available overburden materials in place of Agricultural soil are warranted.

(4) With the exception of the saximontana fescue, which tended to die after a good initial growth, the species tested in the growth chamber may prove successful in field trials on the lean oil sand areas of overburden piles. Only four grasses (slender wheat grass, bromegrass, hairy wild rye and creeping red fescue) of the grasses and legumes tested grew well on the Malmo-heavy oil sand mix in the second seeding. These four grasses

thus hold the potential for providing a good vegetative cover in areas where there is a high concentration of heavy oil sand, assuming conditions such as optimum fertilization are created so that oil levels can decline through decomposition. They warrant further field testing.

GROWTH OF VARIOUS PLANT SPECIES ON A TAILINGS SAND AND A PEAT-OVERBURDEN MIX ARTIFICIALLY SALINIZED

Introduction

Some overburden materials sampled randomly on the overburden piles are high in salinity and with continued seepage on the dike, sections on the vegetated dike receiving the seepage water may also increase in salinity, with the possibility that the vegetative cover may die out. (See Salts, Part I.) Vegetating such areas or ensuring the survival of an already seeded cover requires a special study to minimize the problems in such areas.

The main objective of this salinity experiment was to establish the ability of selected species to withstand very high salinity levels in two different situations:

(1) Where the salinity of the soil progressively increases, as through seepage in areas where a vegetative cover has been established (first seeding); and

(2) Where the soil is already high in salinity and an attempt is made to establish a vegetative cover (second seeding).

Experimental Procedure

During the course of the experiment two seedings were made in a growth chamber. The first seeding, whose main aim was to find answers to objective (1), was seeded on December 20, 1974 and harvested on May 16, 1975. The second seeding, whose main aim was to find answers to objective (2), was seeded on May 29 and harvested on September 27, 1975.

Each pot in which the species chosen for the experiment were grown consisted of the following mix: tailings sand (1,050 g), GCOS peat (80 g) and GCOS overburden soil (470 g) in approximately a 2:1:1 ratio by volume. (The properties of these materials are given in Table 19.) The experiment was set up in a randomized block design with each treatment having two replications. The following salinity treatments were imposed:

(1) Salinity (salt) levels.

(a) S_0 = electrical conductivity of the original mix (check).

(b) S_1 = low salinity (5.29 mmho/cm at start).

(c) S_2 = medium salinity (9.52 mmho/cm at start).

(d) S_3 = high salinity (18.73 mmho/cm at start).

Soils were salinized using Na_2SO_4.

(2) Species:

(a) Kentucky bluegrass *(Poa pratensis)*

(b) Saximontana fescue *(Festuca saximontana)*

(c) Slender wheat grass *(Agropyron trachycaulum)*

(d) Bromegrass *(Bromus inermis)*

(e) Alkali grass *(Puccinellia nuttalliana)*

(f) Hairy wild rye *(Elymus innovatus)*

(g) Creeping red fescue *(Festuca rubra)*

(h) Cicer milk vetch *(Astragalus cicer)*

(i) Sainfoin *(Onobrychis sp.)*

(j) Wolf willow *(Elaeagnus commutata)*

(k) Alfalfa *(Medicago sp.)*

(3) Replications: two.

In determining the amounts of sodium sulfate to add to obtain salinity levels in treatments S_1, S_2 and S_3, the salt solution (142.04 g/l) was added in different volumes to samples of the soil mix to make a paste and was equilibrated for 72 hours. Electrical conductivity (EC) of the soil mix samples were made; the levels obtained, which were close to 4+, 8+ and 16+ mmho/cm, were arbitrarily set to represent low, medium and high salinity levels. A sample of the original soil mix was also equilibrated with water and the EC level (S_0) determined. EC levels after 72 hours equilibration were S_1 = 5.24 mmho/cm; S_2 = 9.52 mmho/cm; S_3 = 18.73 mmho/cm. These values, with the exception of S_3, were lower than the mean values measured on the samples taken from the pots after the second seeding (Table 29). This suggests that it took longer than 72 hours for the soil mix to come to equilibrium with the sodium sulfate.

The same sowing, fertilization, environmental control of the growth chamber and watering programs described under the section entitled Bitumen Experiment (Part III) were also followed in this experiment for both seedings.

In the first seeding, when each species was well established (two months after germination), predetermined amounts of sodium sulfate solution were added to the pots before watering every other day over a 21-day period. In the second seeding the salinity levels tested already existed in the mix before the seeds were sown.

Another study with dawn alsike (Trifolium hybridum) and the species used for the salinity experiment was conducted to determine germination of the seeds in sodium sulfate solutions in petri-dishes over a six-week period. Levels of salinity for each species in duplicates were: check (distilled-deionized water); 2 mmho/cm; 4 mmho/cm; 8 mmho/cm; and 16 mmho/cm. Each treatment was replicated two times using 15-50 seeds per replicate depending upon the species. Germination was recorded if a radicle of at least 2 mm in length was produced by a seed. Radicle damage was also rated as slight, moderate or severe.

Observations and Results

Growth of the Plant Species

In the first seeding a relatively good growth of each species was maintained on the tailings sand-peat-overburden mix before salinity treatments were imposed on the plants. Germination of the cicer milk vetch, as mentioned under the bitumen experiment, was slow and uneven. With the imposition of salinity treatments several of the species stopped growing, especially at the high salinity levels, and eventually died out. At harvest the Kentucky bluegrass was dead in the higher two salinity levels (S_2 and S_3) and at the low salinity level (S_1) the older leaves were dying. The saximontana fescue was dead in all treatments in which the salinity levels were elevated. Growth in the slender wheat grass ceased with the addition of salt and the plants had started to show signs of dying, expecially in the high salinity treatment. Also, the bromegrass growth had slowed down considerably and although most of the plants were still living, growth was expected to stop and the plants eventually die out. The alkali grass seemed to have been least affected by the high salinity levels of the mix; none of the plants really showed any signs of dying except for a few leaves on the high salinity treatment. The addition of salts resulted in the death of the hairy wild rye in the two higher salinity levels. Death also occurred in the low salinity treatment, except for one plant which was still alive at harvest. Growth of the creeping red fescue was not affected much at the low salinity level, however, at the medium and high salinity levels plants were showing signs that they might die out later. The cicer milk vetch had started dying by harvest at the high and medium salinity levels, but salinity tolerance at the low level appeared to be high. The sainfoin was dead at harvest in the high salinity level and was only beginning to show a salinity effect at the medium level. Growth was near normal in the low salinity level. Growth of the wolf willow was slowed by the presence of the salts and it showed signs of dying out early in the high salinity level. Growth of the alfalfa was relatively poor in the check. The plants were dead in the other salinity treatments; however, in the low salinity treatment, although the older stems were dead, new growth had started at harvest.

In the second seeding in which the plant species were grown on the soil mix at four salinity levels all throughout the duration of the experiment, the growth patterns, with the exception of the check salinity treatment, were different from the first seeding. Almost all the species did not germinate at the high salinity level and of those germinating in the medium salinity level very few survived after the sixth week. There was germination of all species at the low salinity level, although growth in two of the species was very poor. Germination in nearly all species was slightly delayed by the alkalinity in the mix. At harvest there was growth of Kentucky bluegrass and bromegrass only on the check (S_0) and the low salinity treatment. The grass had grown more slowly with salinity and as such did not lack nutrients at harvest, as did the check treatment. Saximontana fescue growth was almost non-existent even at the low salinity level. Growth of the slender wheat grass was maintained at low and medium salinity levels, although growth at the medium salinity level was poor. Growth at the low salinity level was much better and plants seemed to have depleted the nutrients at harvest at a more rapid rate than the check. The alkali grass was the only species that maintained some form of growth at all salinity levels throughout the second seeding. Growth at the high salinity level was comparatively poor. Growth on the salinity treatments was slow as compared with the check, which grew faster, became nutrient deficient and produced seeds at harvest. The hairy wild rye and creeping red fescue grew well on the check but had depleted the nutrients supply by harvest time. At low salinity level the plants grew more slowly and at medium salinity level only one replicate had good growth; a very poor growth was maintained in the other. The cicer milk vetch, sainfoin and wolf willow gave very poor growth even at the low salinity level. At harvest of the wolf willow all plants but one had died. Some growth of the alfalfa, although poor, was maintained on the low salinity treatment; in one replication a very poor growth was obtained on the medium salinity treatment.

Dry Matter Production

Tops. Dry matter production in the first seeding was best in the check salinity treatment for each species (Table 24). In several salinity treatments the plants died before harvest. The yields shown in brackets in Table 25 may be taken to represent the extent of growth before dying; where some plants still survived the salinity effect, the fractions of the dead plants are indicated. The species with any degree of salinity tolerance (Table 27) showed a wide range

Table 24. Dry matter yields of different species on a soil mix of different salinity levels -- salinity progressively increased by adding sodium sulfate solution to the soil mix surface after species were well established (first seeding) -- grams per pot.

	Yield (S/pot) Average of 2 replicates											
	Tops				Roots				Tops + Roots			
	Check (S_o)	Low (S_1)	Med. (S_2)	High (S_3)	Check (S_o)	Low (S_1)	Med. (S_2)	High (S_3)	Check (S_o)	Low (S_1)	Med. (S_2)	High (S_3)
Kentucky bluegrass	1.48	(1.35)*	(1.03)	(0.78)	3.36	(1.00)	(0.99)	(1.04)	4.85	(2.35)	(2.02)	(1.82)
Saximontana fescue	2.85	(1.05)	(0.92)	(0.77)	1.90	(0.22)	(0.24)	(0.34)	4.75	(1.27)	(1.16)	(1.11)
Slender wheat grass	2.03	(1.63)	(1.14)	(0.58)	1.86	(0.85)	(0.85)	(0.60)	3.89	(2.48)	(1.99)	(1.18)
Bromegrass[1]	1.51	1.22	1.22	1.01	1.14	0.85	1.06	1.06	2.65	2.07	2.28	2.07
Alkali grass[1]	1.08	1.27	0.95	0.76	0.53	0.86	0.51	0.47	1.61	2.13	1.46	1.23
Hairy wild rye	2.37	(1.38)	(0.90)	(0.77)	2.17	(1.04)	(0.76)	(0.75)	4.54	(2.42)	(1.66)	(1.52)
Creeping red fescue	3.26	2.55	1.16	1.14	1.59	0.65	0.64	0.82	4.85	3.20	1.80	1.96
Cicer milk vetch[1]	0.21	0.21	(0.21)	(0.25)	0.19	0.27	(0.21)	(0.20)	0.40	0.48	(0.42)	(0.45)
Sainfoin[1]	0.74	0.38	0.41	(0.61)	0.36	0.28	0.28	(0.36)	1.10	0.66	0.69	(0.97)
Wolf willow	0.69	0.27	0.21	(0.21)	0.55	0.25	0.17	(0.25)	1.24	0.52	0.38	(0.46)
Alfalfa	1.73	(0.80)	().89)	(0.40)	2.13	(1.12)	(1.42)	(1.97)	3.86	(1.92)	(2.31)	(2.37)

[1] Reseeded 33 days after other plants

* Figures in brackets indicate yields for both live and dead plants -- see Table 25 for percentages of dead plants in each treatment at the time of harvest.

Table 25. Percent of dead plants in each salinity treatment level at harvest -- First seeding.

	Check (S_o)	Low (S_1)	Medium (S_2)	High (S_3)
Kentucky bluegrass	0	20	100	100
Saximontana fescue	0	100	100	100
Slender wheat grass	0	20	40	80
Bromegrass	0	0	0	0
Alkali grass	0	0 -	0	0
Hairy wild rye	0	80	100	100
Creeping red fescue	0	0	0	0
Cicer milk vetch	0	0	50	100
Sainfoin	0	0	0	100
Wolf willow	0	0	0	100
Alfalfa	0	40	60	100

of variability in their tolerance. Overall, the alkali grass was most tolerant to salinity at the levels tested. The creeping red fescue gave the best yield (Table 24) in the low salinity level; alkali grass and bromegrass were the next best. Yields of the other species surviving low soil salinity were poor. These same three grasses gave progressively lower yields at the medium and high salinity levels.

In the second seeding (Table 26), in which the soil mix was already treated to different salinity levels before sowing the various species, again the check salinity treatment (S_0) gave comparatively much better yields than the other salinity treatments, except the slender wheat grass which gave a higher yield at low salinity than did the check. As compared with the check, yields dropped by more than 100 percent at the low salinity treatment for each species except in the slender wheat grass and alkali grass; yields, however, remained relatively high in the creeping red fescue and bromegrass. At the medium salinity level the only species giving a substantial yield was the alkali grass. Practically every species gave no yield at the high salinity level.

Roots. Root yields (Tables 24 and 26) as affected by the different salinity levels in both seedings essentially followed the same yield patterns as the tops, discussed above.

Salinity Tolerance

Relative salinity tolerance, expressed as a percentage of the check yields (Table 27), showed that of the species with any degree of tolerance to increasing salinity the alkali grass has the highest salt tolerance. Bromegrass and creeping red fescue were next best among the grasses. None of the remaining grasses and legumes tested indicated much salinity tolerance. Sainfoin had the highest salinity tolerance among the legumes tested. Although the cicer

Table 26. Dry matter yields of different species on a soil mix of different salinity levels -- salinity levels already existing in soil mix at seeding (second seeding) -- grams per pot.

	Tops				Roots				Tops + Roots			
	Check (S_o)	Low (S_1)	Med. (S_2)	High (S_3)	Check (S_o)	Low (S_1)	Med. (S_2)	High (S_3)	Check (S_o)	Low (S_1)	Med. (S_2)	High (S_3)
Kentucky bluegrass	3.73	0.50	0	0	10.77	0.50	0	0	14.50	1.00	0	0
Saximontana fescue	3.87	0.02	0	0	4.71	*	0	0	8.58	0.02	*	0
Slender wheat grass	4.10	5.67	0.79	0	4.93	3.53	0.32	0	9.03	9.20	1.11	0
Bromegrass	5.55	1.05	0	0	7.43	0.99	0	0	12.98	2.04	0	0
Alkali grass	5.32	4.01	2.05	0.05	4.80	2.51	0.72	0.02	10.12	6.52	2.77	0.06
Hairy wild rye	5.46	0.98	0.03	0	5.18	0.85	0.07	0	10.64	1.83	0.10	0
Creeping red fescue	7.81	2.18	0.05	0	16.62	1.24	*	0	24.43	3.42	*	0
Cicer milk vetch	1.37	0.08	0	0	1.85	0.17	0	0	3.22	0.25	0	0
Sainfoin	3.01	0.24	0	0	5.24	0.13	0	0	8.25	0.37	0	0
Wolf willow	0.84	0.06	0	0	0.81	*	0	0	1.65	0.06	0	0
Alfalfa	4.25	0.35	0.06	0	7.07	0.33	0.04	0	11.32	0.69	0.10	0

* Root yield was too low to recover.

Table 27. Yields of the species with some degree of salinity tolerance expressed as a percentage of the check (S_o) -- in a situation where salinity progressively increases. (First seeding)

	Tops			Roots			Tops + Roots		
	Low (S_1)	Med. (S_2)	High (S_3)	Low (S_1)	Med. (S_2)	High (S_3)	Low (S_1)	Med. (S_2)	High (S_3)
Bromegrass	80.8	80.8	66.9	74.6	93.0	93.0	78.1	86.0	78.1
Alkali grass	117.6	88.0	70.4	162.3	96.2	88.7	132.3	90.7	76.4
Creeping Red Fescue	78.2	35.6	35.0	40.9	40.3	52.2	66.0	37.1	40.4
Cicer milk vetch	100.0	nd	nd	142.1	nd	nd	120.0	nd	nd
Sainfoin	51.4	55.4	nd	77.8	77.8	nd	60.0	62.7	nd
Wolf willow	39.1	30.9	nd	45.5	30.9	nd	41.9	30.6	nd

nd - not determined, plants dead at harvest milk vetch indicated a high tolerance at low salinity it died out at medium salinity.

In the second seeding, where the salinity levels already existed in the mix before sowing (Table 28), every species showed some degree of salinity tolerance at the low level. Tolerance declined very sharply at the medium salinity level in each species, and at the high salinity level the only species still exhibiting any form of tolerance was the alkali grass. The only species with any form of generally higher salinity tolerance were the slender wheat grass and alkali grass.

Salinity Levels of the Mix

The reaction of the soil mix in all four salinity levels remained slightly above neutrality at the harvest of the second seeding (Table 29). This is to be expected, considering a neutral salt was used to achieve the different salinity levels on the mix. Salinity levels on the soil mix as determined at harvest of the second seeding (Table 29) were, with the exception of the high salinity (S_3) level, higher than the levels measured on samples equilibrated with sodium sulfate solution for 72 hours.

In the first seeding the sodium sulfate solution was applied to the surface; observations indicated that nearly all the salt applied remained near the surface of the mix. After the surface of the mix dried, substantial accumulation of the salt, as indicated by its color, occurred on the surface. Under the experimental condition of the first seeding, salt damage to the species was probably mostly the result of damage to the crowns and to those roots closer to the surface. In the second seeding salinity was evenly distributed in the soil mix and was, therefore, evenly distributed in the pots by hand mixing the contents. In the course of the second cropping, salt was observed to accumulate

Table 28. Yields of the species at different salinity levels expressed as a percentage of the check (So) -- in a situation where the salinity already existed (Second seeding).

	Tops			Roots			Tops + Roots		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
Kentucky bluegrass	3.4	--	--	4.6	--	--	6.9	--	--
Saximontana fescue	0.5	--	--	*	--	--	*	--	--
Slender wheat grass	138.3	19.3	--	71.6	6.5	--	101.9	12.3	--
Bromegrass	18.9	--	--	13.3	--	--	15.7	--	--
Alkali grass	75.4	38.5	0.9	52.3	15.0	0.4	64.4	27.4	0.6
Hairy Wild Rye	17.9	0.5	--	16.4	1.4	--	17.2	0.9	--
Creeping Red Fescue	27.9	0.6	--	7.5	*	--	14.0	*	--
Cicer milk vetch	5.8	--	--	9.2	--	--	7.8	--	--
Sainfoin	8.0	--	--	2.5	--	--	4.5	--	--
Wolf willow	7.1	--	--	*	--	--	*	--	--
Alfalfa	8.2	1.4	--	4.7	0.6	--	6.1	0.9	--

* Root yield was too low to recover.

Table 29. Mean pH and salinity levels of soil mix at harvest of the second seeding.

	Check (S_o)	Low (S_1)	Medium (S_2)	High (S_3)
pH	7.29	7.19	7.31	7.37
Conductivity (mmho/cm)	1.40	7.91	12.16	17.97
Conductivity (mmho/cm)*				
0-1"	nd	6.57	14.37	20.71
1-2"	nd	5.82	10.13	15.58
(rest of pot) 2-4"	nd	8.57	11.42	17.78
Mean by depth	--	7.38	11.83	18.06

*for alkali grass, creeping red fescue, and alfalfa

nd -- not determined

on the surface between waterings; at harvest, therefore, three species were chosen and the mix on which they grew was sampled at three depths -- 0 to 1 inch, 1 to 2 inches and 2 to 4 inches (rest of pot) -- to measure the salinity levels at these depths. In the low salinity level (S_1, Table 29), although the lowest depth was highest in salinity, the surface depth was higher in salinity than the immediate depth below. In the medium and high salinity treatments, the highest salinity levels were measured at the surface, and the immediate depth below was the lowest. Under conditions where there is salt movement to the surface on drying, salinity damage to the species may be similar to where salt was added to the surface of the soil, as in the first seeding.

Germination at Different Salinity Levels

The germination of each species in petri-dishes, with salinity levels adjusted with sodium sulfate solution was, with the exception of the wolf willow, not affected by levels up to 8 mmho/cm (Table 30). Salinity levels of 8 mmho/cm and above decreased germination of the Kentucky bluegrass. Salinity level at 16 mmho/cm decreased germination of all species except the hairy wild rye. Damage to the radicles was evident at different salinity levels in the different species. Severe damage to the radicle at the highest salinity level occurred in all species except the alkali grass and dawn alsike, which sustained a moderate damage. At the 8 mmho/cm level, severe damage occurred only on the saximontana fescue and cicer milk vetch. Although germination occurred in most species, at a salinity level as high as 16 mmho/cm salt damage was severe enough to prevent much further growth. At a salinity level of 8 mmho/cm most of the species could be expected to continue growing, as damage to roots was moderate or slight. The damage to radicles observed here explains the poor germination and growth of the second seeding at salinity levels greater than medium.

Table 30. Relative percent germination of the different species in petri dishes at different sodium sulphate salinity levels.

	Distilled water				
	.005 mmho/cm	2 mmho/cm	4 mmho/cm	8 mmho/cm	16 mmho/cm
Kentucky bluegrass	100.0	73.4	73.4	6.6	6.6*se
Saximontana fescue	96.7	100.0	95.6*vs	80.2*se	0.0
Slender wheat grass	100.0	86.4	65.4	42.3*s	0.0
Bromegrass	100.0	66.7	75.0	66.7*m	11.1*se
Alkali grass	75.0	75.0	62.5	50.0	100.0*m
Hairy wild rye	66.7	95.2	100.0	78.6*s	54.8*se
Creeping red fescue	99.0	100.0	91.8	88.7	24.7*se
Cicer milk vetch	88.9	83.3	100.0	94.4*se	5.6*se
Sainfoin	100.0	100.0	100.0	61.8*m	10.8*se
Wolf willow	77.2	100.0	13.6	18.1*m	9.1*se
Alfalfa	92.0	94.7	100.0	96.0*m	0.0
Dawn Alsike	90.1	100.0	94.5	80.0	7.3*m

*Root damage: vs = very slight
s = slight
m = moderate
se = severe

Tentative Conclusions and Practical Implications

(1) Germination of several of the species tested was generally high, with the salinity levels not greater than 8 mmho/cm. Although germination of several of the species occurred at a much reduced percentage at salinity levels as high as 16 mmho/cm, root damage was severe and, under such conditions, growth would normally be expected to be very poor.

(2) In a situation where the salinity of the soil is slowly increased by seepage to the surface, the extent of damage or eventual death of any species already well established is dependent upon the eventual salinity attained and on the salinity tolerance of the individual species. The alkali grass, bromegrass and creeping red fescue were found, at the age of two months, to withstand salinity to levels as high as almost 18 mmho/cm. (At this stage of development plants were subjected to varying levels of salinity.)

(3) In a situation where the soil salinity was already established before the species were seeded, germination of the seeds at salinity levels of 12 mmho/cm or more was poor and growth in most cases was poor, even if the species eventually became established. Alkali grass, and to a limited extent slender wheat grass, grew comparatively well at salinity levels as high as 12 mmho/cm.

(4) Salinity levels in the mix treated with sodium sulfate solution indicated that with increasing salinity the salt moved from the middle of the pot (1 to 2 inch depth) to the surface (0 to 1 inch depth). This salt generally accumulated around the crown of the plants, perhaps contributing significantly to the salt damage done at the ground level.

THE SOIL REACTION (pH) EXPERIMENT

Introduction

The main solid waste from the soil extraction process is the tailings sand which comes out of the processing plant. It has a high alkaline reaction due to the sodium hydroxide used for extracting oil. Some materials in the overburden piles may also be very alkaline in reaction. The possibility also exists that the alkaline liquids which have passed through the plant in the extraction process could accidentally find their way into areas where they may, due to their high pH, cause a considerable problem in a vegetation program. The fresh tailings sand can have a pH of over 9, and slightly older tailings sand values of around 8.5 are not uncommon (see Table 1).

It appears the alkalinity of the tailings sand decreases very rapidly when stored in the open, so that within two years it is only very slightly alkaline. However, in vegetating the tailings sand (as on the dike), the pH of the seedbed depends greatly on the pH of the peat used with the sand. The tailings sand effect on the final pH of the seedbed is almost negligible as it is very poorly buffered in comparison to well buffered peat or overburdens (see Figs 6-8). Peats on the GCOS and Syncrude leases collected in this study have been found to range from very acid (pH of about 4.0) to near neutral (pH of about 6.5) but more alkaline peats also exist in this region. Under conditions where the acid peat is used for vegetating the tailings sand, liming may be a requirement at seeding.

The objective of this experiment, which was conducted in a growth chamber, was to determine the effects of pH levels that may be encountered in a vegetation program on mine wastes, on the performance of a number of plant species. Although the original intent was to produce a low soil pH value, the slow but substantial buffering of the mix used resulted in the final pH values being only slightly acidic. See page 144 for results of buffering properties.

Experimental Procedure

In this experiment two crops were grown. The first crop was grown from December 23, 1974 to May 18, 1975 and the second from May 29 to September 27, 1975. The experiment was set up in a randomized block design with each treatment replicated two times. The plant species grown and the desired pH of the soil mixes are as follows:

(1) Desired soil mix pH:

- (a) pH 3.5 (Level A)
- (b) pH 5.0 (Level B)
- (c) pH 7.0 (Level C)
- (d) pH 9.5 (Level D)

(2) Species:

- (a) Saximontana fescue *(Festuca saximontana)*
- (b) Slender wheat grass *(Agropyron trachycaulum)*
- (c) Bromegrass *(Bromus inermis)*
- (d) Alkali grass *(Puccinellia nuttaliana)*
- (e) Hairy wild rye *(Elymus innovatus)*
- (f) Creeping red fescue *(Festuca rubra)*
- (g) Cicer milk vetch *(Astragalus cicer)*
- (h) Sainfoin *(Onobrychis sp.)*
- (i) Alfalfa *(Medicago sp.)*

(3) Replications: two

The soil mix on which each species was grown was composed of 1050 g of tailings sand, 80 g of GCOS acid peat and 470 g of Syncrude overburden material per pot. On a volume basis the mix had a ratio of 2:1:1. Sulfuric acid was used in order to attain the two lower pH levels (A and B) and sodium carbonate was used in attempts to attain the two higher pH levels (C and D). Samples of the soil mix were equilibrated with varying amounts of sulfuric acid and sodium carbonate for 48 hours and pH measurements were made. Measured pH values after equilibration which were closest to the desired levels were selected and the pH levels of the mix in the pots were adjusted accordingly. The initial adjusted pH levels were 3.40, 5.10, 7.50 and 9.62. At harvest of the first seeding, the pH and salinity levels of the mix were checked and the two lower pH levels were found to be much higher than the adjusted levels at seeding. The pH levels were not readjusted.

Control of the growth chamber environment, fertilization, and care of the plants in both seedings were the same as outlined under the section entitled Bitumen Experiment.

Observations and Results

Growth of the Plant Species and Nodulation by the Legumes

Good germination of each species was achieved in each of the adjusted pH levels of the soil mix except at the highest pH (Level D) in the first seeding. The only species which presented a germination problem was the cicer milk vetch. The reason for this has been discussed under the Bitumen Experiment. Throughout the entire first seeding, malfunctioning of the environmental control system of the growth chamber created some problems. Humidity and temperature were often high enough to automatically shut down the system. This affected the growth of the plants which were poorer than the same species grown in the experiments in other growth chambers. The alfalfa and three grasses grew particularly poorly. Growth of each species at the lowest pH level was generally slow in the first three months, but was fast towards the end of the growing period, so that at harvest visual differences in growth between the three pH levels in which germination was achieved were almost non-existent. The alfalfa and cicer milk vetch produced no nodules at the lowest pH (Level A); the sainfoin, however, produced a few small yellowish-white nodules which were mostly white in color.

In the second seeding a much more satisfactory set of plants was grown as the mechanical problems with the growth chamber appeared to have been corrected. There was still no germination in the mix at the highest pH (Level D). In general, there were no consistent visual growth differences in each species between plants growing on the mix at different pH levels (Plates 75 to 83). Visually the creeping red fescue and bromegrass grew slightly better at the lowest pH (Level A), the alfalfa and sainfoin at the next higher pH (Level B) and the hairy wild rye and slender wheat grass at the next higher pH (Level C). By harvest time grasses were showing nutrient deficiency symptoms while the alkali grass had already gone to seed.

Dry Matter Production

Tops. Yields of the tops (Table 31) were essentially unaffected by the pH levels of the soil mix with the saximontana fescue, cicer milk vetch, sainfoin, slender wheat grass, alkali grass and creeping red fescue, yields increased with increase in soil mix pH. Yields of alfalfa and bromegrass were low at the lower pH (Level A).

In the second seeding (Table 32) the pH level of the soil mix did not have much effect on the yields of saximontana fescue, slender wheat grass, alkali grass, sainfoin, alfalfa and creeping red fescue. Yield of the brome-

Table 31. Dry matter yields of legume and grass species at different pH levels* adjusted with Na_2CO_3 and H_2SO_4 -- first seeding.

	Dry Matter Yield (g/pot)								
	Tops			Roots			Tops + Roots		
	pH 6.56 A*	pH 7.05 B*	pH 7.64 C*	pH 6.56 A*	pH 7.05 B*	pH 7.64 C*	pH 6.56 A*	pH 7.05 B*	pH 7.64 C*
Saximontana fescue	3.11	3.41	3.66	3.89	6.32	3.82	7.00	9.73	7.48
Slender wheat grass	2.54	3.04	3.23	3.99	6.55	3.20	6.53	9.59	6.43
Bromegrass[1]	1.69	2.52	2.19	2.32	2.83	3.04	4.01	5.35	5.23
Alkali grass[1]	1.56	2.00	2.72	0.77	0.86	1.40	2.33	2.86	4.12
Hairy wild rye	2.67	1.95	2.96	3.47	2.98	2.87	6.14	4.93	5.83
Creeping red fescue	4.06	4.69	5.81	5.86	8.79	5.10	9.92	13.48	10.91
Cicer milk vetch[1]	0.44	0.55	0.51	0.79	1.01	0.64	1.23	1.56	1.15
Sainfoin[1]	0.80	1.01	0.91	0.80	1.59	1.17	1.60	2.60	2.08
Alfalfa	0.95	1.62	1.46	1.64	3.01	2.76	2.59	4.63	4.22

*None of the species germinated in the fourth pH level (pH 10.50, level D). See Table 34.

[1]Reseeded 30 days after other plants

Table 32. Dry matter yields of legume and grass species at different pH levels* adjusted with Na_2CO_3 and H_2SO_4 -- second seeding.

	Dry Matter Yield (g/pot)								
	Tops			Roots			Tops + Roots		
	pH 6.56 A*	pH 6.76 B*	pH 7.06 C*	pH 6.56 A*	pH 6.76 B*	pH 7.06 C*	pH 6.56 A*	pH 6.76 B*	pH 7.06 C*
Saximontana fescue	3.02	3.25	3.11	1.32	0.89	1.41	4.34	4.14	4.52
Slender wheat grass	3.80	3.23	4.05	2.72	2.47	5.43	6.52	4.70	9.48
Bromegrass	6.03	5.02	4.63	5.88	4.37	6.11	11.91	9.39	10.74
Alkali grass	3.69	4.00	3.51	1.92	2.16	2.21	5.61	6.16	5.72
Hairy wild rye	3.40	2.03	3.77	1.73	1.38	2.57	5.13	3.41	6.34
Creeping red fescue	8.43	7.40	7.35	9.06	9.39	12.24	17.49	16.79	19.59
Cicer milk vetch	1.07	2.42	1.79	1.28	2.85	2.67	2.35	5.27	4.46
Sainfoin	3.11	3.25	3.15	2.81	3.89	4.20	5.92	7.14	7.35
Alfalfa	3.42	3.90	3.38	3.80	4.96	5.00	7.22	8.86	8.38

*None of the species germinated in the fourth pH level (pH 10.12, level D). See Table 34.

grass was poor at the high pH (Level C) and yield of the cicer milk vetch was poor at the low pH (Level A). As in the first seeding there was a yield depression at the medium pH (Level B) in the hairy wild rye.

Roots. With the exception of the alkali grass, the root yields were much higher than the top yields in the first seeding. There was no definite trend in the yields of the roots in relation to the pH of the mix (Table 31), other than the higher root yields at the almost neutral pH (Level B) in the saximontana fescue, slender wheat grass, creeping red fescue and the legumes.

In the second seeding only the legumes and creeping red fescue gave root yields higher than the yields of the tops. With the exception of the cicer milk vetch the highest root yield (Table 32) occurred at near neutral pH (Level C).

In general, yield differences in each species were not entirely attributable to the slight differences in the pH of the mix. Other factors such as excess sodium or excess sulfate, and the resultant chemical changes caused in the mix due to their presence, more probably accounted for the differences in the yields of each species observed. It is possible that in the course of the first seeding, especially in the first two or three months of growth, the pH levels in the mix were close to the adjusted levels. In this case the pH of the mix greatly affected the growth of the species through the effect it had on the proper balance and availability of plant nutrients in the mix. Although no visual evidence was readily recognizable at harvest, nutrient deficiencies or toxic conditions created by one or more elements in the mix probably affected yields at the different pH levels in the first seeding.

The pH Levels of the Mix

Although this was an experiment primarily to determine the effects of soil mix reaction on the growth of several plant species, salinity also played a role in the soil mix. Salinity levels of the soil mix at harvest (Table 33) reflect the amounts of sulfuric acid and sodium carbonate used for adjusting the pH levels of the mix (see Table 19 for initial salinity levels of materials in the mix). While salinity levels were low enough not to affect the growth of the species at the three lower pH levels (A,B and C), salinity was high enough at the highest pH level (D) to have killed all of the species with the exception of the alkali grass. There was no germination in any of the species at the highest pH level, not even of the alkali grass. Thus it appears that pH played the most important role in stopping germination.

The pH levels of the soil mix, adjusted before the first seeding, had risen by harvest time. At harvest of the first seeding (Table 33) the two lower pH levels (A and B) had increased by between approximately two to three units, and the highest pH level had increased by 0.9 unit. At harvest of the second seeding, pH levels were still higher than the originally adjusted levels, although the three higher levels had shown slight decreases of between 0.3 and 0.5 unit. The difficulty in maintaining the adjusted pH at one level over the nine-month duration of the experiment demonstrates the dynamic nature of soil chemical conditions.

As indicated earlier, each species germinated and grew well at the three near neutral pH levels (A,B and C). At the highest pH level (D), however, the species germinated in spite of two attempted seedings during each experiment. Dispersia of organic material present in the peat and overburden by high sodium levels was also observed. The organic material moved to the surface, whereupon

Table 33. pH and salinity of the tailings sand-peat-overburden mix adjusted with Na_2CO_3 and H_2SO_4.

	pH level A	pH level B	pH level C	pH level D
Desired pH	3.50	5.00	7.00	9.50
Adjusted pH (after 48 hrs. equilibration)	3.40	5.10	7.50	9.62
pH at harvest (1st seeding)	6.56	7.05	7.64	10.50
pH at harvest (2nd seeding)	6.56	6.76	7.06	10.12
Electrical conductivity (mmho/cm)	4.00	2.92	2.03	14.15

drying it formed a black crust (see Plate 74). An examination of the soil indicated that seeds of the species sown had also been physically damaged in the presence of the sodium carbonate.

Although the pH levels of the mix at harvest of the second seeding (Table 33) in the two lower pH levels (A and B) were much greater than their initially adjusted levels, they were close to what may be encountered under field conditions in a vegetation program. The pH level A (6.56) is close to the level in the surface 0 to 6 inch layer on a vegetated area of the dike (Table 11, all treatments without lime; mean pH = 6.35) and pH level B (6.76) is close to the level in the surface 0 to 6 inch layer on a vegetated area which was treated with five tons of lime per acre (Table 11; mean pH = 6.71). The pH level C, which is about neutral (pH 7.06), is an acceptable pH level at which to attempt vegetation of stored tailings sand. The three pH levels (A, B and C) used in this study therefore represent the practical range of pH at which a vegetation program would normally be attempted. Lime should invariably maintain the pH within range even if the dike or overburden pile seem to become progressively acid through fertilization or sulfur dioxide emissions from the processing plants. The failure to establish growth of any of the species at the very high pH level illustrates the problems to be encountered in areas where highly alkaline wastes may occur. Reclaiming such areas would involve an expensive acidification and desalinization program.

Tentative Conclusions and Practical Implications

(1) In the pH range that may normally be encountered (slightly acid to slightly alkaline) in a vegetation program on tailings sand and overburden piles, any of the species tested could be grown successfully.

(2) Small areas of high pH (about 10 and above) which are to be vegetated, no germination of any of the species would occur. In addition to the alkalinity in these areas, salinity would also be high. Vegetating such areas would involve reclaiming the soil from any salinity damage and acidifying the areas if the pH remained high.

(3) In areas which are naturally highly acid, or in areas where sulfur dioxide emissions or elemental sulfur dust may damage the soil, a controlled liming program would be necessary to reclaim the affected areas.

Our data do not indicate whether or not any of the tested species would tolerate acidic soil conditions without liming. Perhaps in discussing and assessing acidity problems in the future, the concentrations of Al, Mn, Fe, etc. should be manipulated rather than just pH. This would probably provide more accurate interpretable and useful information.

GROWTH OF NITROGEN FIXING PLANTS ON TWO SOIL MIXES WITH AND WITHOUT ADDED LIME

Introduction

A general survey of the area of the GCOS tailings pond dike where vegetative cover was established about four years ago indicates that, although legumes were included in the seeding mixture, grasses (especially creeping red fescue) dominate and the legumes have all but disappeared. In recently vegetated areas legumes, especially yellow and white sweet clover (*Melilotus*) are still to be found. Although the sweet clover is growing well and producing seed, the experience is that it may eventually die out and grasses will predominate.

Two possible reasons that legumes die out in the older vegetated areas of the dike are: (1) nitrogen fertilization, and (2) unfavorable pH in the tailings sand-peat growth medium on the dike, with the possibility that the legumes are not fixing any nitrogen.

The objective of this experiment was to measure the amount of growth and nitrogen content of selected nitrogen fixing plant species in the growth chamber using two types of growth media simulating materials on which vegetation is to be established: (1) a tailings sand-peat seedbed, as is presently found on the GCOS tailings pond dike; and (2) a tailings sand-peat-overburden seedbed.

Experimental Procedure

Two seedings of the legumes were carried out under growth chamber conditions. The first seeding was grown from December 23, 1974 to May 16, 1975, and the second seeding from May 29 to September 27, 1975. The experiment was set up in a randomized block design with each of the treatments replicated two times. The treatments imposed are as follows:

(1) Soil mixes:

(a) Tailings sand (1,050 g)-GCOS peat (80 g)-GCOS overburden (470 g), in approximately a 2:1:1 ratio by volume.

(b) Tailings sand (840 g)-GCOS peat (160 g), in approximately a 1:1 ratio by volume.

(2) Lime (dolomitic limestone, 10:1 ratio by weight of $CaCO_3$ and $MgCO_3$):

(a) Nil.

(b) Lime (2:1:1 soil mix, 1.08 g lime per pot; 1:1 soil mix, 4.05 g per pot; see soil mixes above).

(3) Nitrogen-fixing plant species used:

(a) Cicer milk vetch *(Astralagus cicer)*.

(b) Sainfoin *(Onobrychis sp.)*

(c) Dawn alsike *(Trifolium hybridum)*.

(d) Wolf willow *(Elaeagnus commutata)*, a shrub which fixes nitrogen.

(e) Alfalfa *(Medicago sp.)*

(4) Replications: two.

Maintenance of the experiment was identical to that described for the Bitumen Experiment except that for fertilization only a single application of 20 lb of nitrogen per acre was made at sowing in each of the two seedings.

The total nitrogen content of the tops and roots was measured and related to the amount of mineral nitrogen in the soil mix.

Observations and Results

Growth of the Nitrogen-fixing plants

In the sainfoin, growth differences between limed and unlimed treatments on the soil mix including overburden were small in the first seeding. In the tailings sand-peat mix (1:1) lime greatly improved growth; some plants in a replication which received no lime were dying out by harvest. With lime, growth on the 1:1 soil mix was as good as or better than on the **2:1:1 tailings** sand:peat:overburden soil mix. Growth of the dawn alsike on the 1:1 soil mix was generally better than on the 2:1:1 soil mix; growth on the unlimed 1:1 soil mix even appeared to be better than growth on the limed 2:1:1 soil mix. Lime generally improved growth on both soil mixes and on the limed 1:1 mix the deep green color of the leaves indicated that nitrogen supply was adequate whether through fixation or mineralization from the soil materials. The best growth of the alfalfa occurred on the limed 1:1 soil mix; on the unlimed 1:1 soil mix growth was poor and several of the plants were dead by harvest time. In the 2:1:1 soil mix alfalfa growth was about the same in the limed and unlimed treatments; in both treatments several of the older branches were dead at harvest time.

In the second seeding growth of the cicer milk vetch was generally poor. On both the limed and unlimed 2:1:1 soil mix the color of the leaves indicated nitrogen deficiency in the plant, thus implying that very little if any nitrogen was being fixed. On the 1:1 soil mix the older leaves were dying, especially in the unlimed treatment. This might have been a disease or related to a micro-element problem rather than a pH problem as it also appeared to a lesser extent in the 2:1:1 soil mix treatments where the pH levels were above neutrality. Growth of the sainfoin in both mixes was good in the limed treatments, expecially the 1:1 soil mix. Several plants on the unlimed 1:1 soil mix were dead by harvest time. Of the species grown, dawn alsike produced the greatest growth in each of the treatments. Lime improved growth, especially on the 1:1 soil mix. Growth of the wolf willow was best in the limed 2:1:1 soil mix. Although the plants in the unlimed 1:1 soil mix appeared to be much better than in the limed 1:1 soil mix, they appeared to lack nitrogen. Liming the 1:1 soil mix gave as much alfalfa growth as did both of the 2:1:1 soil mix treatments (Plate 57). Although no plants were dead at harvest, as in the first seeding, plants grown on the unlimed 1:1 soil mix were poor. Dead leaves, as observed on the cicer milk vetch, were common throughout the treatments.

Nodule Production

Nodulation, examined visually on the roots, occurred in nearly every treatment except in one replication in the first seeding where the unlimed 1:1 soil mix was seeded to sainfoin and alfalfa. In the limed treatments in the sainfoin the nodules were of medium size and relatively abundant. The color ranged from yellowish white to yellow and brown. In the unlimed treatments in the dawn alsike the nodules were relatively few, mostly brown to white, and small in size. The nodules in the alfalfa were relatively abundant in number, mostly small, and ranged in color between white and pink.

In the second seeding each species produced nodules in each treatment except the cicer milk vetch and wolf willow grown on the unlimed 1:1 soil mix. Nodulation of the cicer milk vetch was low in the 2:1:1 mix and moderate in the limed 1:1 mix; most of the nodules were white and of a medium to large size. The sainfoin and dawn alsike produced relatively large number of nodules in each treatment, with the exception of the sainfoin grown on the unlimed 1:1 mix. In the sainfoin most of the nodules were pink to yellow and medium to large, while in the dawn alsike they were mostly small to medium in size and ranged in color from white to almost dark brown. Nodules produced by the wolf willow were relatively few, mostly white and ranged in size between medium and large. In the alfalfa, nodules were low to medium in number, mostly white to pink and small to mostly medium in size. Although it was sometimes difficult to distinguish the colors of the nodules produced by the individual species, the general indication was that the probability of nitrogen fixation was low in many cases. Since nodulation was generally possible, more work should be done to accurately assess the amount of nitrogen fixed in each species and to increase it if possible.

Dry Matter Production

Tops plus Roots. Dry matter yields of the entire legume plants in the first seeding (Table 34) were highest on the limed tailings sand-peat mix (1:1). In the sainfoin and alfalfa there was no benefit derived by liming the tailings sand-peat-overburden mix (2:1:1); in the dawn alsike, however, lime gave a substantial yield increase on the same mix. Yields on the unlimed 1:1 mix were very poor in the sainfoin and alfalfa and comparatively good in the dawn alsike; lime further improved yields substantially.

In the second seeding (Table 35) liming the 2:1:1 mix resulted in little or no benefit to yields of the entire cicer milk vetch, wolf willow and alfalfa plants. Lime improved yields of the sainfoin and dawn alsike. Liming of the 1:1 mix was beneficial to all species except wolf willow. Liming the 1:1 soil mix generally improved yields to close to the same levels as yields obtained on the 2:1:1 soil mix.

Nitrogen Content of Entire Plants

The percent nitrogen and total nitrogen content of the combined tops and roots of the legumes in the first seeding (Tables 36 and 37) averaged highest in the dawn alsike and lowest in the alfalfa. Liming the 2:1:1 soil mix had no effect on the percent nitrogen content of the entire plants of each species.

Table 34. Dry matter yields of legume species grown on tailings sand-peat-overburden (2:1:1) mix and tailings sand-peat (1:1) mix with and without lime. First seeding.

	Yield (g/pot) average of 2 replicates											
	Tops				Roots				Tops + Roots			
	2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix	
	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime
Sainfoin[1]	1.00	0.83	0.33	1.66	1.22	1.23	0.37	1.74	2.22	2.06	0.70	3.40
Dawn Alsike[1]	1.50	2.33	2.43	4.65	0.88	0.70	1.99	0.80	2.38	3.03	4.42	5.45
Alfalfa	1.98	1.98	0.29	3.73	2.43	2.55	0.33	4.83	4.41	4.53	0.62	8.56

[1]Reseeded 30 days later than the alfalfa

Table 35. Dry matter yields of legume species grown on tailings sand-peat-overburden (2:1:1) mix and tailings sand-peat (1:1) mix with and without lime. Second seeding.

	Yield (g/pot) average of 2 replicates											
	Tops				Roots				Tops + Roots			
	2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix	
	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime
Cicer milk vetch	0.29	0.29	0.30	0.72	0.48	0.51	0.22	0.70	0.77	0.80	0.53	1.42
Sainfoin	1.44	2.32	0.39	1.92	1.64	2.57	0.21	1.46	3.08	4.89	0.60	3.38
Dawn Alsike	5.89	9.02	2.33	10.57	2.96	2.95	1.88	4.93	8.85	11.97	4.21	15.50
Wolf willow	0.50	0.82	0.61	0.40	0.33	0.29	0.37	0.41	0.83	1.11	0.98	0.81
Alfalfa	3.32	3.63	0.90	3.03	4.44	4.36	1.70	3.91	7.77	7.99	2.60	6.94

Table 36. Percent nitrogen content of legume species grown on tailings sand-peat-overburden (2:1:1) mix and tailings sand-peat (1:1) mix with and without lime. First seeding.

	% Nitrogen average of 2 replicates											
	Tops				Roots				Tops + Roots			
	2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix	
	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime
Sainfoin[1]	2.12	1.89	2.15	2.02	1.64	1.87	2.15	1.70	1.88	1.88	2.15	1.86
Dawn Alsike[1]	2.05	2.04	2.22	2.62	2.29	2.66	1.40	2.31	2.17	2.35	1.81	2.46
Alfalfa	1.74	1.80	1.13	2.05	1.66	1.70	2.17	1.29	1.70	1.75	1.65	1.67

[1]Reseeded 30 days leter than the alfalfa

Table 37. Total nitrogen content of legume species grown on tailings sand-peat-overburden (2:1:1) mix and tailings sand-peat (1:1) mix with and without lime. First seeding.

	Total Nitrogen Content (mg/pot) average of 2 replicates											
	Tops				Roots				Tops + Roots			
	2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix	
	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime
Sainfoin[1]	21.20	15.69	7.10	33.53	20.01	23.00	7.96	29.58	41.21	38.69	15.06	63.11
Dawn Alsike[1]	30.75	47.53	53.95	121.83	20.15	18.62	27.86	18.48	50.90	66.15	81.81	140.31
Alfalfa	34.45	35.64	3.28	76.47	40.34	43.35	7.16	62.31	74.79	78.99	10.44	138.78

[1]Reseeded 30 days later than the alfalfa

On the 1:1 soil mix, lime depressed the percent nitrogen content in the sainfoin, increased it in the dawn alsike and had no effect in the alfalfa. Total nitrogen content of the entire plants (tops plus roots, Table 37), in each species (especially the alfalfa) was very greatly increased by lime in the 1:1 soil mix. In the soil mix containing the overburden material (2:1:1) liming resulted in minimal or no increase in the total nitrogen content of the entire plants of each species.

In the second seeding the percent nitrogen content of the entire plants (tops plus roots, Table 38) of each species grown in the 2:1:1 soil mix was not markedly affected by lime. In the 1:1 soil mix only the wolf willow and alfalfa showed a marked increase in nitrogen content with lime. In the 2:1:1 soil mix the total nitrogen content of the entire plants (tops plus roots, Table 39) was greatly increased by liming in the sainfoin and dawn alsike; in the cicer milk vetch, wolf willow and alfalfa, lime made no difference on the total nitrogen content. In the 1:1 soil mix, total nitrogen content of the entire plants was greatly increased by the lime in every species but the wolf willow.

The reactions of the two mixes measured at harvest of the first seeding were slightly alkaline in both the lime and unlimed 2:1:1 mix, while the limed 1:1 mix was slightly acid and the unlimed 1:1 mix remained highly acid (Table 40). Good growth and nodulation in these legumes would normally be expected on the mix including overburden (2:1:1) and on the limed tailings sand-peat mix (1:1). In the unlimed 1:1 mix the low pH would be expected to hinder nodulation. The combined yields (roots plus tops) of each legume species in both seedings indicated that with incorporation of the overburden material is well buffered and slightly above neutral, good growth could be expected of any of the legume

Table 38. Percent nitrogen content of legume species grown on tailings sand-peat-overburden (2:1:1) mix and tailings sand-peat (1:1) mix with and without lime. Second seeding.

	% Nitrogen average of 2 replicates											
	Tops				Roots				Tops + Roots			
	2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix	
	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime
Cicer milk vetch	1.71	1.64	3.22	2.81	1.68	1.33	1.58	1.83	1.70	1.48	2.40	2.32
Sainfoin	2.46	2.50	2.64	2.56	2.55	2.54	2.20	2.59	2.50	2.52	2.42	2.57
Dawn Alsike	2.75	2.44	2.36	2.59	3.39	3.32	2.58	2.89	3.07	2.88	2.47	2.74
Wolf willow	2.03	2.27	1.13	2.27	2.10	2.23	1.68	2.28	2.06	2.25	1.40	2.27
Alfalfa	2.47	2.39	1.96	2.45	2.70	2.68	1.71	2.41	2.58	2.53	1.83	2.43

Table 39. Total nitrogen content of legume species grown on tailings sand-peat-overburden (2:1:1) mix and tailings sand-peat (1:1) mix with and without lime. Second seeding.

	Total Nitrogen Content (mg/pot) average of 2 replicates											
	Tops				Roots				Tops + Roots			
	2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix		2:1:1 Mix		1:1 Peat Mix	
	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime	Nil	+ Lime
Cicer milk vetch	4.96	4.76	9.66	20.23	8.06	6.78	3.48	12.81	13.02	11.54	13.14	33.03
Sainfoin	35.42	58.00	10.30	49.15	41.82	65.28	4.62	37.81	77.24	123.28	14.92	86.96
Dawn Alsike	161.98	220.09	54.99	273.76	100.34	97.94	48.50	142.48	262.32	318.03	103.49	416.24
Wolf willow	10.15	18.61	6.89	9.08	6.93	6.47	6.22	9.35	17.08	25.08	13.11	18.43
Alfalfa	82.00	86.76	17.64	74.24	119.88	116.85	29.07	94.23	201.88	203.61	46.71	168.47

Table 40. pH and electrical conductivity in the soil mixes on which legume species were grown.

	Tailings sand-peat-overburden 2:1:1 mix		Tailings Sand-Peat 1:1 mix	
	Nil	Lime	Nil	Lime
pH	7.41	7.57	4.20	6.30
Conductivity (mmho/cm)	1.26	1.31	0.80	0.75

species with or without lime on tailings sand and peat mix. In the peat-tailings sand mix used in this experiment, the resultant low pH requires that the medium be limed to ensure good nutrient balance for a good growth of legumes. The relative abundance of nodules was to a degree dependent on the pH.

The total nitrogen content of the plants (tops plus roots) of each species in both seedings was an indirect measure of the probability of nitrogen being fixed by the species in each treatment. On the basis of a comparison of the mineral nitrogen applied per pot (25.5 ppm N) at each seeding and the mineral nitrogen content of the materials (Table 19) in the two soil mixes, and allowing for the amounts of each material used in formulating the mixes, the amount of nitrogen in the harvested plants could be accounted for in that added for the sainfoin or alfalfa in the low pH 1:1 mix (unlimed) in the first seeding. In the second seeding the same situation was observed for both the cicer milk vetch and wolf willow in all the treatments. Dawn alsike contained much more nitrogen at harvest than was applied in all treatments. With sainfoin this was the case in each treatment except in the unlimed 1:1 mix; and with alfalfa in each treatment except the unlimed 1:1 mix, where the difference was small. With sainfoin, dawn alsike and alfalfa, liming of the 1:1 soil mix to a pH of 6.30 or above generally resulted in results similar to those obtained by incorporating a slightly alkaline overburden material (2:1:1) into the mix.

A specific inoculant for the cicer milk vetch was not available at seeding, and this perhaps explains the poor results for this experiment. The wolf willow is a perennial shrub, and although the specific inoculant was applied at seeding perhaps the experiment did not last long enough for the plant to begin fixing nitrogen.

Tentative Conclusions

(1) Good growth for the nitrogen-fixing plant species tested can occur on the oil sand mine waste materials if conducive conditions are created. Dawn alsike, alfalfa and sainfoin would seem to be the most likely to fix nitrogen under these conditions and further studies into their fixation capacity on these materials is warranted.

(2) In a tailings sand-peat mix, similar to the presently vegetated areas on the GCOS dike, a near neutral reaction is a prerequisite condition for ensuring good growth by legumes. In a situation where a strongly acid peat is used to prepare a seedbed to vegetate the dike, liming to attain a near neutral reaction would be the major step in ensuring optimum conditions for nitrogen fixation by legumes. Mixing a slightly alkaline overburden material with the peat and tailings sand would also create conditions suitable to ensure good growth of nitrogen fixing plants.

THE FERTILITY, SOIL MIXES AND GRASS-LEGUME MIXTURES EXPERIMENT

Introduction

Vegetating the GCOS tailings pond dike has so far only involved the mixing of the tailings sand with peat, which is normally transported and spread on the dike during the winter months. The types of growth cover provided, the composition of the seeded species remaining after three or four years, the possibility of more volunteer native species establishing themselves, and the possibility of a self-sustaining cover being more readily established by the inclusion of overburden material in preparing a seedbed on the dike, are some of the many unknown factors in vegetating dikes. The role of fertilizers and lime in the different possible seedbed mixes also requires investigating, especially in mixed legume-grass seeding mixtures.

The objective of this growth chamber experiment was to obtain some preliminary information on how well two mixtures of grasses and legumes grow at different fertility levels on different mixes of materials obtainable in the oil sands leases, in attempts to vegetate the dike. A comparison of plant growth was made between the soil mixes and an agricultural soil. Yields of the plants grown under different fertility levels were used as the basis for comparing the different soil mixes.

Experimental Procedure

There were two seedings conducted in this growth chamber experiment. The first seeding was grown from January 24 to May 16, 1975 and the second seeding from May 29 to September 27, 1975. A randomized block design was used in this experiment; each treatment was replicated two times. The soil mixes, the grass-legume mixtures and the different fertility levels used were as follows:

(1) Soil mixes:

(a) Tailings sand (1,600 g per pot).

(b) Tailings sand (840 g)-GCOS peat (160 g) mixed in an approximate ratio of 1:1 by volume, per pot.

(c) Tailings sand (850 g)-GCOS overburden (750 g) mixed in an approximate ratio of 1:1 by volume, per pot.

(d) Tailings sand (1,050 g)-GCOS peat (80 g)-GCOS overburden (470 g) mixed in an approximate ratio of 2:1:1 by volume, per pot.

(e) Agricultural soil (Malmo; 1,200 g per pot).

(2) Fertility levels:

(a) Nil (no fertilizers or lime).

(b) NPKS (same as described in The Bitumen Experiment but excluding nicro-elements).

(c) NPKS plus micro-elements (as described in the Bitumen Experiment).

(d) NPKS plus micro-elements (as described in the Bitumen Experiment).

(3) Grass-legume mixtures (seed mixtures):

(a) Bromegrass *(Bromus inermis)*-Alfalfa *(Medicago sp.)* mixture.

(b) Slender wheat grass *(Agropyron trachycaulum)*-sainfoin *(Onobrychis sp.)* mixture.

(4) Replications: two

The control of the growth chamber environment was exactly as outlined under The Bitumen Experiment, for both seedings. Each pot was sown with the same number of legume and grass seeds and were thinned one month after germination to three plants of legume and three plants of grass per pot. Nitrogen, phosphorus, potassium, sulfur and micro-element rates were the same as in the other experiments; the lime rate (where applicable) was, however, six tons of finely ground dolomitic limestone per acre. Times of fertilizer application, watering, and the general care of the experiment were exactly as outlined for the Bitumen Experiment.

Yields of legume tops, grass tops and the unseparated roots of both legumes and grasses were calculated and used as a basis for estimating the performance of the plants on the different soil mixes. A soil mix sample from each pot was taken at harvest and analyzed for pH, salinity, mineral nitrogen, phosphorus, potassium, sulfate-sulfur and sodium.

Observations and Results

Growth of Grass-Legume Mixtures

In both seedings each soil mix, with the exception of the agricultural soil (Malmo), produced poor growth in both seed mixtures in the unfertilized treatments. Phosphorus deficiency was evident in the alfalfa on the soil mixes made up of material from the GCOS lease and also in the brome-grass grown on the agricultural soil. Nitrogen was lacking in the brome-grass in all soil mixes. The slender wheat grass and sainfoin mixture generally grew better than the alfalfa and brome-grass mixture. The slender wheat grass, which dominated the sainfoin in the tailings sand, was very deficient in nitrogen and the sainfoin grew very poorly. In the tailings sand-overburden mix the grass was greatly dominated by the sainfoin.

Both grass-legume mixtures showed a very good improvement in growth with fertilizers (NPKS and NPKS plus micro-elements) on the soil mixes. The grasses dominated in all soil mixes;the legumes, however, were still strongly evident on the agricultural soil. Micro-element deficiency symptoms were not clearly evident, even on the straight tailings sand receiving no micro-elements.

Lime in addition to NPKS and micro-elements did not appear to have much improved the growth of the plants in the soil mixes. On the tailings sand-overburden mix, lime actually depressed growth in both grass-legume mixtures. On the tailings sand, although both legumes germinated and grew well in the first few weeks, they were mostly dead by harvest time in the first seeding and they grew very poorly in the second seeding. The slender wheat grass also grew very poorly in the first seeding, but it showed good improvement in the second seeding.

Growth comparisons of the legume-grass mixtures at different fertility levels on the tailings sand showed that although fertilizers (NPKS) improved growth the lime was not required. Fertilizers with lime tended to lower the competitive ability of both legumes in both seedings. In the tailings sand-peat mix, fertilizers improved growth considerably; with lime, growth was even better. The percent growth of the legumes in each treatment did not appear to have been influenced by either the fertilizers or fertilizers and lime. Fertilizers improved the growth of both legume-grass mixtures on the tailings sand-overburden mix, especially the alfalfa-bromegrass mixture; the sainfoin grew particularly well on the unfertilized soil mix. Lime with fertilizer tended to depress growth slightly in the same soil mix (tailings sand-overburden). Although micro-elements improved growth no definite micro-element deficiency symptoms were observed in the treatments that received no micro-elements. In the tailings sand-peat-overburden mix (2:1:1) fertilizers improved growth and neither the addition of lime nor the addition of micro-elements seemed to have improved growth beyond the level achieved with the straight fertilizer. Fertilizers did not raise the percent of legumes in the treatments. In every treatment the agricultural soil gave better growth than any of the other soil mixes. Although the nil treatment gave a comparatively good growth, fertilizers gave further improvements in growth. Lime and micro-elements appeared to have improved growth beyond levels observed on the NPKS treatments in the second meeting.

Nodulation by the Legumes

There was almost no nodulation in both legumes on the tailings sand and tailings sand-peat mix at all fertility levels, even in the presence of lime. In all fertility treatments on the tailings sand-overburden mix, nodules in the sainfoin were few to moderate, mostly yellowish-brown in color and ranged from small to moderately large. In the alfalfa, nodulation was practically non-existent. On the tailings sand-peat-overburden mix (2:1:1) alfalfa produced no nodules in any of the fertility treatments, except in one replication where lime was applied with fertilizers; the nodules were very few, tiny and mostly white. Nodules in the sainfoin were few in the fertilized treatments and moderately abundant in the unfertilized treatment, and were mostly yellowish brown and ranged in size from medium to large. In the agricultural soil, nodules in the alfalfa were few and the nodules were mostly white and small in size at all fertility levels. In the agricultural soil, nodulation in the sainfoin was very similar to the nodulation pattern in the 2:1:1 soil mix.

Dry Matter Production in Tops Plus Roots

In the first seeding the combined average yields of the tops and roots (Table 41) on the 2:1:1 mix were the highest, aside from the yields on the agricultural soil. Average yields on the remaining three soil mixes were lower and averaged about the same. Yields of the two seed mixtures also averaged about the same on each soil mix. On each soil mix the NPKS alone gave a substantial yield increase above the nil treatment. Micro-elements gave further

Table 41. Dry matter yields of legume-grass mixtures grown on different soil mixes as affected by fertilizer and lime. First seeding.

	Yield (g/pot) average of 2 replicates											
	Tops				Roots				Tops + Roots			
	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
Tailings Sand	0.15	2.07	2.57	0.57	0.26	1.82	2.41	0.30	0.41	3.89	4.97	0.87
Tailings - Sand:Peat (1:1)	0.22	1.91	1.72	2.65	0.43	1.63	1.13	1.80	0.69	3.59	2.85	4.45
Tailings - Sand:Over-burden(1:1)	0.21	1.43	2.16	2.03	0.30	0.95	1.45	1.92	0.51	2.37	3.60	3.95
Tailings - Sand:Peat: Overburden (2:1:1)	0.21	2.41	2.36	2.31	0.38	1.71	1.44	1.71	0.58	4.11	3.80	4.02
Agricultural Soil(Malmo)*	2.12	4.22	4.24	4.51	1.36	1.82	2.33	1.63	3.53	6.04	6.57	6.14

*A high percentage of the fine roots in the Malmo could not be recovered.

yield increase above the nil treatment. Micro-elements gave further yield increases only on the tailings sand and tailings sand-overburden soil mix and made little or no difference on the yields on other soil mixes. Lime greatly improved yields on the tailings sand-peat mix, greatly depressed yields on the tailings sand and generally made little or no difference in yields on the other soil mixes.

In the second seeding the combined average yields of tops and roots were best in the agricultural soil followed by the 2:1:1 mix and the 1:1 tailings sand-overburden mix (Table 42). Average yields on the tailings sand and the tailings sand-peat mix were the lowest. Yields for the sainfoin-slender wheat grass mixture and alfalfa-bromegrass mixture averaged about the same on the tailings sand. On the tailings sand-peat mix, however, the average yield of the slender wheat grass-sainfoin mixture was slightly better than the alfalfa-bromegrass mixture. On the tailings sand-overburden mix, the 2:1:1 mix and the agricultural soil, average yields of the alfalfa-bromegrass mixture were considerably higher than the sainfoin-slender wheat grass mixture. As with the first seeding, NPKS alone gave a very high yield increase on each of the five soil mixes, even on the agricultural soil, whose yield on the nil fertilizer treatment was comparatively high. Micro-elements gave no further yield increases in any of the mixes. Liming in addition to the fertilization depressed yields of the sainfoin-slender wheat grass mixture, although not to the same extent as was observed for the two legume-grass mixtures in the first seeding. Lime was particularly beneficial in the tailings sand-peat mix seeded to the alfalfa-bromegrass mixture; both legume-grass mixtures benefited from the lime on the agricultural soil.

The lower combined yield of tops and roots of the legume-grass mixtures

Table 42. Dry matter yields of legume-grass mixtures grown on different soil mixes as affected by fertilizer and lime. Second seeding.

	Yield (g/pot) average of 2 replicates											
	Tops				Roots				Tops + Roots			
	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
Tailings Sand	0.36	3.15	3.28	2.92	0.60	3.14	3.19	2.32	0.96	6.29	6.46	5.24
Tailings - Sand:Peat (1:1)	0.13	2.34	2.25	2.97	0.38	3.72	3.50	4.15	0.50	6.06	5.75	7.12
Tailings - Sand:Over-burden(1:1)	0.63	4.39	4.44	3.88	1.02	4.08	3.94	3.81	1.64	8.46	8.37	7.68
Tailings - Sand:Peat: Overburden (2:1:1)	0.47	4.02	3.88	4.04	0.63	4.33	4.89	4.80	1.09	8.34	8.77	8.84
Agricultural Soil(Malmo)*	2.40	4.75	5.15	5.61	2.83	5.08	5.20	6.13	5.23	9.83	10.35	11.74

*A high percentage of the fine roots in the Malmo could not be recovered.

on the nil fertilizer treatment on each soil mix is attributable to the initial low fertility levels of the materials in the mixes (see Table 19), with the exception of the agricultural soil. The higher yields in the fertilized treatments are attributable to the fertilizer nutrients applied. By harvest time nutrient levels in the soil mixes, including the agricultural soil (Table 47), indicated that with the exception of sulfate-sulfur, which was initially high in the material used for the soil mixes, the legume-grass mixtures had absorved hearly all the major fertilizer nutrients applied. A continued healthy growth of the legumes and grasses beyond harvest time would have required at least additional nitrogen, phosphorus and potassium applications. In the unlimed tailings sand-peat soil mix the low yields in the two fertilized treatments are attributable to the low pH of the mix. In these same treatments, total mineral nitrogen in the mix remained relatively high at harvest.

Percent of Legumes and Grasses in Yields of Tops

In all soil mixes in both first and second seedings the grasses generally formed the higher percentage of the combined yields where yields of the tops were substantial (all fertilized treatments) (see Tables 43 and 44). In the nil fertilizer treatment in the soil mixes in which overburden material was included, the legumes in both seedings constituted greater percentages of the yields than the grasses.

The inclusion of overburden material with the tailings sand, especially if peat was also present in the mix, greatly improved the yields of the legumes that the percent of legumes relative to that of the grasses (Table 45) approached that of the agricultural soil. Percent legumes in the yields of

Table 43. Percent grasses and legumes in the dry matter yields of the tops in seeding mixtures grown on different soil mixes as affected by fertilizer and lime. First seeding.

		GRASSES (%)				LEGUMES (%)			
		Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
Tailings Sand	A*	75.0	91.5	90.0	98.9	25.0	8.5	10.0	1.1
	B	54.5	92.0	96.4	94.7	45.5	8.0	3.6	5.3
	Mean	64.7	91.7	93.2	96.8	35.3	8.3	6.8	3.2
Tailings Sand:Peat(1:1)	A	85.7	86.6	80.6	88.6	14.3	13.4	19.4	11.4
	B	65.5	87.4	94.5	85.9	34.5	12.6	5.5	14.1
	Mean	75.6	87.0	87.5	87.2	24.4	13.0	12.5	12.8
Tailings Sand:Overburden(1:1)	A	55.6	87.6	85.5	87.6	44.4	12.4	14.5	12.4
	B	21.9	80.0	82.8	88.8	78.1	20.0	17.2	11.2
	Mean	38.7	83.8	84.1	88.2	61.3	16.2	15.9	11.8
Tailings Sand:Peat:Overburden(2:1:1)	A	50.0	80.8	86.5	83.7	50.0	19.2	13.5	16.3
	B	25.7	86.6	91.3	88.1	74.3	13.4	8.7	11.9
	Mean	37.8	83.7	88.9	85.9	62.2	16.3	11.1	14.1
Agricultural Soil (Malmo)	A	66.7	75.9	78.6	83.3	33.3	24.1	21.4	16.7
	B	47.5	63.3	67.5	53.3	52.5	36.7	32.5	46.7
	Mean	57.1	69.6	73.0	68.3	42.9	30.4	27.0	31.7

*A, Grass is bromegrass
Legume is alfalfa

B, Grass is slender wheat grass
Legume is sainfoin

Table 44. Percent grasses and legumes in the dry matter yields of the tops in seeding mixtures grown on different soil mixes as affected by fertilizer and lime. Second seeding.

		GRASSES (%)				LEGUMES (%)			
		Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
Tailings Sand	A*	38.1	74.8	88.8	93.4	61.9	25.2	11.2	6.6
	B	24.0	92.5	96.8	99.6	76.0	7.5	3.2	0.4
	Mean	31.0	83.6	92.8	96.5	69.0	16.4	7.2	3.5
Tailings Sand:Peat(1:1)	A	100.0	50.4	49.8	80.0	0.0	49.6	50.2	20.0
	B	55.6	93.5	87.8	70.8	44.4	6.5	12.2	29.2
	Mean	77.8	71.9	68.8	75.4	22.2	28.1	31.2	24.6
Tailings Sand:Overburden(1:1)	A	19.1	75.6	82.9	76.8	80.9	24.4	17.1	23.2
	B	24.6	90.4	87.6	83.2	75.4	9.6	12.4	16.8
	Mean	21.8	83.0	85.2	80.0	78.2	17.0	14.8	20.0
Tailings Sand:Peat:Overburden(2:1:1)	A	24.0	56.3	75.3	58.2	76.0	43.7	24.7	41.8
	B	7.4	87.1	85.9	81.3	92.6	12.9	14.1	18.7
	Mean	15.7	71.7	80.6	69.7	84.3	28.3	19.4	30.3
Agricultural Soil (Malmo)	A	17.9	71.5	62.0	72.7	82.1	28.5	38.0	27.3
	B	13.0	62.0	70.8	68.1	87.0	38.0	29.2	31.9
	Mean	15.4	66.7	66.4	70.4	84.6	33.3	33.6	29.6

*A, Grass is bromegrass
Legume is alfalfa

B, Grass is slender wheat grass
Legume is sainfoin

Table 45. Percent composition of grasses and legumes grown on different soil mixes (dry yields of tops)

	Grasses (%)			Legumes (%)		
	1st Seeding	2nd Seeding	Mean	1st Seeding	2nd seeding	Mean
Tailings Sand	86.6	76.0	81.3	13.4	24.0	18.7
Tailings Sand:Peat (1:1)	84.3	73.5	78.9	15.7	26.5	21.1
Tailings Sand:Overburden (1:1)	73.7	67.5	70.6	26.3	32.5	29.4
Tailings Sand:Peat:Overburden (2:1:1)	74.1	59.4	66.8	25.9	40.6	33.2
Agricultural Soil (Malmo)	67.0	54.7	60.9	33.0	45.3	39.1

Table 46. Percent composition of grasses and legumes grown on different soil mixes as influenced by the fertility levels of the soil mixes. (dry yields of tops)

	Grasses (%)			Legumes (%)		
	1st Seeding	2nd Seeding	Mean	1st Seeding	2nd Seeding	Mean
Nil	54.8	32.3	43.6	45.2	67.7	56.4
NPKS	83.2	75.4	79.3	16.8	24.6	20.7
NPKS + micro	85.3	78.8	82.1	14.7	21.2	17.9
NPKS + micro + lime	85.3	78.4	81.9	14.7	21.6	18.1

Table 47. pH, salinity and nutrient levels of each soil mix for each fertility treatment at harvest of the second seeding.

	Tailings Sand				Tailings Sand:Peat(1:1)				Tailings Sand:Overburden(1:1)				Tailings Sand:Peat:Overburden(2:1:1)				Agricultural Soil (Malmo)			
	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
pH	7.43	6.45	6.35	8.34	4.29	4.41	4.42	7.45	8.01	7.79	7.73	8.11	7.61	7.30	7.26	7.87	6.16	5.99	5.94	7.65
Conductivity (mmho/cm)	0.44	0.55	0.51	1.03	0.37	0.38	0.41	0.48	1.23	1.34	1.06	1.29	0.51	0.73	0.76	0.78	0.17	0.24	0.20	0.45
NH_4^+ ppm	1.53	1.43	1.57	0.70	1.44	14.69	12.43	1.45	0.18	0.48	0.05	0.07	0.11	0.09	0.05	0.18	0.29	0.53	0.33	0.26
NO_3^- ppm	0.78	1.32	1.05	11.20	0.86	5.98	9.31	3.32	0.11	0.08	0.21	0.09	0.18	0.10	0.37	0.44	0.22	0.19	0.34	0.30
NH_4^+ plus NO_3^- ppm	2.31	2.75	2.62	11.90	2.30	20.67	21.74	4.77	0.29	0.56	0.26	0.16	0.29	0.19	0.42	0.62	0.51	0.72	0.72	0.56
P ppm	3.48	6.01	5.68	5.02	2.89	6.72	6.58	5.20	2.32	5.38	5.24	3.60	2.63	4.97	5.37	3.57	1.49	4.23	4.38	2.18
K ppm	22.0	55.0	58.0	73.7	28.0	86.3	120.7	69.5	35.7	68.7	61.5	71.0	32.5	43.0	48.0	43.5	103.7	141.5	133.2	131.0
SO_4 - S ppm	20.20	17.80	21.10	38.50	53.35	30.00	39.50	16.25	70.35	78.10	77.20	75.00	31.90	59.05	58.45	58.50	4.45	11.55	9.25	21.85
Na ppm	76.5	66.0	65.0	79.3	72.3	68.5	80.2	90.0	77.5	76.7	77.2	80.0	65.5	71.2	76.2	6.60	4.60	48.5	47.2	57.2

the tops in the straight tailings sand and the tailings sand-peat mix were comparatively much lower than on the agricultural soil. Therefore the overburden material included in the mixes could in general be considered to have improved the relative competitive ability of the legumes grown with the grasses. Fertility levels in the soil mixes could have some influence on the percent legumes and grasses of yields of the tops in any seeding mixture.

Fertilizers tended to reduce the proportions of legumes in the total top growth. In this experiment fertility treatments did not allow for the assessment of differences in species composition resulting from the inclusion or exclusion of one or more major plant nutrients. In all the soil mixes, micro-elements or micro-elements plus lime did not influence the percent of legumes and grasses in the seeding mixtures (Table 46). In the nil fertilizer treatments the slightly higher percent of legumes in the mixture indicated that the legumes could tolerate the lower nutrient status better than the associated grasses. Lack of legumes in the field is likely not as a result of low nutrient status. These results would indicate that low pH and nitrogen fertilization combine to improve the competitive ability of grasses over legumes.

Tentative Conclusions and Practical Implications

(1) The establishment of a vegetative cover composed of grass-legume mixtures on a tailings sand-peat soil mix in which overburden material is included would possibly produce as good as if not better vegetative cover than that produced on the ordinary tailings sand-peat mix.

(2) The inclusion of the overburden material of the type used here, in preparation of a tailings sand-peat mix would favor the legumes tested in a legume-grass seeding mixture.

(3) In establishing a grass-legume cover on a seedbed in which tailings sand is the major component, fertility has to be maintained at a high level as these mixtures seem to require considerable nutrients to produce good growth.

(4) With high soil fertility, percent (by weight) grasses is greater than percent legumes on all soil mixes in the first few months of growth. Where the primary aim in a vegetation program on the dike is the establishment of nearly equal percentages of legumes and grasses, the seeding mixture would have to consist of species of grasses and legumes which would compete on an equal basis, together with soil conditions favoring competition by legumes.

(5) In a situation where peat may be lacking, the overburden material could be used in vegetating a tailings pond dike. One disadvantage of using the overburden material is that it would not provide the same protection from erosion as would the peat in early stages of plant growth (that is, before the total vegetative cover is achieved).

(6) Plants could be grown on the straight tailings sand if a good fertilization program is followed. The major problems would be ensuring adequate germination, and the control of both water and wind erosion.

THE ROOT DISTRIBUTION EXPERIMENT

Introduction

Several 'profiles' examined on the vegetated areas of the tailings pond dike showed that the roots of the vegetative cover were mostly concentrated in the peat zone. Actual percent distribution in the 'profile' (see Table 15) indicated that 86 percent of the roots are in the surface peat zone. Other than providing effective erosion control on the surface of the slope, stability in the immediate tailings sand below is not much improved by root penetration.

This simple experiment in the growth chamber was planned to determine the extent of root distribution in two types of tailings sand-peat seedbeds.

Experimental Procedure

A mixture of creeping red fescue (festuca rubra) and alfalfa (Medicago sp.) was seeded in pots, using the following two seedbeds:

(a) Tailings sand-peat mix (1:1 ratio by volume); and

(b) Peat (1½-inch depth overlying the tailings sand in the pots; peat was near neutral, with a pH of 6.25).

At seeding, 100 lb N, 40 lb P and 160 lb K per acre were applied in solution to the surface of the mixes. Control of the growth chamber environment and the general care of the experiment were the same as outlined in Part III, The Bitumen Experiment. The experiment, which was replicated ten times, lasted four months. At harvest time the dry matter yields of the tops, the roots in the surface 1¼ inches and the roots in the remaining lower three inches were recorded.

Observations and Results

Growth

In the course of the experiment visual estimations indicated that growth on the thoroughly mixed tailings sand and peat appeared to be better than growth where the peat was placed on the tailings sand without their being mixed. By harvest time root distribution in the pots showed very clearly that with mixing of the peat and tailings sand, rooting appeared to be evenly distributed throughout the pot and the roots held the soil mix together. With the peat left on top of the sand, the roots remained mostly in the peat. On emptying the pots it became evident that the roots could not hold the sand together.

Dry Matter Production

Dry matter yields of the tops and of the roots were considerably higher on the tailings sand-peat (1:1) mix than when the peat was placed over the tailings sand without their being mixed (Table 48). Nearly 84 percent of the roots in the unmixed medium remained in the peat layer. In the mixed soil medium a greater percentage of the roots penetrated the lower half of the mix.

Considering that fertilizer nutrients were added at the surface of both types of mixes at seeding, concentration of the roots in the surface layer could not be attributable to the method of fertilizer application. The peat was simply a better medium for growth than the pure tailings sand.

Tentative Practical Implication

In preparing a seedbed with peat for vegetating a tailings pond dike, mixing peat with the tailings sand as deeply as possible would be expected to ensure that a considerable percentage of the roots would penetrate the lower

Table 48. Dry matter yields of creeping red fescue-alfalfa mixture on two types of tailings sand-peat mixes in pots.

	Yield (g/pot)	
	Peat placed on surface of sand	Peat mixed in with the sand (1:1 v/v)
Total Yield	7.49	12.10
Tops	3.39	4.73
Roots: Top 4 cm.	3.44	3.19
Bottom 4 cm.	0.66	4.18
	% Distribution of Roots	
Top 4 cm.	83.9	43.3
Bottom 4 cm.	16.1	56.7

depths of the dike. Depth of root penetration would depend considerably on the thickness of the mixed peat layer. The vegetative cover produced on the peat mixed with the sand is better than that produced on the peat spread over the tailings sand without mixing.

PART IV

BIOLOGICAL STUDIES AND FURTHER CHEMICAL CHARACTERIZATION OF SOILS AND MIXES

Introduction

The object of this study was to supply baseline information, primarily of a biological nature, concerning the materials and mixes of possible use in vegetation programs. Included in this study was an assessment of the materials ability to withstand acidification likely to arise from SO_2 emissions, sulfur dust and heavy fertilizer applications.

Microbial studies centred upon the measurement of the numbers of organisms present in broad microbial groups such as bacteria, fungi and algae as well as specific microbial groups involved in key transformations such as denitrification and sulfate reduction. An innovative approach was taken in the determination of various enzyme activities with the purpose of essessing the possible extent of nitrogen, phosphorus and sulfur mineralization in the soils. The composition of the soil mixes used is shown in Table 49.

Hydrolysable Nitrogen

Nitrogen is one of the major nutrients required by plants and occurs largely in the organic form in soils. Organic nitrogen must be mineralized into inorganic forms such as ammonium and nitrate before it can be readily taken up by plants. Organic nitrogen occurs in such compounds in soil as amino acids (about 20-40%), hexoseamines (5-10%) and purines and pyrimidines (less than 1%). However, a substantial amount can not be identified (Bremner, 1965c). It is possible that heterocyclically bound nitrogen may comprise a proportion of the unidentified fraction. Some nitrogen may occur in soil humus as amino acids that are combined in such a way to the aromatic components of soil

Table 49. Soils studied and composition of mixes.

Material	% of each component by volume	by weight
GCOS Peat	100	100
Tailing Sand	100	100
Malmo Soil	100	100
GCOS Overburden	100	100
Syncrude Overburden	100	100
Heavy Tar Sand	100	100
Lean Tar Sand	100	100
Peat + Tailing Sand	50:50	16:84
Malmo + Heavy Tar Sand	60:40	54:46
Peat + Tailing Sand + GCOS Overburden	25:50:25	5:65:30
Peat + Tailing Sand + Syncrude Overburden	25:50:25	5:65:30
Tailing Sand + GCOS Overburden	50:50	53:47

All weights refer to the material in the air dry state. Peat was partially air dried and heavy tar sand was used field moist.

organic matter that they can not be released by conventional isolation methods. Part of the organic nitrogen in soils is thought to be more labile than the rest. Acid hydrolysis probably releases the majority of nitrogen in this "active fraction" from soil organic matter. Thus the amount of acid hydrolysable nitrogen contained in a soil may give us an indication of the potential nitrogen supplying power of that soil.

Table 50 shows the amounts of the total soil organic nitrogen that was recovered after acid hydrolysis as NH_4-N, amino acid-N or hexoseamine-N. It should be noted that during the hydrolysis a certain amount of ammonia is released through deammination reactions, so that much of the ammonia recovered after hydrolysis is not initially present in that form in the soil. Of the soils and mixes studied only the peat, Malmo soil and the Malmo/heavy oil sand mix contained large amounts of organic nitrogen.

It is difficult to draw any firm conclusions from results involving the tailings materials and overburdens due to the very low amounts of organic nitrogen that they initially contained. It was evident however that in materials such as the lean and heavy oil sands that contained significant amounts of hydrocarbons there was a high proportion of the organic nitrogen that was not acid hydrolysable. Thus most of the nitrogen that they contain would probably not be easily made available to plants.

Buffering Capacity

The soils used in revegetation should be well buffered against rapid fluctuations in soil pH. Most plants grow well only within a reasonably restricted pH range. Plants as a whole tolerate a pH range of 4.0 to 8.5 although the effects of other plant constituents are very important. Buffering is important in view of the acidification likely from SO_2 emissions and the

Table 50. Nature of hydrolysable nitrogen in soils and mixes.

Soil or soil mix	Acid hydrolysable nitrogen NH_4-N (mg/g)	Hexoseamine-N (mg/g)	Amino-N (mg/g)	Total soil Nitrogen (mg/g)
Peat (GCOS)	0.516	0.334	0.919	7.112
Tailings Sand	0.026	0.033	0.000	0.112
Malmo Soil	0.842	0.194	1.013	3.955
GCOS Overburden	0.256	0.011	0.165	0.448
Syncrude Overburden	0.068	0.058	0.054	0.378
Peat + Tailings Sand	0.074	0.032	0.077	0.266
Lean Oil Sand	0.035	0.060	0.063	0.343
Malmo + Heavy Oil Sand	0.383	0.058	0.434	2.758
Peat + Tailings + GCOS Overburden	0.111	0.041	0.103	0.259
Peat + Tailings + Syncrude Overburden	0.022	0.074	0.063	0.168
Tailings Sand + GCOS Overburden	0.098	0.026	0.032	0.140
Heavy Oil Sand	0.012	0.063	0.002	0.350

possible use of large additions of fertilizers. Soils are naturally buffered against changes in pH by the presence of soil organic matter, soil clays and various salts. The Malmo soil typifies a well buffered agricultural soil (see Figure 6). It has an organic matter content of over 10% and a clay content of about 16%. It takes about 3 meq H^+/100g to lower its pH by one unit and slightly over 3 meq OH^-/100g to raise it by one unit. It is well buffered over the entire range especially between pH 4.5 and 9.0 which encompasses the range for plant growth. Organic soils are also well buffered due to their acidic nature and accompanying high cation exchange capacity. The GCOS peat has a pH of about 3.6, an organic matter content of 98% and is well buffered over the entire acidic range.

Materials that contained high contents of sand such as tailings sand, lean oil sand and heavy oil sand were essentially unbuffered (see Fig. 6&7). The two overburden materials investigated were remarkably well buffered against acidification (Fig. 7). In both the GCOS and Syncrude overburden samples and buffering is primarily due to the presence of high amounts of carbonate and to a certain extent sulfate anions in association with calcium. Clay probably plays a minor role.

The effect of mixing various components together may be seen by reference to Figure 7 . Addition of 3 meq H^+/100g soil to pure tailings sand (an amount that reduced the pH of Malmo soil by one pH unit) reduces its pH from 7.5 to about 2.7. Mixing equal volumes of peat and tailings sand has two effects. Firstly the addition of peat reduces the pH initially to 4.4. Secondly the pH can be reduced to about pH 2.7 by the addition of 3 meq H^+/100g of the mix as before. However, considerable buffering is observed above pH 4. Mixing tailings sand and overburden has a similar beneficial effect upon the

Figure 6. Buffering capacities of an acid peat, an agricultural soil and overburden materials.

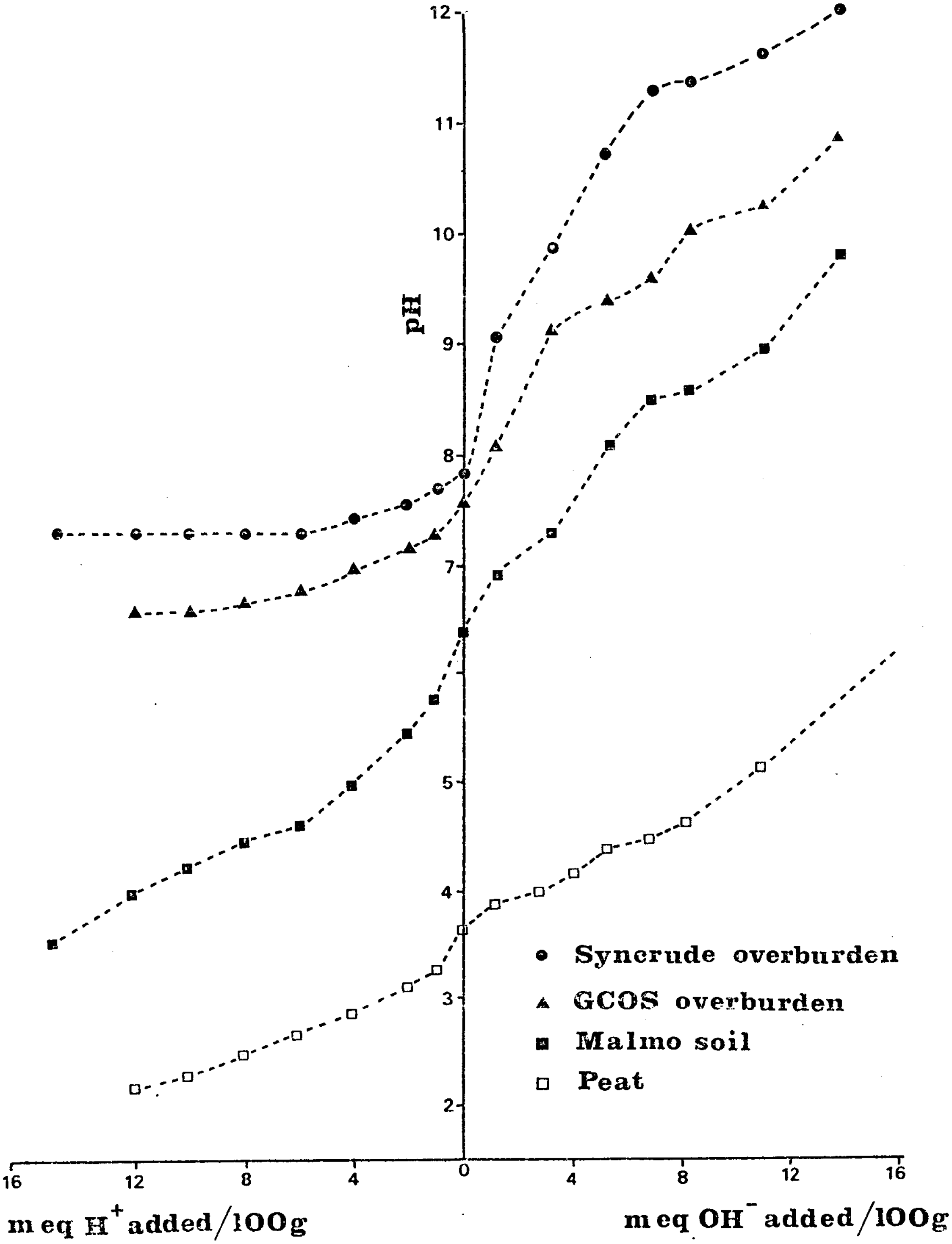


Figure 7. Buffering capacities of tailings sand and tailings sand soil mixes.

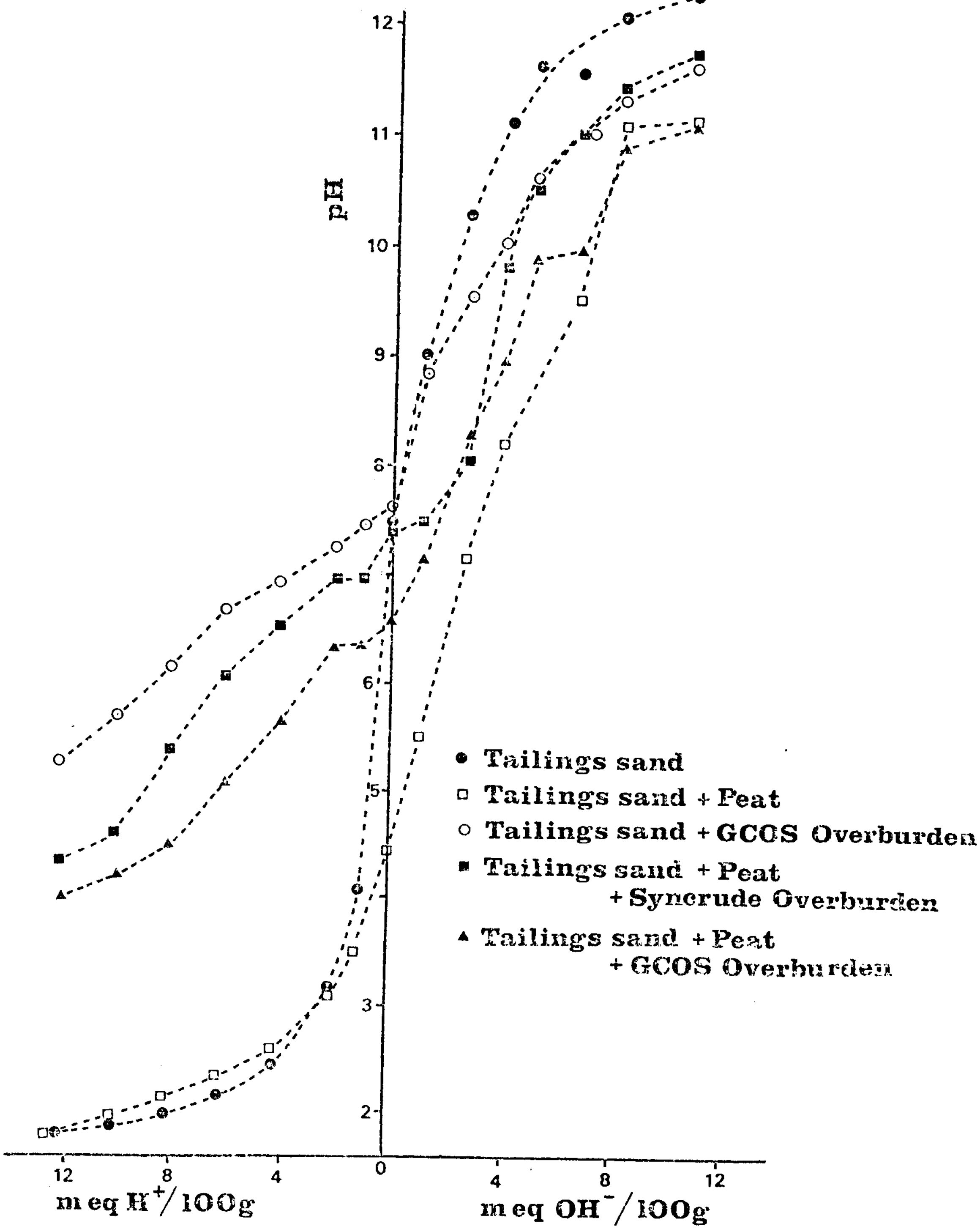
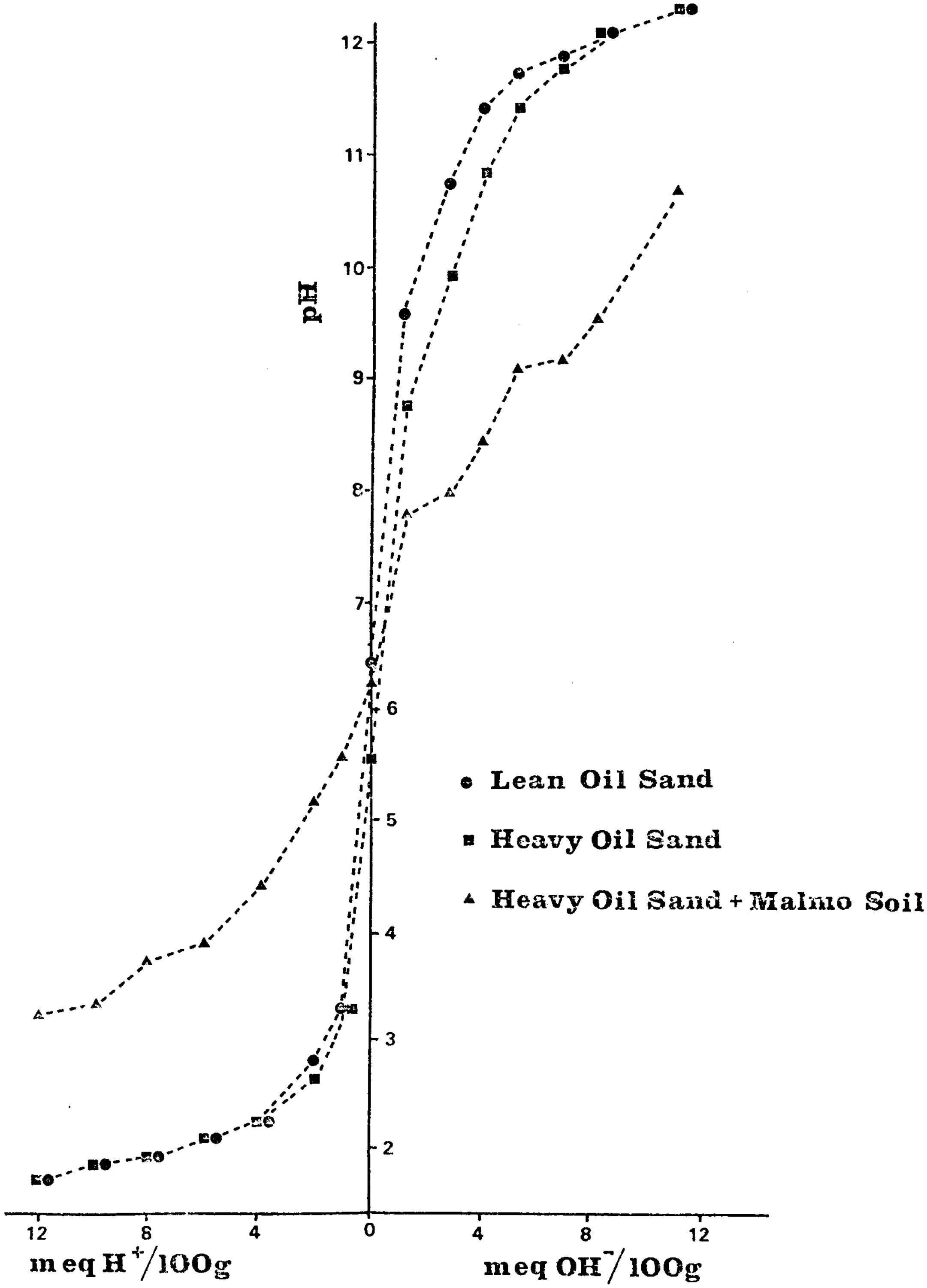


Figure 8. Buffering capacities of lean and heavy oil sands and a heavy oil sand-Malmo soil mix.



buffering capacity. For example a mix of 1 part tailings sand and 1 part GCOS overburden creates a "soil" with a pH of 7.6 and a drop of only 0.5 of the pH unit by the addition of 3 meq of acidity per 100g. A mixture of peat, tailings sand and overburden has even more desirable properties in that it contains the buffering capacity derived from the peat as well. In fact in many ways the buffering capacity of this mix is superior to the Malmo soil.

The heavy oil sand sample is very poorly buffered. This provides some concern since if areas containing appreciable amounts of relatively rich oil sand are to be revegetated the more labile material in the oil sand will be degraded by the soil organisms by the addition of fertilizer. In a material such as oil sand that has a high sulfur content this would result in the release of relatively high amounts of mineral-S. Possible acidification by sulfate could occur. Addition of Malmo soil was found to significantly improve the buffering capacity and reduce the danger of acidification (Fig.8). Other beneficial effects of revegetation of heavy oil sand through soil amendment have already been discussed. The use of overburden materials should be a practical method of producing a well buffered system. Also note that the buffering curves may be used in the prediction of lime additions needed.

The data may be used to demonstrate the possible effects of SO_2 emissions in the lease area on the pH of soil surfaces composed of different materials or even the effect of acidic fertilizers. The information presented in Table 51 is calculated by conservatively estimating that in such an area 40 lb of sulfur/acre may enter the soil annually from aerial contamination. The depression of soil pH in tailings sand and peat is considerable. Satisfactory buffering can be obtained by the incorporation of overburden materials.

TABLE 51

PREDICTED pH CHANGES IN SOILS AND MIXES AS A CONSEQUENCE OF HYPOTHETICAL SULFUR EMISSIONS*

Soil or mix	bulk density g/cm	time (yrs)	predicted pH 0	5	10	25
Malmo soil	1.1		6.5	5.9	5.6	4.9
Peat	0.1		3.6	2.3	1.5	
Tailings sand	1.4		7.5	4.9	3.3	2.7
Syncrude overburden	1.4		7.8	7.7	7.6	7.4
Tailings sand:peat: Syncrude overburden 2:1:1 mix	1.1		7.5	7.0	7.0	6.5

*Based upon 40 lb-S/acre/yr uptake by the soil and assuming that all the sulfur is rapidly oxidized and that no losses by leaching occur.

The degree of acidification would be predicted to be the same by the annual addition of 65 lb-N/acre/yr as 34-0-0 fertilizer.

Numbers and Types of Organisms

Two plating media were used to study the numbers of bacteria in each of the soils and mixes. A standard plate count was used to give an estimate of total numbers. A more selective medium, ammonium stearate agar, was used to estimate numbers of organisms capable of growth on a fatty acid substrate. Such organisms occur naturally in soil in quite large numbers where they may degrade naturally occurring fatty acid, fatty acid esters, waxes, etc. in soils. They may be enriched in soils that contain saturated paraffinic hydrocarbons. Results showed that the Malmo agricultural soil contained about 10^8 bacteria/g (see Table 52). The remaining soils and mixes contained between 10^6 and

Table 52. Numbers of bacteria, fungi and algae in soils and mixes

Soil or soil mix	Numbers of organisms			
	Bacteria		Fungi	Algae
	PCA $/g \times 10^6$	ASA $/g \times 10^4$	$/g \times 10^4$	$/g \times 10^2$
Peat (GCOS)	2.2	21.5	130	9.75
Tailings Sand	9.1	3.9	0.1	0
Malmo Soil	70.5	130	14.0	2.40
GCOS Overburden	1.3	0.3	0.2	6.20
Syncrude Overburden	14.0	0.7	0.2	0
Peat + Tailings Sand	1.0	6.5	0.5	49.0
Lean Oil Sand	2.5	9.5	3.0	0
Malmo + Heavy Oil Sand	2400	1490	20.0	2.40
Peat + Tailings Sand + GCOS Overburden	14.0	18.0	2.4	0.40
Peat + Tailings Sand + Syncrude Overburden	20.0	8.0	115	1.90
Tailings Sand + GCOS Overburden	2.2	4.6	0.3	2.00
Heavy Oil Sand	27.5	20.0	135	0

slightly over 10^7 bacteria/g. An exception was the Malmo/heavy oil sand mix. Unamended oil sand contained 2.8 x 10^7 bacteria/g but when mixed with the Malmo soil and incubated, numbers increased dramatically to 2.4 x 10^9/g. This similar pattern is observed in other studies that we have conducted where crude oil has been added to soil.

None of the soils could be considered low in bacteria. This was especially noticeable with the tailings sand that contained nearly 10 million organisms per gram. It was evident however, that this number was made up of a relatively small number of different types of bacteria. It seems possible that many of the organisms present in the tailings sand are engaged in the decomposition of the residual oil present in the sand. No counts were made on freshly deposited tailings sand.

The numbers of organisms capable of growth on the ammonium stearate agar were lower by a factor of about 100 except in the peat where there was only a ten-fold difference. This is probably due to the relative greater abundance of hydrocarbons naturally present in the peat. It was noticeable that mixing peat with poorly buffered materials that would tend to reduce the mix pH resulted in lower bacterial counts. An example was the comparison of tailings sand alone with tailings sand/peat mix. Also differences between the bulk density of peat and sand will tend to favour the sand in enumerations based on weight.

The peat contained a high fungal population. This is predictable since fungi compete more favourably than bacteria at low pH. However, mixing of peat and tailings sand did not increase the numbers of fungi over those found in tailings sand alone although it decreased bacterial numbers. Increases in fungal numbers probably require the presence of viable fungal spores in the soil as a prerequisite. The peat + tailings sand + Syncrude overburden mix did, however, have a sizeable fungal population. Unamended heavy oil sand contained a large number of fungi. Possibly the filamentous growth habit of fungi is more adaptable to the degradation of oil components in such a soil with tough impenetrable soil aggregates.

Algae are primarily limited to surface soil horizons since they require sunlight to grow. Consequently it was not surprising to find the highest numbers in peat and peat and tailings sand mixes. Moderate numbers were found in the Malmo soil, GCOS overburden, Malmo/heavy oil sand mix, tailings sand/GCOS overburden mix and the peat, tailings sand and Syncrude overburden mixture. Algae could not be detected in the tailings sand, Syncrude overburden, heavy oil sand and lean oil sand.

Sulfate reducing organisms

In a well aerated soil, organisms are able to use oxygen as the terminal electron acceptor in their metabolism. In an anaerobic soil or in anaerobic sites in a largely aerobic soil, alternate electron acceptors may be used.

Sulfate may be used as a terminal electron acceptor and results in the accumulation of reduced forms of sulfur such as sulfide. High sulfide concentrations may be toxic to plant growth.

Large numbers of sulfate reducing organisms occurred in many of the soils and mixes (Table 53). This would be expected for peat which may be considered primarily anaerobic. Similarly large numbers of sulfate reducing organisms would be expected in sub-surface soils such as the overburden, especially in view of their high sulfate contents. Sulfate levels were low in the Malmo soil which had the lowest counts of sulfate reducers. Numbers of sulfate reducers

Table 53. Numbers of denitrifying and sulfate reducing organisms.

	Sulfate Reducers	Denitrifiers
	number per g oven dry soil	
Peat (GCOS)	$>>10^5$	2095
Tailings sand	$>>10^5$	330
Malmo soil	1.02×10^3	63500
GCOS overburden	0.91×10^4	8000
Syncrude overburden	3.20×10^4	1900
Heavy oil sand	2.46×10^4	385
Lean Oil sand	$>>10^5$	5250
Peat + tailings sand	$>>10^5$	1100
Malmo + heavy oil sand	$>>10^5$	2700
Peat + tailings sand + GCOS overburden	1.30×10^5	4150
Peat + tailings sand + Syncrude overburden	1.26×10^5	320
Tailings sand + GCOS + overburden	9.60×10^4	1350

were surprisingly high in the tailings sand. Numbers were also large in hydrocarbon-containing materials. This has also been observed in soils containing crude oil (Rowell & McGill, unpublished).

We may conclude that the high levels of sulfate reducing organisms in the McMurray derived materials is either a consequence of the high input of S into the soils from the atmosphere or due to high natural levels of sulfate in the soils as was the case with the overburden materials. Under appropriate conditions they may lead to the accumulation of sulfides or production of H_2S in sulfate-rich overburden materials where organic sources of energy are not limiting.

Denitrifying Organisms

Denitrification occurs where nitrate is used as the electron acceptor. This results in the loss of nitrogen from the soil in the form of gaseous oxides. However the numbers of denitrifiers recorded did not follow the pattern found for sulfate reducers. This tends to support the contention that sulfate reducers are high in numbers in McMurray soils due to the high sulfate levels from natural sources or from aerial S-contamination. Denitrifiers were highest in the Malmo soil (Table 53). Low numbers occurred in tailings sand, heavy oil sand, and peat + tailings sand + GCOS overburden mix. The remainder contained over 10^3 denitrifiers/g. Again the number should be regarded primarily as comparitative.

The importance of denitrification in relation to reclamation concerns the fate of added fertilizer nitrogen. In a potentially active denitrifying soil large amounts of fertilizer nitrogen may be lost from the soil rather than being used for plant growth and incorporation into the soil system. The numbers observed in these materials are sufficient to provide an innoculum that could develop into a large active population if the soil environmental conditions were to favor them.

Enzyme Activity

The need to apply plant nutrients as fertilizers depend principally on how much a soil can supply from the natural reserves within the soil. The majority of soil-N and considerable amounts of S and P occur in organic forms in the soil. To be made available to plants they must normally be converted into inorganic forms. Soil microorganisms attack organic-N as protein for instance and break it down into amino acids and eventually ammonium. Enzymes involved in the degradation of proteins and peptides are called proteases. Similarly organically bound P and S may be converted ultimately into phosphates and sulfates. We can possibly assess the potential of a soil to mineralize organic N, P and S by measuring certain enzyme activities in the soil. We have looked at the activities of proteases, sulfatases and phosphatases in these soils. The results are shown in Table 54. The specific substrates used to estimate phosphatase and sulfatase activities were p-nitrophenyl phosphates and p-nitrophenol sulfates respectively. These are not naturally occurring soil compounds but are convenient to use as organic phosphate and sulfate analogues of soil compounds. The substrate used to measure protease activity, casein, also does not occur in natural soils although it has the general basic structure found in any protein molecule. The enzyme parameters measured were the maximum velocity and the Michaelis Constant (K_m). The maximum velocity tells us in a comparitative way how much enzyme is present in the soil. The K_m value tells us how efficient the enzymes are or how quickly they are able to perform the reactions in question. With the more active soils it was possible to measure V_{max}, the maximum velocity and K_m by conventional enzymological methods. With

Table 54. Enzyme activities of soils and mixes

	Enzyme activity		
	Phosphatase (μM p-NP/g/hr)	Sulfatase (μM p-NP/g/hr)	Protease (μM tyrosine equivalents /g/hr)
Peat (GCOS)	0.499	0.0624	0.491
Tailings Sand	0.007	nd	0.021
Malmo Soil	1.164	0.0373	0.125
GCOS Overburden	0.072	nd	0.003
Syncrude Overburden	0.006	nd	0.016
Heavy Oil Sand	nd	nd	0.002
Lean Oil Sand	0.015	nd	0.040
Peat + Tailings Sand	0.032	nd	0.069
Malmo + Heavy Oil Sand	1.160	0.0125	0.054
Peat + Tailings + GCOS Overburden	0.012	nd	0.018
Peat + Tailings + Syncrude Overburden	0.005	nd	0.054
Tailings Sand + GCOS Overburden	nd	nd	0.001

p-NP p-nitrophenol
nd not detectable

The following K_m values were obtained:

	Phosphatase	Sulfatase
Peat	4.76×10^{-3}M	5.19×10^{-3}M
Malmo Soil	5.19×10^{-3}M	2.44×10^{-3}M
Malmo Soil/Heavy Oil Sand	4.60×10^{-4}M	1.19×10^{-3}M

most of the soils activities were so low that this was not possible and instead the velocity obtained at a high substrate concentration was assumed to approximate to V_{max}.

(a) Phosphatase

The results clearly showed that only the peat, Malmo soil and the Malmo/heavy tar sand mix have high phosphatase activities (Table 54). Aryl phosphatase activities may be expected to be high in well aerated, organic rich soils which do not contain large amounts of available phosphate. It has been found that the addition of phosphate fertilizers to soil depresses phosphatase activity (E.A. Paul, personal communication). It is interesting to note that the K_m value for the Malmo/heavy oil sand mix is a power of ten lower than for the Malmo soil alone. This may indicate that different phosphatase enzymes are active in the mix than are found in the Malmo alone. No phosphatase activity could be detected in the heavy oil sand alone.

(b) Sulfatase

Sulfatase activity could only be detected in the peat, Malmo and Malmo/heavy oil sand samples (see Table 54). By analogy to our knowledge of phosphatase we may speculate that soils naturally rich in sulfate would not be expected to have enzymes active in the degradation of aryl sulfates. The observations of aryl sulfatase activity seem to be consistent with the counts of sulfate reducing organisms recorded previously. It is also noteworthy that while the general activity of the Malmo/heavy oil sand mix is greater than for Malmo alone (as determined by CO_2 production), the sulfatase activity is less. This could be a consequence of mineralization of sulfate from organic S-containing components in the tar sand.

(c) Protease activity

Protease activity may be discussed in a similar manner to measurements of the hydrolysable nitrogen content of a soil. The level of protease activity is a measure of the ability of the soil to degrade proteins and peptides into amino acid units. This is the first step in the mineralization of proteins that eventually results in the formation of inorganic nitrogen as ammonium, a portion of which may be available for plant growth. Highest protease activities were recorded for soils that had the highest total nitrogen contents (see Table 54). However, despite the very low nitrogen contents of some samples, activity could be detected in all the soils. The tailings sand, heavy oil sand and the overburden samples contained the lowest activities. In the mixes containing peat or Malmo soil the activity observed seemed to be due almost entirely to the presence of the peat or agricultural soil. Therefore it seems that available nitrogen will be released from organic nitrogen fractions in the unamended lease materials in very small amounts. Only when they are mixed with amendments such as peat, top soil or fertilizers will the levels of available nitrogen be maintained at concentrations adequate to support plant growth.

Nitrogen Fixation

Two types of specialized microorganisms can fix atmospheric nitrogen for growth. Symbiotic nitrogen fixing organisms exist in a mutualistic relationship with a plant while non-symbiotic nitrogen fixing microbes live free in the soil. Non-symbiotic fixation in temperate soils is largely due to the aerobic bacterium Azotobacter though in certain instances the blue-green algae Nostoc and Anabaena may also be important. Under anaerobic conditions Clostridium spp. bacteria are also active in nitrogen fixation.

From the results presented in Table 55 it is apparent that very little fixation was occurring in the soils and mixes studied. The highest rates measured would have accounted for only 0.2 lb-N/acre/yr. However, through the use of nitrogen fixing plants in a reclamation project the process of nitrogen fixation may possibly be used to advantage in the establishment of a self-sustaining plant community. In soils under severe nitrogen deficiency such as occurs after an oil or natural gas spill, quite large increases of total nitrogen have been recorded (Harper, 1939). It is concluded that these increases are due to free-living nitrogen fixing organisms. Such a situation may have existed in soils containing tar sand. No efforts were made to assess potential nitrogen fixation by blue-green algae.

Carbon dioxide production

Carbon dioxide production or oxygen uptake are probably the most practically useful overall indication of total microbial activity in a soil. Table 56 shows the amounts of CO_2 evolved from soils and mixes after a two-week preincubation period. Activity of the tailings sand, lean tar sand and unamended heavy tar sand were low. The activity of the various mixes was generally consistent with the observed activity of the components alone. Addition of Malmo soil to heavy oil sand caused a marked increase in activity. The Malmo soil provides nutrients, better aeration and an additional suite of microorganisms. All these factors enable labile hydrocarbons in the oil sand to be readily decomposed. The overburden materials were more active than would be expected from their low organic carbon contents. However, the release of some CO_2 from carbonate can not be ruled out.

As was noted in the discussion of the total microbial numbers present, none of the materials, not even the tailings sand, can be considered sterile.

Table 55. Nitrogen fixation rate in untreated soils and mixes.

Materials	Nitrogen fixation M^{-10} ethylene/h/g air dry soil
GCOS Peat	3.05
Tailings Sand	2.25
Malmo Soil	2.95
GCOS Overburden	2.60
Syncrude Overburden	2.10
Heavy Oil Sand	2.10
Lean Oil Sand	2.15
Peat + Tailings Sand	2.85
Malmo + Heavy Oil Sand	2.95
Peat + Tailings Sand + GCOS Overburden	2.90
Peat + Tailings Sand + Syncrude Overburden	2.75
Tailings Sand + GCOS Overburden	2.85

Table 56. Carbon dioxide production from untreated soils and mixes.

Material	CO_2 rate μg CO_2-C/h/100 g air dry soil*
GCOS Peat	72.5
Tailings Sand	7.5
Malmo Soil	25.5
GCOS Overburden	24.6
Syncrude Overburden	16.7
Heavy Oil Sand	7.5
Lean Oil Sand	3.4
Peat + Tailings Sand	7.5
Malmo + Heavy Oil Sand	52.5
Peat + Tailings Sand + GCOS Overburden	26.7
Peat + Tailings Sand + Syncrude Overburden	29.6
Tailings Sand + GCOS Overburden	17.5

* Heavy tar sand was field moist, peat was partially air dried.

The results of growth chamber experiments also indicate that a biological mechanism is involved in amelioration of some of the undesirable properties of the oil sand materials.

BIBLIOGRAPHY

General References

BERRY, C.B. 1974. Reclamation of disturbed land. Revision 1. GCOS lease site. Great Canadian Oil Sands Ltd., Fort McMurray, Alberta.

LESKO, G.L. 1974. Preliminary revegetation trials on tar sands tailings at Fort McMurray, Alberta. Rept. No. NOR-X-103, Northern Forest Research Centre, Edmonton, Alberta.

MASSEY, D.L. 1972. Tailings sand to trees; a report on tailings sand revegetation at Fort McMurray, Alberta. Alberta Soils and Feed Testing Laboratory, Alberta Department of Agriculture.

WHEELER, G.W. 1973. Establishment and survival of ground cover plantings on disturbed areas in Alberta. Rept. No. 1. Revegetation of disturbed sites such as pipelines, cutlines and strip mining areas. Alberta Department of Agriculture.

Cited References

BREMNER, J.M. 1965a. Total Nitrogen. In Methods of Soil Analysis, C.A. Black ed., American Society of Agronomy Inc., Madison Wisc. pp 1149-1178.

BREMNER, J.M. 1965b. Organic Forms of Nitrogen. In Methods of Soil Analysis, C.A. Black ed., American Society of Agronomy Inc., Madison, Wisc. pp 1238-1255.

BREMNER, J.M. 1965c. Organic Nitrogen in Soils. In Soil Nitrogen, W.V. Bartholomew and F.E. Clark eds., American Society of Agronomy Inc., Madison, Wisc. pp 93-149.

COCHRAN, W.G. 1950. Estimation of bacterial densities by means of the "most probable number". Biometrics, 6, 105-116.

HARPER, H.J. 1939. The effect of natural gas on the growth of microorganisms and the nitrogen and organic matter in the soil. Soil Sci., 48, 461-466.

LADD, J.N. and J.H.A. BUTLER. 1972. Short term assays of soil proteolytic enzymic activities using proteins and dipeptide derivatives as substrates. Soil Biol. Biochem., 4, 19-30.

RICE, W.A. and E.A. PAUL. 1971. The acetylene reduction assay for measuring nitrogen fixation in waterlogged soils. Can. J. Microbiol., 17, 1049-1056.