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REVEGETATION AND MANAGEMENT OF TAILINGS SAND SLOPES: 1977 RESULTS

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FOREWORD

Syncrude Canada Ltd. continues to conduct revegetation reseach on disturbed land surfaces in the Athabasca Tar Sands. The following report describes experiments which took place during 1977 on the face of the Great Canadian Oil Sands Ltd. tailings pond dyke. The report is the fourth to be published in Syncrude under the broad heading of revegetation, and the third to deal specifically with tailings sand slopes. The previous three reports are numbered 1974-3, 1977-1, and 1977-4 respectively, in Syncrude's Environmental Research Monograph series.

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ACKNOWLEDGMENTS

This is the third annual report on the study of different aspects of soil reclamation and revegetation in the Athabasca Tar Sands area. The work was carried out for Syncrude Canada Ltd. under Contract No. 98-0145-EA.

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SUMMARY

The tailings sand slope that was seeded in July, 1976, was considered completely stable in 1977. No wind or water erosion or movement of soil particulates was detected in 1977.

Of the fourteen species seeded in 1976, only Lupine and the oat cover crop did not grow in 1977.

At the lowest rate of fertilizer used (80 Kg-N; 35 Kg-P; 75 Kg-K and 20 Kg-S per hectare), the remaining eight grasses and three legumes (Alfalfa, Cicer Milk Vetch and Sainfoin) were all well represented. As the fertilizer rates were increased to 150 Kg-N; 40 Kg-P; 150 Kg-K and 40 Kg-S, added either in June or in June and August, Brome Grass, Pubescent Wheat Grass, Streambank Wheat Grass and Slender Wheat Grass became more dominant.

A comparison of fall seeding versus spring seeding indicated that fall seeding could be successfully used but that poor distribution of seed resulted from seed wash-off during snow melt in the spring.

The yield of above ground vegetation was related to the amount of fertilizer added rather than to the use of peat or overburden soil amendments. No differences were noted by using soil conditioners and contouring the plot surface. It was concluded that where peat or overburden are readily available, other soil treatments of this nature are unnecessary in providing adequate erosion control.

The yield of plant roots was less affected by fertilization although the uptake of nitrogen and potassium was increased.

Incorporation of peat or peat and overburden to a depth of 30 cm rather than 15 cm resulted in deeper root penetration and an overall increase in root yield.

Only 1-2% of the intercepted rainfall was collected as runoff in 1977. Fertilizer nitrogen losses in runoff varied between 0.03 and 1.1 Kg-N/ha at the highest rate of fertilizer addition in comparison to 0.5 to 6.4 Kg-N/ha last year. The amount of nitrogen leached below the 30 cm depth varied be-

tween 0.1 and 2.3 Kg-N/ha, less than one-tenth the amount recorded in 1976.

Studies of nutrient cycling and mineralization indicated that at the lower fertilizer rate (80 Kg-N; 35 Kg-P; 75 Kg-K and 20 Kg-S/ha added in June), some net mobilization of nutrients did occur between the March thaw and June but that levels of nitrogen and potassium in particular were low throughout much of the summer. Addition of 150 Kg-N; 40 Kg-P; 150 Kg-K and 40 Kg-S/ha in June resulted in good supplies of available nutrients over most of the summer but by September nitrogen and potassium were in poor supply. The addition of a similar rate both in June and August gave an excess of available nutrients at all times. The large excess of nitrate present in September seemed to present a potential for denitrification losses.

The results show that although two applications of fertilizer may be warranted in the first year, only one addition of no more than 150 Kg-N/ha is needed in the second year. If a balanced growth of grasses and legumes is desired, the rates of fertilizer should be less.

Long term management studies were continued on a six year old vegetated area of the tailings dike.

Parts that had not been fertilized since 1974 showed the poorest growth recorded during the three year study. Total above ground yields varied from 540 Kg/ha on the unfertilized parts up to 3430 Kg/ha where fertilizers had been added. In terms of plant yield, there was no additional benefit to the addition of more than 90 Kg-N/ha/year. Application of fertilizer in the previous August did result in significantly greater early growth but improvements over the year in yield and in nutrient uptake and cycling did not justify the extra application.

The fertilizer program that was started in 1975 has resulted in a wide difference in plant species distribution over the area. Unfertilized or minimally fertilized areas show at least 71% cover by Creeping Red Fescue and up to 11% cover by legumes. In comparison, heavily fertilized areas are almost entirely covered by Brome Grass and are devoid of legumes.

The yield of roots showed no significant differences between treatments although the uptake of nitrogen and potassium was significantly improved by the addition of fertilizers at or above a rate of 90 Kg-N; 23 Kg-P and 90 Kg-K/ha.

There was no damage from wind or water erosion during 1977.

Although the pH of the surface 0-2.5 cm is between 5.5-5.7 and between 6.2 and 6.4 between 0-15 cm, the addition of lime in 1975 has not significantly improved plant growth.

In 1977, work was started to study the relative rates of plant residue decomposition in both the old and the newly revegetated experimental areas specifically to determine the effect of fertilizers on nutrient turnover.

Results show that litter decomposition was most intense between June and August and that decomposition rates were related to previous and current applications of fertilizer.

Cellulose decomposition in the surface 15 cm was much slower in pure tailings sand or overburden than in tailings sand mixed with peat or peat and overburden. The differences are thought to be due to the lack of cellulolytic organisms in the tailings sand and overburden rather than to a lack of nutrients.

The numbers of bacteria and the total soil respiration were similar to those recorded last year. Fungal counts have increased since 1976. Values were similar to those expected from normal undisturbed soils.

The microbial population in fresh and vegetated tailings sand samples from the G.C.O.S. lease were considerably lower than vegetated sands mixed with peat or overburden. The pure sands were 10-100 times lower in bacteria, 30-200 times lower in fungi and had respiration rates that were 3-10 times lower.

Bacteria isolated from fresh and vegetated tailings sand were compared with those from vegetated peat and peat plus overburden containing tailings sand mixes.

The bacteria from fresh tailings sand and vegetated tailings sand were largely Gram negative short rods or cocci-bacilli and showed a poor ability to grow in the presence of 10% NaCl or 0.1% phenol. A majority of the isolates failed to grow on starch, gelatin or on citrate as a sole carbon source. In contrast, the mixes of sand and peat or sand, peat and overburden contained more Gram positive or Gram variable organisms and a higher proportion that was catalase positive, withstood growth in 10% salt or 0.1% phenol, or could use starch, gelatin or citrate for growth.

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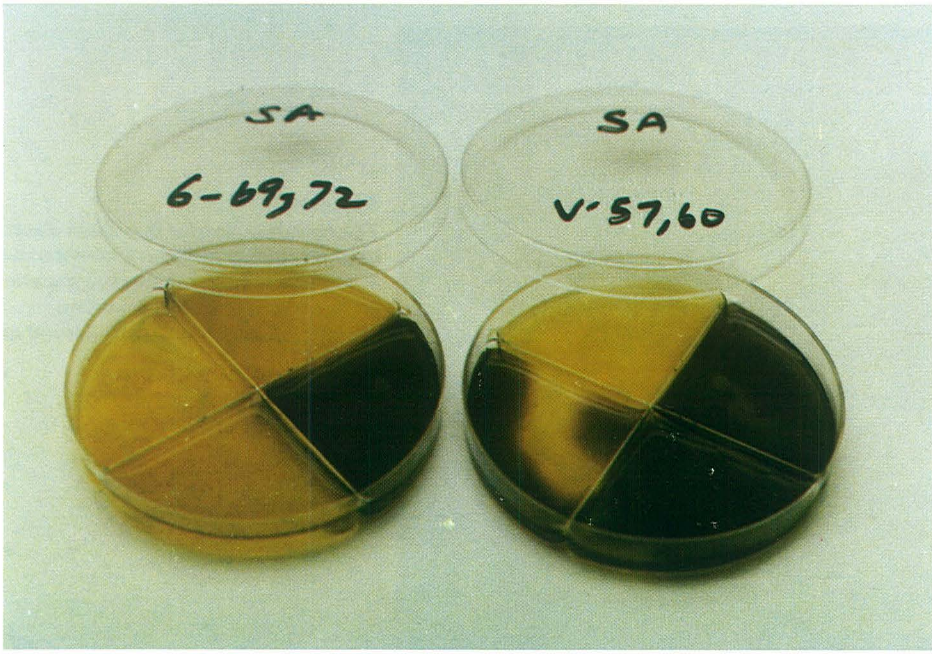

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1. INTRODUCTION

Tailings sand dikes present many soil stability problems due to their steep slopes, uniform sandy construction and low fertility.

The objectives of this research were to study methods for the establishment of vegetation for erosion control and to determine cost effective methods for the long term management of such areas.

This report presents the results of the third year of the study.

The research area is located on a tailings sand dike at the Great Canadian Oil Sands Limited tar sand extraction plant, 50 Km north of Fort McMurray, Alberta. The legal location is 23/24-92-10-W4.

In 1975, a management study site was set up on an area of tailings sand that had been revegetated in 1971 by adding 15 cm of peat to the tailings sand surface and seeding with grasses and legumes. Small amounts of fertilizers had been added to maintain the surface cover. Since 1975, this area has been used to study the effectiveness of different fertilization programs in maintaining surface stability and improving nutrient cycling in the soil.

In 1976, two additional areas were studied on previously unvegetated tailings sand. One area was used to investigate the performance of a variety of different grasses and legumes seeded into the tailings sand with peat or peat plus overburden amendments tilled to a depth of 15 cm. Different fertilization programs were also studied.

The other area was set aside to study the benefit of deeper tillage of surface amendments of peat and overburden in improving plant rooting and surface stability.

2.0 ANALYTICAL METHODS

2.1 Sampling and Laboratory Preparation

Soil samples were taken with Oakfield soil samplers. Each sample was a composite of 6-12 randomly located cores. The soil cores were broken up by hand in the laboratory and a subsample taken to determine the field moisture content. Samples were air dried and ground to 2 mm and stored for analysis.

Plant samples were obtained by hand clipping a 1 m^2 area. Samples were air dried and weighed to determine dry matter yields. The whole sample was chopped into small pieces, mixed well, and a subsample ground to 40 mesh in a Wiley mill.

Root samples were obtained by taking six 5 cm diameter cores to a depth of 60 cm. In Experiments II and III the soil surface was too dry and loose to allow cores to be taken from the surface 30 cm. Instead, a 20 cm x 20 cm section was cut out with a sharp knife to a depth of 30 cm and then cores were taken to recover the 30-60 cm depth sample. To reduce decomposition of the roots, the cores were stored in a deep freeze until they could be processed. A washing method was employed to separate root tissues from the soil. The roots were dried and ground before they were analyzed.

2.2 Chemical Analysis

Details of the methods used may be found in Agronomy Monograph No. 9[3] or in the Manual on Soil Sampling and Methods of Analysis[4].

Soil pH was measured in a 1:2.5 soil/water paste. Electrical conductivity was determined in a saturated soil paste. Ammonium and nitrate nitrogen were measured by steam distillation after extraction with 1M potassium chloride. Available phosphorus was measured colorimetrically using an ammonium molybdate/ammonium vanadate/nitric acid reagent after extraction with 0.03N ammonium fluoride/0.03N sulfuric acid solution. Sulfate was extracted with 0.01M calcium chloride and the concentration of sulfate was determined colorimetrically with a bismuth reagent following reduction with a hydriodic acid/formic acid/hypophosphorous acid mixture. Available potassium was determined by atomic absorption spectroscopy after extraction with neutral 1M ammonium acetate.

Plant samples were digested with a 5:1 mixture of nitric acid and perchloric acid. The concentration of phosphorus, sulfur and potassium were determined as described for the soil samples. Calcium was determined by atomic absorption spectroscopy. Nitrate was measured from a water extract. Total nitrogen was determined by Kjeldahl digestion followed by steam distillation.

Soil respiration rates were determined in the laboratory. The soils were allowed to incubate for two weeks at field moisture content. A 30-50 g sample was placed in a litre capacity glass container in which a small vial containing sodium hydroxide was placed. The production of carbon dioxide over a 24 hour period was measured by back titrating the sodium hydroxide with standard acid after the addition of excess barium chloride.

2.3 Microbial Methods

Total numbers of microorganisms were determined by dilution plate counting methods. Standard Methods Agar was used for bacteria and a Rose Bengal-Antibiotic Agar for fungi.

A large number of bacterial isolates were obtained from the dilution plates. The following tests were applied to these bacterial isolates:

Gram Reaction. Heat fixed bacterial smears were prepared from 48-hour slants of half strength nutrient agar (NA_{50}). Smears were stained with crystal violet and iodine, decolorized with ethanol/acetone, and counter stained with safranine[5].

Cell Dimensions. Gram stained smears were used for the determination of cell dimensions.

Sporulation. The production and position of spores, and determination of the shape of the sporangium, were examined on smears from 14 day cultures on soil extract agar by staining with malachite green and counterstaining with safranine[5].

Motility. Isolates were grown on semi-solid NA_{50} containing 2,3,5-triphenyl tetrazolium chloride at a concentration of 0.005% (w/v). Tubes were stab inoculated and incubated at 22°C for 14 days. Growth was indicated by the reduction of the colorless dye to the red insoluble formazan derivative. For non-motile organisms, the coloration is limited to the initial stab while for motile forms the coloration extends throughout the medium[6].

Growth at High pH. The ability of organisms to grow at high pH was tested by observing the extent of growth after seven days at 22°C on NA_{50} adjusted to a pH at 9.5 with sterile sodium hydroxide.

Growth at High Salt Concentration. The ability of organisms to grow at high concentrations of salt was determined in NA_{50} containing 10% w/v of sodium chloride. The presence or absence of growth was determined after seven days at 22°C.

Catalase Production. Isolates were grown for seven days on plates of NA_{50} and then flooded with hydrogen peroxide. The appearance of gas bubbles indicates the presence of the enzyme catalase.

Gelatin Hydrolysis. Gelatin at a concentration of 0.4% (w/v) was added to NA_{50} and dispensed into sterile Petri plates. Following inoculation and incubation for seven days at 22°C the plates were flooded with 15% (w/v) mercuric chloride in dilute hydrochloric acid. A white opaque precipitate forms with unhydrolyzed protein within 30 minutes. Colonies which showed zones of clearing around or below were actively hydrolyzing the gelatin.

Starch Hydrolysis. Plates containing Difco starch agar were inoculated and incubated for seven days at 22°C. Plates were then flooded with dilute iodine solution. Hydrolysis of starch was indicated by a colorless zone around or below the colonies. Unhydrolyzed starch gave a dark blue reaction.

Cellulose Hydrolysis. Basal inorganic salts medium was supplemented with 0.1% (w/v) ammonium nitrate and 1% (w/v) cellulose powder. After inoculation, plates were incubated for up to two months at 22°C in a humid atmosphere. Areas of clearing appeared around or below cellulolytic organisms.

Voges-Proskauer Test. A low phosphate nutrient medium was dispensed into tubes and sterilized. The tubes were incubated for 14 days at 22°C. To test for acetoin, 5 ml of 40% NaOH and 0.5 mg of creatine were added to each tube. The appearance of a red color after 60 minutes indicates the presence of acetoin[6].

Sulfide and Indole Production. Tryptone water of 1% (w/v) was dispensed into tubes and sterilized. A small sterile nail was placed into each tube and the tube inoculated. After 14 days incubation, the tubes were examined. The production of hydrogen sulfide was indicated by blackening of the nail.

The immediate production of a red color after the addition of 0.5 ml of Kovac's Reagent[6] indicated the presence of indole.

Growth in the Presence of Phenol. Sterile plates of NA_{50} containing filter sterile phenol at a concentration of 0.1% (w/v) were inoculated and incubated for seven days at 22°C. The presence or absence of growth and the production of brown pigment was noted.

Nitrate Reduction. Potassium nitrate broth was dispensed into tubes containing inverted Durham tubes and sterilized. Tubes were incubated for 14 days at 22°C and tested for the presence of nitrite and gas production.

Growth on Citrate as Sole Carbon Source. Basal inorganic salts medium was supplemented with 0.1% w/v ammonium nitrate and filter sterilized sodium citrate at 1% (w/v). The medium was inoculated and incubated for seven days at 22°C. Use of citrate as a sole source of carbon was indicated by profuse growth on the medium.

Growth on the Hugh and Leifson Glucose Medium. Filter sterilized glucose as a 2% (w/v) aqueous solution was added to an equal amount of autoclaved double strength basal medium[7] and the medium dispensed into sterile plates. For each organism two tests were performed. One compartment of the plate was incubated aerobically while the other was flooded with sterile liquid paraffin. A yellow color any time indicated acid production.

2.4 Statistical Methods

The replicated data were treated statistically to determine standard deviation about the mean and to indicate significant treatment differences.

The more important data show individual replicate values and standard deviations within the text. A complete set of data which gives full replication with standard deviations and other statistical treatments is provided in a separate appendix to this report.

Where possible, significant differences between treatments were examined using an analysis of variance. Significant results are noted in the text using the following scheme:

- *** Significant at the 1% level
- ** Significant at the 2.5% level
- * Significant at the 5% level
- N.S. Not Significant.

If significance was noted, LSD (Least Significant Differences) at the 5% level are given in the table.

3.0 CONTINUED STUDIES OF A 6 YEAR VEGETATED AREA ON A TAILINGS SAND DIKE - EXPERIMENT I

3.1 Introduction

The experimental area is situated on the east facing slope of the Great Canadian Oil Sands Limited tailings sand dike.

The tailings sand has a surface pH of 8.5, very low amounts of available plant nutrients and is easily eroded. A layer of peat approximately 15 cm in depth was added to the tailings sand surface in May, 1971, and the area seeded with a seed mix containing 33% Brome Grass by volume, 24% Crested Wheatgrass, 15% Creeping Red Fescue, 14% Sweet Clover and 14% Alsike Clover. The area received six small additions of mineral fertilizer between May, 1971, and July, 1974.

During the first year of study in June, 1975, an experiment was set up to study the effectiveness of different fertilizer programs in improving the stability of the dike surface by stimulating plant growth.

The experimental design is shown in Figure 1. Treatments studied involved programs of fertilization ranging between high annual additions, small yearly maintenance additions and no fertilizer application at all. The amount of fertilizer that has been added to date is shown in Table 1.

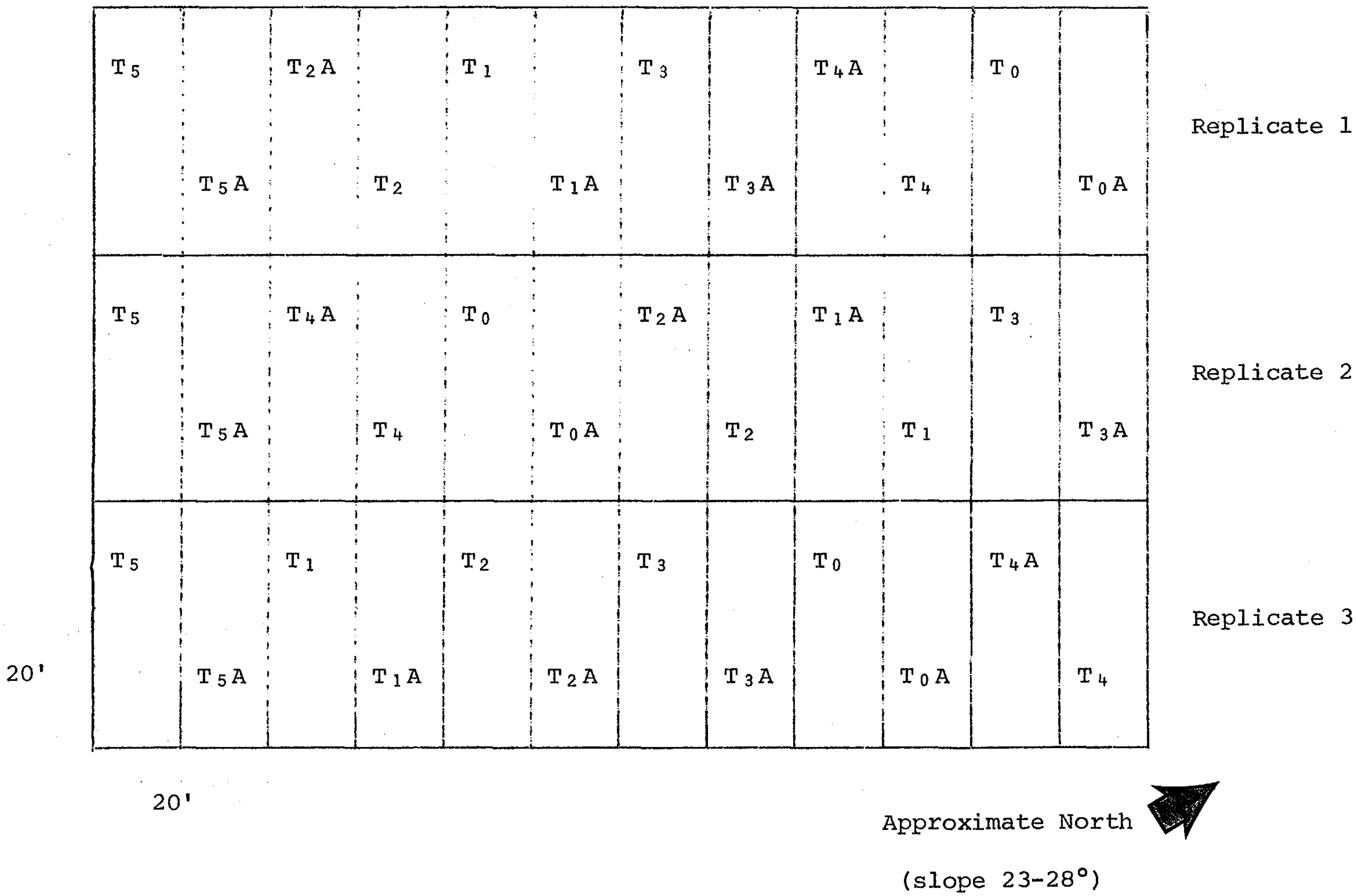


FIGURE 1. Field Plan of Experiment on a Vegetated Tailings Sand Dike at the G.C.O.S. Plant Site at Fort McMurray, Alberta (Experiment I).

TABLE 1

Fertilizers Added to a Vegetated Tailings Sand Dike at the G.C.O.S. Plant Site at Fort McMurray Between 1971 and 1977

Fertilizer Additions (Kg/ha)	Treatment											
	T_0	T_0A	T_1	T_1A	T_2	T_2A	T_3	T_3A	T_4	T_4A	T_5	T_5A
May 1971 to July 1974												
N	279	279	279	279	279	279	279	279	279	279	279	279
P	138	138	138	138	138	138	138	138	138	138	138	138
K	188	188	188	188	188	188	188	188	188	188	188	188
S	-	-	-	-	-	-	-	-	-	-	-	-
June 1975												
N	0	0	90	90	90	90	180	180	180	180	15	15
P	0	0	23	23	23	23	46	46	46	46	6	6
K	0	0	90	90	90	90	180	180	180	180	11	11
S	0	0	9	9	9*	9*	18	18	18*	18*	14	14
August 1975												
N	0	90	0	90	0	90	0	180	0	180	26	76
P	0	0	0	0	0	0	0	0	0	0	6	6
K	0	0	0	0	0	0	0	0	0	0	11	11
S	0	9	0	9	0	9	0	18	0	18	26	26
June 1976												
N	0	0	90	90	90	90	0	0	0	0	43	43
P	0	0	23	23	23	23	0	0	0	0	11	11
K	0	0	90	90	90	90	0	0	0	0	22	22
S	0	0	0	0	0	0	0	0	0	0	9	9

(... continued)

Fertilizer Additions (Kg/ha)	Treatment											
	T_0	T_0A	T_1	T_1A	T_2	T_2A	T_3	T_3A	T_4	T_4A	T_5	T_5A
June 1977												
N	0	90	90	90	90	90	180	180	180	180	43	43
P	0	23	23	23	23	23	46	46	46	46	11	11
K	0	90	90	90	90	90	180	180	180	180	22	22
S	0	0	0	0	0	0	0	0	0	0	9	9
August 1977												
N	0	0	0	90	0	90	0	180	0	180	0	69
P	0	0	0	23	0	23	0	46	0	46	0	0
K	0	0	0	90	0	90	0	180	0	180	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0
Total												
N	279	359	549	729	549	729	639	1019	639	1019	406	525
P	138	161	207	230	207	230	230	276	230	276	172	172
K	188	278	458	548	458	548	548	728	548	728	254	254
S	0	9	9	18	9	18	18	36	18	36	58	58

* Lime added at 4.5 Tonnes/ha

Fertilizers added as ammonium nitrate, ammonium sulfate, ammonium phosphate, potassium chloride and potassium sulfate.

Note that in the Monograph 1977-4 (page 11) an incorrect conversion was used: To convert lb/ac to Kg/ha multiply by 1.121.

Two cuts of plant material were made in 1977, one in June and the other in September, to study productivity and nutrient uptake. Soil samples were also taken in June and September. Studies of rooting were limited to Treatments T_0, T_2, T_4 and T_5.

3.2 Observations

Estimates of species distribution were made in June and August. Table 2 shows a comparison between measurements made in August, 1976, and August, 1977. Treatments such as T_1A, T_2A, T_3A and T_4A, which received frequent additions of fertilizer now contained almost pure stands of Brome Grass. By comparison, unfertilized areas (T_0) or those that received low rates of mineral fertilizers (T_0A, T_5) were dominated by Creeping Red Fescue. With the medium fertilizer treatments (T_1, T_2, T_3, T_4) the Fescue was also being rapidly replaced by Brome Grass.

Crested Wheatgrass, Alsike Clover and Sweet Clover had been eliminated from most plots. The two legumes were growing well only on one replicate of Treatments T_0 and T_0A.

The prevalence of Brome Grass over Creeping Red Fescue may be significant in several ways. The Fescue forms a dense mat of litter up to about 4 cm in thickness at the soil surface. This may help in conserving soil moisture losses but also provides an excellent habitat for rodents.

TABLE 2

Distribution of Plant Species on Experimental Plots on a Vegetated Tailings Sand Dike at Fort McMurray

Treatment	Percentage Cover									
	1976					1977				
	Creeping Red Fescue	Brome Grass	Alsike Clover	Sweet Clover	Crested Wheatgrass	Creeping Red Fescue	Brome Grass	Alsike Clover	Sweet Clover	Crested Wheatgrass
T_0	88	9	2	1	0	88	1	9	2	0
T_0A	79	18	0	1	2	71	27	1	1	0
T_1	66	33	0	1	0	20	80	0	0	0
T_1A	42	58	0	0	0	7	93	0	0	0
T_2	50	50	0	0	0	23	77	0	0	0
T_2A	45	55	0	0	0	8	92	0	0	0
T_3	80	20	0	0	0	17	83	0	0	0
T_3A	30	70	0	0	0	3	97	0	0	0
T_4	69	25	1	0	5	32	67	0	0	1
T_4A	52	45	0	0	3	8	91	0	0	1
T_5	80	19	1	0	0	74	24	2	0	0
T_5A	71	28	1	0	0	53	47	0	0	0

Brome Grass has a high leaf surface area and a greater potential dry matter production than Creeping Red Fescue. Moisture uptake and transpiration losses are liable to be high.

The beneficial effect of atmospheric nitrogen fixation is lost when legumes are eliminated from the sward. Also, where fertilizers are applied and the legumes survive the rate of nitrogen fixation may be quite low.

Some plant diseases were observed during the latter part of the summer. These mainly took the form of Powdery Mildew (*Erysiphe polygoni*) on Alsike Clover and Brome Grass. The percentage of plants affected was so small that the occurrence of plant disease was not considered a significant problem. However, since the fungus persists on the foliage and overwinters as mycelium or spores, a careful check of this problem should be conducted next year.

3.3 Soil Analysis

The results of analysis of soil samples taken in June and September are presented in Tables 3 and 4.

June Soil Samples

Soil moisture did not differ significantly between the various treatments. The moisture content varied between 22.6% and 41.3% in the predominantly peaty surface 15 cm and from

TABLE 3

Analysis of Soil Samples from a Vegetated Tailings Sand Dike at the G.C.O.S. Plant Site at Fort McMurray - June, 1977

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
T_0	0-15	26.9	6.3	0.63	5.6	2.7	14.1	55	32
	15-30	9.7	6.4	0.62	11.3	6.9	3.1	18	33
T_0A	0-15	23.8	6.3	0.59	6.6	2.7	15.6	55	24
	15-30	11.2	6.4	0.57	4.0	1.0	2.9	17	23
T_1	0-15	29.5	6.3	0.74	13.1	13.7	24.9	58	48
	15-30	16.5	6.4	0.87	4.5	1.8	5.5	29	77
T_1A	0-15	24.3	6.2	0.81	7.0	7.0	17.0	54	65
	15-30	9.2	6.2	0.90	8.5	5.9	3.3	24	82
T_2	0-15	41.3	6.6	0.93	7.6	7.3	19.3	63	50
	15-30	15.1	6.7	0.76	3.0	1.2	3.8	27	32
T_2A	0-15	22.6	6.6	0.96	7.4	13.1	21.1	61	46
	15-30	7.4	6.8	0.78	3.1	2.1	4.1	25	50
T_3	0-15	31.8	6.3	0.72	4.7	3.1	20.8	69	57
	15-30	12.3	6.2	0.85	8.4	6.9	5.1	30	67
T_3A	0-15	27.7	6.2	0.84	6.2	6.0	15.4	69	112
	15-30	17.6	6.3	0.75	2.9	1.3	3.7	29	60
T_4	0-15	28.0	6.7	0.87	10.4	6.9	19.2	55	57
	15-30	12.1	6.7	0.73	4.5	1.3	3.9	28	38
T_4A	0-15	35.6	6.8	0.83	7.3	7.5	19.3	74	58
	15-30	14.8	6.8	0.85	9.3	8.5	4.6	27	72

(....continued)

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
T_5	0-15	28.8	6.3	0.77	6.4	2.6	23.3	61	86
	15-30	8.4	6.9	0.74	3.2	1.0	5.1	22	53
T_5A	0-15	41.3	6.3	0.72	12.2	8.7	18.9	71	80
	15-30	15.8	6.5	0.68	4.4	2.0	4.2	22	59
Significance		N.S.	***	N.S.	***	***	N.S.	N.S.	N.S.
L.S.D.			0.3		4.2	3.2			

L.S.D. values apply to the 0-15 cm depth only.

All values are means of three replicates.

Statistical analyses and complete data are presented in the Appendix.

TABLE 4

Analysis of Soil Samples from a Vegetated Tailings Sand Dike at the G.C.O.S. Plant Site at Fort McMurray - September, 1977

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
T_0	0-15	26.8	6.4	0.52	2.1	0.1	17.0	41	26
	15-30	6.8	6.5	0.65	1.3	0.1	4.5	23	28
	30-60	4.9	7.0	0.50	1.3	0.0	3.0	16	17
	60-90	4.8	7.5	0.55	0.9	0.2	2.3	18	16
	90-120	6.2	7.7	0.41	1.2	0.2	1.8	20	27
T_0A	0-15	21.6	6.2	0.54	4.5	0.4	25.3	54	28
	15-30	5.3	6.6	0.55	1.9	0.0	4.7	21	30
T_1	0-15	22.0	6.2	0.59	5.6	1.6	31.8	92	36
	15-30	2.5	6.6	0.62	2.6	0.2	8.3	28	34
T_1A	0-15	18.1	6.1	0.79	10.3	22.2	36.7	98	49
	15-30	2.0	6.6	0.75	2.2	1.8	6.0	29	43
T_2	0-15	25.1	6.6	1.10	9.4	17.2	29.3	127	85
	15-30	4.0	6.6	0.84	2.2	1.1	6.2	33	53
	30-60	3.1	6.9	0.62	1.5	0.8	3.0	21	30
	60-90	4.2	7.0	0.48	2.2	0.6	2.5	18	21
	90-120	4.7	7.1	0.41	0.7	0.1	1.8	16	20
T_2A	0-15	32.3	6.4	1.05	14.5	46.9	49.3	126	53
	15-30	2.9	6.7	0.93	3.8	6.3	9.7	31	43

(....continued)

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
T_3	0-15	20.1	6.2	0.57	7.0	7.6	34.5	84	32
	15-30	6.1	6.5	0.67	2.9	1.9	10.7	27	42
T_3A	0-15	25.4	6.0	1.25	35.7	101	59.3	113	39
	15-30	4.9	6.3	0.94	9.2	17.3	16.8	29	50
T_4	0-15	21.9	6.6	0.85	7.0	18.1	48.2	219	32
	15-30	5.1	6.7	0.61	3.5	4.3	9.7	28	36
	30-60	3.9	7.1	0.56	1.9	2.3	4.3	20	22
	60-90	4.5	7.2	0.40	2.3	1.2	4.2	18	14
	90-120	5.0	7.5	0.47	2.0	1.4	3.7	23	16
T_4A	0-15	21.8	6.3	1.63	30.2	128	65.7	472	46
	15-30	6.6	6.4	1.23	7.7	40.6	13.0	24	43
T_5	0-15	22.5	6.3	1.00	4.1	0.7	34.3	114	104
	15-30	3.8	6.6	0.78	2.2	0.1	8.0	24	64
	30-60	3.4	6.9	1.17	1.9	0.2	5.3	17	70
	60-90	4.3	7.3	1.07	1.8	0.0	4.3	18	69
	90-120	4.7	7.5	0.99	1.4	0.0	4.5	17	66
T_5A	0-15	32.7	6.2	0.69	7.6	6.5	22.8	78	101
	15-30	8.1	6.6	0.84	2.6	1.5	7.7	30	84
Significance		N.S.	**	***	***	***	***	N.S.	***
L.S.D.			0.3	0.38	43.4	13.6	15.1		34

Statistical treatments applied to 0-15 cm depth only.

All values are means of three replicates.

For conversions to Kg/ha in the text, the following bulk densities were used:

0 - 15 cm   0.5 g/cm^3
15 - 30 cm   1.2 g/cm^3

7.4% to 17.6% in the mixed peat and tailings sand material in the 15-30 cm depth.

Surface pH values varied between 6.2 and 6.8 and were slightly higher than were recorded in September, 1976. The treatments that had received lime in 1975 had pH values between 0.2 and 0.5 units higher than those recorded for unlimed treatments.

In May, two sets of samples were taken to determine whether the soil surface was becoming significantly acidified relative to the soil layers below. The results presented in Table 5 do indicate that the litter layer and the surface 2.5 cm of the soil are moderately acidic. However, as yet pH levels over the dike are not low enough to consider the addition of lime.

Electrical conductivity in the surface 0-15 cm of soil samples taken in June varied between 0.59 and 0.96 mmhos/cm. The values were not significantly different between treatments nor were they high enough to adversely affect the growth of the plants.

Mineral nitrogen was present as both ammonium and nitrate ions. Those treatments that had received fertilization in 1976 (T_1, T_1A, T_2, T_2A, T_5, T_5A) did not contain greater amounts of mineral nitrogen than the other treatments. Available nitrogen varied between about 15 and 43 Kg-N/ha in the surface 30 cm. There was evidence from the presence of

TABLE 5

The pH of Litter and Surface Soil from Vegetated Areas of a Tailings Sand Dike - May, 1977

Treatment and Depth		pH
T_0A	Litter	5.6
	0-2.5 cm	5.5
	2.5-5.0 cm	6.2
	5.0-10.0 cm	6.4
T_2A	Litter	5.7
	0-2.5 cm	5.6
	2.5-5.0 cm	5.9
	5.0-10.0 cm	6.3

moderate amounts of nitrate in the 15-30 cm depth that some nitrogen losses below 30 cm may have occurred in some treatments.

The results indicated that there were moderate amounts of available phosphorus present at this time. Most occurred in the 0-15 cm depth. Values varied between 14 and 25 ppm in the surface 15 cm and from 3 to 6 ppm in the 15-30 cm depth. This is equivalent to about 16-29 Kg-P/ha in the surface 30 cm. There were no significant differences between treatments.

The content of potassium was low throughout. There were no significant trends evident between the treatments studied. Between 54 and 74 ppm occurred in the surface 15 cm and 17-30 ppm in the 15-30 cm depth. This is equivalent to about 72-105 Kg-K/ha and would indicate that insufficient supplies of potassium to meet the needs of the plants were present in most of the treatments.

Sulfate sulfur showed no significant difference between treatments. All plots contained adequate amounts of sulfur to maintain plant growth. Equivalent of 59-195 Kg-S/ha was found in the surface 30 cm.

September Soil Samples

All experimental treatments except T_0 received fertilizer after sampling in June (see Table 1 for specific rates). Treatments T_1A, T_2A, T_3A, T_4A and T_5A received a second addition in August.

Percentage moisture present in the 0-15 cm depth was not significantly different between treatments. Although the surface 15 cm contained approximately the same amount of moisture as in June, the 15-30 cm depth contained less moisture in September. It was frequently difficult to take samples since the dry sand freely ran out of the sampling probe. Samples taken to 120 cm showed that minimum moisture contents of 3.1 to 4.8% were found between 30 cm and 60 cm. The moisture content increased below a depth of 60 cm.

Surface pH values were affected by the addition of fertilizers. The limed treatments still had significantly higher pH values than the equivalent unlimed treatment. However, treatments such as T_3A, which had received two increments of fertilizer, had the lowest surface pH values in the surface 15 cm varying from 6.0 to 6.6. Soil pH increased with depth and values between 7.1 and 7.5 were measured at 120 cm.

Large significant differences were found in electrical conductivity due to the addition of fertilizer salts. A maximum mean value of 1.63 mmhos/cm was recorded for surface samples from Treatment T_4A. This is not high enough to adversely affect the growth of most plant species. There was no evidence to suggest that fertilizer salts were accumulating below the rooting zone. However, electrical conductivities at 15-30 cm had increased slightly where the highest rates of fertilizer had been added.

As noted last year, some abnormally high salt concentrations were encountered below a depth of 30 cm in Treatment T_5A. This, together with high sulfate concentrations, suggested that a pocket of saline overburden existed in this region.

Mineral nitrogen was very low in treatments that had not been fertilized in August. The unfertilized treatment T_0 contained 2.1 ppm NH_4-N and 0.1 ppm NO_3-N.

Much of the ammonium nitrogen added in the August fertilizer application had been either immobilized or converted into the nitrate form by September. Only in Treatment T_4A, which contained an average of 41 ppm NO_3-N in the 15-30 cm depth, was there evidence for potentially large leaching losses of the mobile nitrate anion.

At this time, levels of available nitrogen ranged from 3 to 330 Kg-N/ha in the surface 30 cm. Nitrogen was considered to be severely deficient in Treatments T_0, T_0A, T_1 and T_5.

In contrast to the available nitrogen content, levels of phosphorus had not decreased since June even in Treatment T_0. Surface concentrations ranged from 17.0 to 65.7 ppm. No treatments were considered phosphorus deficient. Only in treatments that had been heavily fertilized during 1977 (e.g. T_3A, T_4A) had the applied phosphate moved significantly into the 15-30 cm depth. This is of concern if good spread of roots into the tailing sand is to be achieved.

The amount of available potassium varied widely between replicates of the same treatment and statistical analysis did not show any significant differences in the surface 15 cm. Average values were highest in Treatment T_4A which had received 144 Kg-K/ha in August. Only Treatments T_4 and T_4A were considered to contain adequate amounts of available potassium.

There was little available potassium below a depth of 15 cm even in the treatments that were liberally fertilized in 1977.

In the four treatments sampled to a depth of 120 cm only 16-23 ppm of available potassium was recorded between 30 cm and 120 cm.

Sulfate sulfur concentrations showed no significant treatment effects in the surface 0-15 cm. All treatments contained adequate sulfur for plant nutrition. No significant change could be noted between June and September.

3.4 Plant Analysis

Productivity

Vegetative growth occurring before June was noticeably poorer in comparison to the same time the previous year. This was most evident on the unfertilized plots (T_0) which showed little evidence of new shoot growth when the June cut was taken. New growth was particularly luxurious on plot T_3A which had last received fertilizer (144 Kg-N/ha) in August, 1975. In fact, the superior growth of Treatments T_3A and T_4A relative to Treatments T_3 and T_4 indicated that the fertilizer nutrients taken up into plant tissues in late 1975 and early 1976 were being actively released early in 1977.

Some winterkill of Creeping Red Fescue was noted but these bare patches became overgrown later in the summer.

Continued good regrowth occurred after June in the treatments that received fertilizers at that time (all except T_0).

Plant top yields to June varied from 0.027 to 0.126 Kg/m^2 (see Table 6) in comparison to 0.054 to 0.170 Kg/m^2 for the same period in 1976. Yields in September varied from 0.054 Kg/m^2 in Treatment T_0 to 0.343 Kg/m^2 for Treatment T_3 (see Table 6). Differences were generally only significant between extreme fertilizer treatments.

The yields of root material at different depths for Treatments T_0, T_2, T_4 and T_5 are presented in Table 7. Total yields were not significantly different between the treatments. About 85-88% of the root biomass occurred in the 0-15 cm depth, 9-12% in the 15-30 cm depth and 2-4% in the 30-60 cm layer. A slightly greater proportion of the

TABLE 6

Dry Weight Yield of Plant Tops in June and September, 1977, on a Vegetated Tailings Sand Dike at Fort McMurray

Treatment	Yield of Plant Tops (Kg/m^2)			
	June, 1977		September, 1977	
	Average	S.D.	Average	S.D.
T_0	0.027	0.010	0.054	0.016
T_0A	0.041	0.030	0.197	0.042
T_1	0.093	0.068	0.245	0.069
T_1A	0.114	0.011	0.272	0.037
T_2	0.091	0.024	0.259	0.064
T_2A	0.081	0.032	0.308	0.020
T_3	0.027	0.007	0.343	0.046
T_3A	0.126	0.061	0.275	0.066
T_4	0.049	0.013	0.271	0.021
T_4A	0.101	0.048	0.317	0.050
T_5	0.070	0.038	0.165	0.014
T_5A	0.086	0.041	0.267	0.060
Significance	*		***	
L.S.D.	0.063		0.078	

TABLE 7

Dry Weight Yield of Plant Roots on a Vegetated Tailings Sand Dike at Fort McMurray - September, 1977

Treatment	Yield of Roots (Kg/m^2)							
	0-15 cm		15-30 cm		30-60 cm			
	Average	S.D.	Average	S.D.	Average	S.D.	Total	Root/Shoot
T_0	1.05	0.26	0.11	0.01	0.046	0.014	1.206	22.3
T_2	1.19	0.12	0.14	0.05	0.036	0.020	1.366	5.3
T_4	1.10	0.15	0.16	0.03	0.042	0.019	1.302	4.8
T_5	1.32	0.37	0.14	0.03	0.040	0.011	1.500	9.1
Significance	N.S.		N.S.		N.S.		N.S.	
L.S.D.								

roots were found below 15 cm in comparison to similar measurements made in 1976. Root yields were within the same range as measured the previous year.

Tissue Analysis

No statistical differences were evident between the nitrogen, phosphorus, potassium, calcium and nitrate concentrations in plant materials from different treatments harvested in June, 1977 (Table 8). Potassium concentrations were higher than were found for the same time last year. Nitrate values were much lower and well below the critical concentration for livestock feed.

Highly significant differences between treatments were noted in the nitrogen, phosphorus, potassium and nitrate concentrations in plant tops harvested in September in response to fertilizers added during the summer (Table 9).

The nitrogen concentration in plant tissues from Treatments T_0 and T_5 was significantly lower than all other treatments. However, there were no significant differences between Treatments T_0A to T_4A although the amount of fertilizer nitrogen received over the summer varied between 90 Kg-N/ha to 360 Kg-N/ha.

A similar trend was found with potassium concentrations. Treatments T_0 and T_5 had significantly lower plant potassium concentrations than most other treatments.

TABLE 8

Analysis of Plant Tops from a Vegetated Tailings Sand Dike at Fort McMurray - June, 1977

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Calcium (%)	Nitrate (%)
T_0	1.60	0.29	2.30	0.15	0.71	0.06
T_0A	2.04	0.31	3.16	0.19	0.56	0.02
T_1	2.44	0.36	3.86	0.21	0.49	0.14
T_1A	2.39	0.39	4.16	0.15	0.41	0.07
T_2	2.15	0.32	3.61	0.14	0.49	0.02
T_2A	2.42	0.34	3.81	0.18	0.51	0.16
T_3	2.36	0.36	4.30	0.33	0.40	0.08
T_3A	1.80	0.31	3.63	0.29	0.47	0.07
T_4	1.68	0.30	3.44	0.29	0.46	0.05
T_4A	1.95	0.27	3.43	0.32	0.51	0.03
T_5	1.69	0.38	3.40	0.30	0.55	0.05
T_5A	1.79	0.33	3.24	0.28	0.49	0.04
Significance	N.S.	N.S.	N.S.	**	N.S.	N.S.
L.S.D.				0.12		

TABLE 9

Analysis of Plant Tops and Roots from a Vegetated Tailings Sand Dike at Fort McMurray - September, 1977

Treatment	Tops (%)						Roots (%)				
	N	P	K	S	Ca	NO_3	N	P	K	S	Ca
T_0	1.25	0.36	2.00	0.26	0.64	0.02	0.83	0.06	0.19	0.18	1.07
T_0A	2.46	0.41	3.34	0.22	0.70	0.02					
T_1	2.15	0.35	2.97	0.20	0.66	0.02					
T_1A	2.43	0.45	3.09	0.20	0.68	0.13					
T_2	2.65	0.45	3.12	0.24	0.72	0.17	1.24	0.10	0.16	0.21	1.82
T_2A	2.60	0.44	3.15	0.20	0.69	0.18					
T_3	2.48	0.27	2.96	0.24	0.62	0.13					
T_3A	2.79	0.30	2.62	0.23	0.61	0.29					
T_4	2.64	0.23	2.65	0.26	0.69	0.01	1.28	0.11	0.22	0.21	1.44
T_4A	2.81	0.29	2.82	0.20	0.79	0.10					
T_5	1.62	0.20	1.99	0.16	0.58	0.03	0.96	0.06	0.19	0.21	1.34
T_5A	2.51	0.24	2.61	0.23	0.58	0.07					
Significance	***	***	***	N.S.	N.S.	***	***	**	N.S.	N.S.	**
L.S.D.	0.42	0.10	0.83			0.12	0.11	0.04			0.39

Phosphorus uptake appeared to be more complex. Significant differences were observed but the treatments receiving the lower phosphorus amendment in June (e.g. T_0A, T_1, T_1A, T_2 and T_2A) had higher phosphorus concentrations than those receiving a higher rate (e.g. T_3, T_3A, T_4 and T_4A). Plant material from the unfertilized T_0 treatment contained as great or a higher concentration of phosphorus than the fertilized treatments.

Nitrate concentrations were statistically different between treatments but the results failed to show any consistent relationship with previous fertilizer additions. Potentially toxic concentrations of nitrate did not occur.

Analysis of root tissues from selected treatments indicated that increasing fertilizer rates caused a significant increase in root nitrogen, phosphorus and, to a lesser extent, calcium (Table 9).

A summary of the total amount of major nutrients in plant tissues in the various treatments is given in Table 10. In comparison to last year's study, generally similar nutrient uptake into plant top growth was recorded, taking into account differences in fertilizer programs in the two years. An exception was found in the unfertilized treatment, T_0, which showed much poorer uptake in 1977. In 1976, 22 Kg-N, 6 Kg-P, 36 Kg-K and 2.2 Kg-S/ha were taken up into new vegetative growth while in 1977 only 7 Kg-N, 1.9 Kg-P, 11 Kg-K and 1.4

TABLE 10

Total Amount of Nutrients in Plant Tissues - 1977

Treatment	Live Tops (Kg/ha)				Roots (Kg/ha)				Total Plant Biomass (Kg/ha)			
	N	P	K	S	N	P	K	S	N	P	K	S
T_0	7	1.9	11	1.4	100	7.2	23	22	107	9.1	34	23
T_0A	48	8.1	66	4.3								
T_1	53	8.6	73	4.9								
T_1A	66	12.2	84	5.4								
T_2	69	11.7	81	6.3	169	13.7	22	29	238	25.4	103	35
T_2A	80	13.6	97	6.2								
T_3	85	9.3	90	8.2								
T_3A	77	8.3	72	6.3								
T_4	72	6.2	72	7.0	167	14.3	29	28	239	20.5	101	35
T_4A	89	9.2	89	6.3								
T_5	27	3.3	33	2.6	144	9.0	29	32	171	12.3	62	35
T_5A	67	6.4	70	6.1								

Kg-S/ha were taken up.

The results from 1977 also indicated that the higher applications of fertilizer to Treatments T_3, T_3A, T_4 and T_4A gave only a small increase in nitrogen uptake, approximately the same potassium uptake and a lower overall phosphorus uptake than the other fertilized areas. Furthermore, the extra addition of fertilizer to Treatments T_1A, T_2A, T_3A and T_4A in August did not result in correspondingly larger nutrient uptakes by material harvested in September.

Large differences were observed in the total content of nitrogen and phosphorus tied up in plant roots. Of the treatments studied, those receiving the heavier fertilizer programs, T_2 and T_4, contained 169 and 167 Kg-N/ha respectively in comparison to the minimally fertilized T_5 (144 Kg-N/ha) and the unfertilized Treatment T_0 (100 Kg-N/ha). In terms of phosphorus, T_2 and T_4 contained 13.7 and 14.3 Kg-P/ha in root tissues while roots of T_5 and T_0 contained 9.0 and 7.2 Kg-P/ha respectively.

Table 11 shows a balance sheet for nitrogen in the soil and plants for Treatments T_0, T_2, T_4 and T_5.

The available soil nitrogen showed a decline from 39 Kg-N/ha to 4 Kg-N/ha between June and September for Treatment T_0. Only 7 Kg-N/ha were taken up into plant foliage. Even though some 100 Kg-N/ha occurs in the root tissue we may assume that no more than 7-10 Kg-N/ha were taken up into new

TABLE 11

An Approximate Balance Sheet for Nitrogen in Soil and Plants on a Vegetated Tailings Sand Dike at Fort McMurray - 1977

Treatment	Nitrogen Added (Kg/ha)				Available Soil Nitrogen (0-30 cm*) (Kg/ha)		Nitrogen in Plants (Kg/ha)	
	1971-74	1975	1976	1977	June 1977	September 1977	Tops	Roots
T_0	279	0	0	0	39	4	7	100
T_2	279	90	90	90	19	26	69	169
T_4	279	180	0	180	19	33	72	167
T_5	279	15	43	43	14	8	27	144

* Calculated using bulk density of 0.5 g/cc and 1.2 g/cc for the 0-15 cm and 15-30 cm depths.

root tissue.

Available soil nitrogen also decreased during the summer in Treatment T_5 from 14 Kg-N/ha in June to 8 Kg-N/ha in September. However, 34 Kg-N/ha were added as fertilizer during June and 27 Kg-N/ha was taken up by above-ground growth.

Increases in available nitrogen occurred in Treatments T_2 and T_4. Differences in available nitrogen and uptake into tops and roots were slight despite the fact that T_2 received 90 Kg-N/ha in June while T_4 received double that amount.

3.5 *Summary*

1. In early June, 1977, levels of available nitrogen were low to moderate, phosphorus was moderate, potassium very low, and sulfur adequate over the vegetated study area. No large differences between treatments could be noted.

2. Good early plant growth was related to the extent of previous fertilizer additions in both 1975 and 1976. Very poor growth occurred where no fertilizer had been added since 1974.

3. In September, 1977, levels of mineral nitrogen were very low where no fertilizer was added, moderate to low where a June application had been made and high where fertilizer had been added in both June and August. The ammonium nitrogen added in August seemed to have been largely nitrified by mid-September to the nitrate anion.

   Plant available phosphorus continued to be present in moderate amounts even where no fertilizer had been added.

   Potassium was very low to low except where fertilizer was added in August. The poor potassium status continues to be a long term problem in maintaining a balanced nutrient supply.

4. There is no evidence to suggest that significant amounts of added nutrients are being leached below the root zone or that salts accumulate within the soil profile.

5. Unlimed areas on this part of the vegetated tailings dike have a surface pH of 6.0 to 6.4. A significant increase in soil acidity has not been noted during the 1975-1977 study period; neither do plants seem to be suffering from the moderately acidic conditions.

6. Plots that have received the highest amounts of fertilizer since 1975 now consist of almost pure stands of Brome Grass. Unfertilized or minimally fertilized areas (T_0, T_5) still are largely covered with Creeping Red Fescue. The remaining plots showed an increase in Brome Grass cover over the previous year. Legumes are largely absent from the sward.

7. The highest above-ground biomass production occurs in plots receiving equivalent to 90 Kg-N/ha annually and above. There was no significant additional response to fertilizer added in excess of the 90 Kg-N/ha addition.

8. A similar trend was noted in nutrient uptake into tops and roots. Where significant differences were noted, they were only significant between unfertilized (T_0) and minimally fertilized treatments (T_5) and the remaining fertilizer treatments. Nitrogen, phosphorus and potassium were all taken up in significantly greater amounts in fertilized treatments.

9. No erosion was noted in 1977.

10. Powdery Mildew of Clover and Brome Grass was noted but did not seem related to any particular treatments.

4.0 CONTINUED STUDY CONCERNING THE USE OF DIFFERENT SURFACE AND FERTILIZER AMENDMENTS IN THE REVEGETATION OF A TAILINGS SAND DIKE - EXPERIMENT II

4.1 Introduction

The experiment was set up in July, 1976, to study the effectiveness of different surface amendments and fertilizer programs in establishing plant growth and thereby minimizing erosion of the tailings sand slope.

A seed mix was used that included both grass and legume species so that the performance of the different species could be assessed under the various soil and nutrient conditions employed. Legumes were of particular interest for their possible benefit in fixing atmospheric nitrogen into the system and thereby reducing the need for applications of fertilizer.

The long term objective of the experiment concerned the management of the revegetated area, particularly in respect to determining when nutrient amendments could be reduced or stopped entirely and when the area could be considered vegetatively self-sustaining.

Thus the experiment had a short term objective of erosion control and a long term management aspect.

Complete details of the experimental design and methods of site preparation are included in the 1976 report[2].

Only a brief resume is given here.

Three main treatments for fertilizer application were studied:

A: Fertilizer added as ammonium sulfate, ammonium nitrate, ammonium phosphate and potassium chloride to give equivalent to 80 Kg-N, 35 Kg-P, 75 Kg-K and 20 Kg-S per hectare, applied in June of each year. This approximates to the initial fertilizer application currently used by G.C.O.S. in their revegetation work.

B: The same type of fertilizers added in June to supply 150 Kg-N, 40 Kg-P, 150 Kg-K and 20 Kg-S per hectare. In addition, 5 Tonnes/ha of lime was added in 1976.

C: The same as was added in B but an additional application in August.

In all, eight sub-treatments were tested to study different soil amendments, stabilizers and binders, slope contouring and fall seeding compared to spring seeding:

Sub-treatment 1 - Peat tilled to a depth of 15 cm.

" 2 - Peat tilled to a depth of 15 cm with contour trenches across the plot.

" 3 - Peat tilled to a depth of 15 cm with 'Aquatain' soil stabilizer added to the soil surface.

Sub-treatment 4 - Peat tilled to a depth of 15 cm with 'Bitumuls' soil binder added to the soil surface.

" 5 - Overburden added at a rate of 750 Tonnes/ha (about 5 cm) onto the surface of applied peat.

" 6 - Overburden added at a rate of 1500 Tonnes/ha (about 10 cm) tilled into the surface 15 cm of peat and tailings sand.

" 7 - Overburden added at a rate of 750 Tonnes/ha and tilled into the surface 15 cm of peat and tailings sand.

" 8 - Peat tilled into a depth of 15 cm (i.e. as Treatment 1) but not seeded until October, 1976.

The standard plot size was 5 m x 4 m and each treatment was replicated three times as shown in Figure 2.

Water runoff collectors were installed on Sub-treatments 1-7 of Treatment C and the water runoff collected monthly.

Double pail lysimeters were set up in Sub-treatments 1, 3, 4, 5, 6 and 7 of all fertilizer treatments. Each received identical treatment to the plot in which it was located. However, seed and fertilizer were weighed out separately to ensure

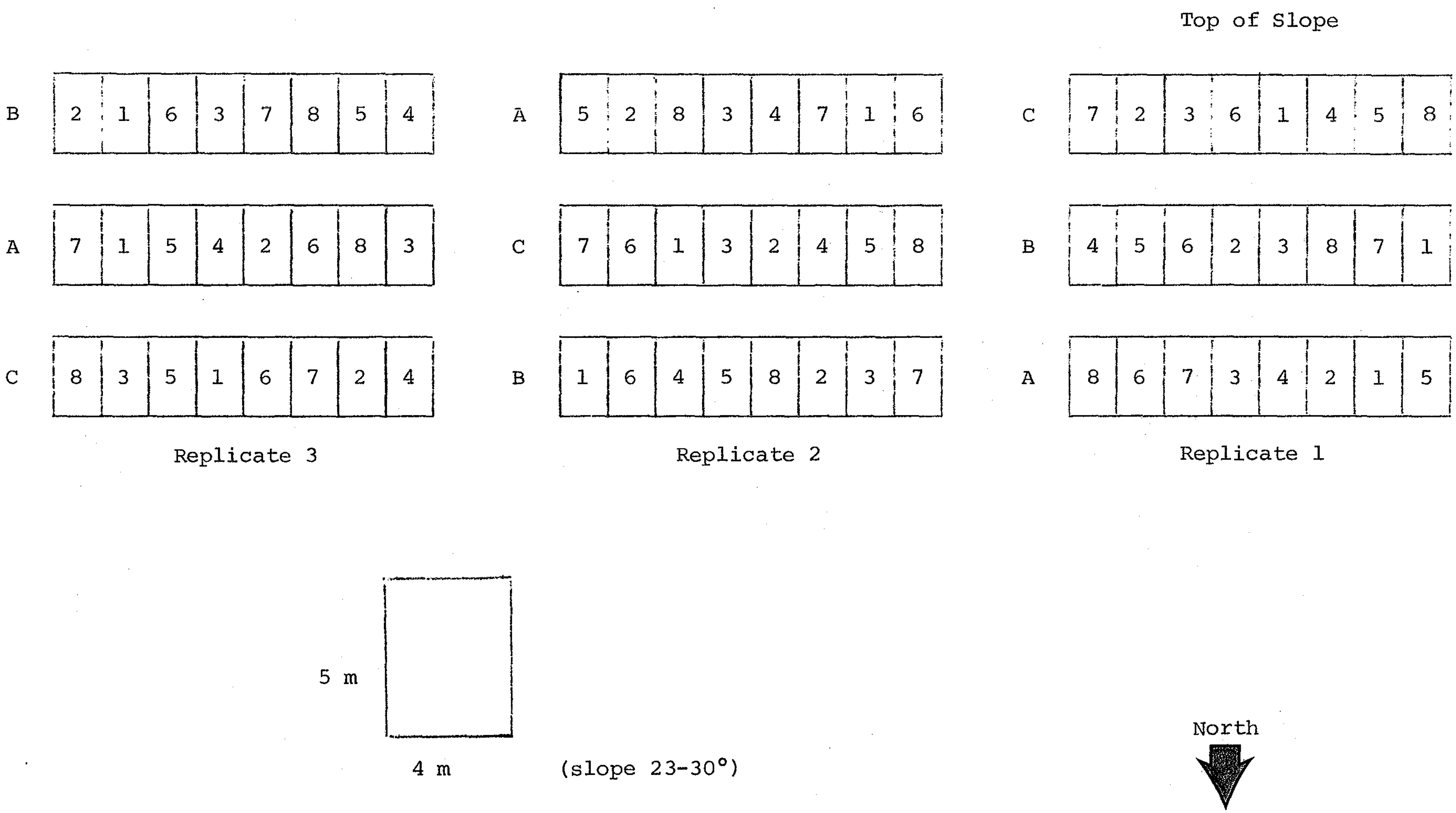


FIGURE 2. Field Plan of Experiment on an Unvegetated Area on a Tailings Sand Dike at the G.C.O.S. Plant Site at Fort McMurray, Alberta (Experiment II).

accuracy. Leachate was collected monthly and one set of soil samples (0-15 cm, 15-30 cm) were taken each year in September. The entire set of lysimeters will be harvested next year after three years growth. Plant and soil samples will be taken to assess root distribution, nodulation, plant nutrient uptake and soil nutrient status. The three years of data will be used to produce a balance sheet for N, P, K and S to describe nutrient cycling and losses during this period.

A progress report of this study is given on pages 89-94.

The seed mix* used had the following composition:

	Kg/ha	Seeds/ha x 10^3	Seeds/g
Altai Wild Rye	1.75	300	171
Streambank Wheatgrass	7.50	2100	280
Smooth Brome	8.00	2000	250
Hard Fescue	1.50	2000	1330
Pubescent Wheatgrass	7.00	1700	243
Slender Wheatgrass	6.00	1500	250
Red Top	0.25	1500	6000
Canada Blue Grass	0.50	2500	5000
Kentucky Blue Grass	0.75	2500	3333
Lupine	4.00	150	38
Cicer Milk Vetch	3.00	750	250
Sainfoin	5.00	150	30
Alfalfa Rhizoma	3.00	1100	367
Pendek Oats	40.00	1100	28

* Please note that Western Wheatgrass was not applied in this seed mix as stated on Page 46 of Monograph 1977-4.

Two cuts of plant material were taken in 1977 to study productivity and nutrient uptake (June and September). Two sets of soil samples were also taken. The June samples were taken to a depth of 30 cm while selected treatments were sampled to 120 cm in September. Studies on root distribution were limited to Treatments 1A, 5A, 6A, 1C, 5C and 6C. Selected treatments were also sampled at monthly intervals between May and October to study soil nitrogen mineralization -nitrification-immobilization characteristics. These results are discussed separately on pages 95-100.

4.1 Soil Analysis

Tables 12, 13 and 14 show the results of analysis of samples taken in June, 1977, prior to the initial application of fertilizer for that year.

At this time, amounts of available nitrogen, phosphorus and potassium were low in all treatments. Although those that had received fertilizer in August, 1976, (Treatment C) did contain significantly more phosphate, potassium and nitrate than the rest.

The surface pH of the unlimed plots (Treatment A) varied between 6.2 and 6.9 while those plots which had received lime in 1976 as well as more fertilizer (Treatments B and C) had values that varied between 6.4 and 7.0.

The soluble salt content was generally low with the highest values recorded at about 1.0 to 1.6 mmhos/cm all occurring in treatments where the moderately saline mine overburden had been incorporated.

Analysis of soil samples taken in September, 1977,

TABLE 12

Analysis of Soil Samples from a Seeded and Fertilized Tailings Sand Dike, June, 1977 - Fertilizer Rate A

Treatment and Depth	(cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	Mineral Nitrogen NH_4-N (ppm)	Mineral Nitrogen NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)
1A	0-15	9.5	6.5	0.53	5.9	4.4	0.3	19	29
	15-30	3.0	6.8	0.44	3.6	3.8	0.3	11	15
2A	0-15	16.8	6.3	0.59	3.1	1.6	1.4	23	44
	15-30	4.8	6.9	0.53	6.2	7.8	0.5	12	23
3A	0-15	20.8	6.2	0.62	4.5	2.8	0.3	29	94
	15-30	6.6	6.7	0.63	2.3	2.6	0.3	13	36
4A	0-15	28.5	6.4	0.67	7.3	4.9	0.0	34	95
	15-30	7.1	6.7	0.72	3.8	3.6	0.0	13	52
5A	0-15	9.5	6.7	1.15	3.1	1.3	1.0	46	130
	15-30	8.6	6.5	0.91	5.4	3.0	1.0	22	82
6A	0-15	9.7	6.9	1.27	4.7	2.8	1.5	39	94
	15-30	5.5	6.8	0.73	2.7	8.7	0.8	15	37
7A	0-15	12.8	6.8	0.95	5.7	7.4	1.2	34	112
	15-30	4.9	6.8	0.69	3.0	7.7	1.0	14	41
8A	0-15	19.4	6.3	0.65	3.6	7.8	1.3	26	52
	15-30	6.4	7.0	0.58	5.3	5.3	1.0	14	24
Significance		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.									

Statistical treatments applied to 0-15 cm depth only.

TABLE 13

Analysis of Soil Samples from a Seeded and Fertilized Tailings Sand Dike, June, 1977 - Fertilizer Rate B

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
1B	0-15	16.5	6.6	0.57	6.1	2.3	0.0	36	43
	15-30	2.7	6.8	0.48	2.1	3.4	0.3	15	19
2B	0-15	14.3	6.8	0.67	6.2	4.6	1.7	26	22
	15-30	8.5	7.0	0.64	4.5	2.4	1.0	16	35
3B	0-15	9.8	7.0	0.82	3.6	0.7	0.5	26	16
	15-30	4.2	7.3	0.62	6.0	5.4	0.3	14	21
4B	0-15	17.7	6.8	0.82	5.5	2.7	1.2	32	64
	15-30	3.6	7.1	0.85	4.1	0.6	1.0	16	32
5B	0-15	13.4	6.7	1.05	8.1	5.6	1.7	65	116
	15-30	7.8	6.7	0.92	4.1	0.8	0.9	24	72
6B	0-15	14.8	6.7	1.32	4.9	0.6	0.7	61	120
	15-30	10.4	6.7	0.87	5.1	3.3	0.3	17	46
7B	0-15	7.9	7.1	0.89	4.0	1.4	2.6	39	84
	15-30	2.5	7.2	0.60	2.2	0.9	1.2	15	21
8B	0-15	16.4	6.5	0.82	6.5	20.4	3.3	42	68
	15-30	5.4	7.2	0.61	2.8	3.1	2.0	18	14
Significance		N.S.	N.S.	N.S.	N.S.	***	N.S.	N.S.	N.S.
L.S.D.						9.6			

Statistical treatments applied to 0-15 cm depth only.

TABLE 14

Analysis of Soil Samples from a Seeded and Fertilized Tailings Sand Dike, June, 1977 - Fertilizer Rate C

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
1C	0-15	11.1	6.5	1.04	7.3	12.9	6.4	74	47
	15-30	3.2	6.9	0.77	7.1	10.0	2.4	29	34
2C	0-15	9.5	6.4	0.86	4.9	10.1	6.4	41	54
	15-30	2.2	6.8	0.81	3.3	2.2	1.1	16	35
3C	0-15	9.8	6.5	0.93	7.5	6.3	11.9	55	36
	15-30	1.7	6.8	0.66	2.5	2.5	0.7	17	25
4C	0-15	8.1	6.8	0.89	3.6	1.7	14.3	69	72
	15-30	3.2	6.9	0.89	4.8	3.6	2.6	25	72
5C	0-15	7.6	6.8	1.58	4.3	17.1	12.0	73	132
	15-30	3.7	6.7	0.81	3.0	3.8	1.3	19	43
6C	0-15	7.1	6.9	1.71	7.4	19.9	16.7	92	151
	15-30	4.4	6.9	1.01	4.0	4.4	2.0	31	57
7C	0-15	15.7	6.5	1.26	5.7	24.2	6.7	83	86
	15-30	2.5	6.8	0.90	6.8	8.6	2.2	20	38
8C	0-15	12.0	6.6	0.76	3.2	6.2	3.3	30	33
	15-30	5.5	7.0	0.55	1.4	2.1	1.2	16	17
Significance		N.S.	N.S.	N.S.	N.S.	N.S.	***	N.S.	N.S.
L.S.D.							6.3		

Statistical treatments applied to 0-15 cm depth only.

(Tables 15, 16 and 17) reflected the different fertilizer treatments employed. Levels of available P, K and both ammonium and nitrate nitrogen were significantly higher in the high rate fertilizer treatment. There were no significant overall differences between the lower fertilizer rates, A and B. In these treatments, much of the fertilizer nitrogen added in June had been depleted although moderate amounts of plant available P and K still existed.

The only significant difference observed at the sub-treatment level was in electrical conductivity. Treatments 5, 6 and 7, which involved addition of mine overburden, had significantly higher salt concentrations than the other treatments. Salt concentrations were greatest where the high fertilizer rate was linked with overburden addition (5C, 6C and 7C). Here conductivity values varied between 3.02 and 3.44 mmhos/cm in the surface 0-15 cm, values which may affect the yield and growth of salt sensitive plant species.

The samples that were taken to a depth of 120 cm did not indicate that any leaching of fertilizer nutrients was taking place. In some treatments, that had received fertilizers in August (Treatment C), there was some movement of nitrate, phosphate and to a less frequent extent potassium into the 15-30 cm depth. However, little migration seemed to occur below this depth. This is in general agreement with the results of the lysimeter study (see pages 89-94).

TABLE 15

Analysis of Soil Samples from a Seeded and Fertilized Tailings Sand Dike, September, 1977 - Fertilizer Rate A

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
1A	0-15	12.5	6.4	0.64	2.2	0.2	15.0	42	37
	15-30	2.2	6.8	0.50	0.8	0.2	7.8	20	22
	30-60	1.9	7.3	0.42	0.8	0.0	4.2	15	9
	60-90	3.2	7.4	0.39	0.7	0.5	6.2	13	9
	90-120	3.8	7.3	0.37	0.5	0.0	6.2	11	18
2A	0-15	18.5	6.2	0.79	2.1	0.7	15.5	42	91
	15-30	4.3	6.5	0.56	1.2	0.2	8.2	15	27
3A	0-15	22.0	6.0	0.87	5.5	1.2	13.0	131	123
	15-30	5.3	6.7	0.83	1.4	0.0	9.3	23	57
4A	0-15	24.6	6.2	0.88	3.6	0.4	14.8	114	149
	15-30	5.1	6.6	0.78	2.0	0.1	9.5	23	52
5A	0-15	19.6	6.5	1.36	3.3	0.8	14.7	164	128
	15-30	6.3	6.5	0.96	1.8	0.2	9.2	24	115
	30-60	1.9	7.1	0.52	1.7	0.4	8.8	15	16
	60-90	3.4	7.0	0.42	1.4	0.3	8.5	12	9
	90-120	4.6	7.2	0.44	1.0	0.3	8.2	11	15
6A	0-15	12.4	6.9	1.36	3.0	0.5	12.0	84	105
	15-30	5.9	6.8	0.97	1.9	0.3	9.5	26	61
	30-60	1.8	7.5	0.51	1.6	0.1	6.5	10	16
	60-90	3.1	7.3	0.56	1.3	0.0	6.8	11	20
	90-120	4.1	7.0	0.74	1.2	0.1	7.0	14	31

(....continued)

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
7A	0-15	13.5	6.7	1.37	2.6	0.4	11.3	96	119
	15-30	3.3	6.7	0.85	1.6	0.4	8.2	20	60
	30-60	2.5	7.2	0.48	1.0	0.2	8.3	12	14
	60-90	3.7	7.3	0.45	1.4	0.3	7.5	12	14
	90-120	4.1	7.1	0.55	1.8	0.3	9.0	11	20
8A	0-15	16.5	6.1	0.71	3.0	2.8	10.3	42	95
	15-30	4.7	6.4	0.69	2.1	1.8	8.0	19	51
Significance		N.S.	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.				0.50					

Statistical treatments applied to 0-15 cm depth only.

TABLE 16

Analysis of Soil Samples from a Seeded and Fertilized Tailings Sand Dike, September, 1977 - Fertilizer Rate B

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
1B	0-15	23.4	6.7	0.97	2.7	8.2	13.7	190	47
	15-30	4.3	6.7	0.77	1.6	2.2	7.5	24	36
	30-60	1.7	7.0	0.54	1.6	0.7	6.5	12	19
	60-90	2.9	7.0	0.44	1.3	0.2	6.5	10	14
	90-120	3.7	7.0	0.40	1.2	0.0	6.5	9	12
2B	0-15	18.2	6.9	0.84	2.9	4.7	13.3	41	48
	15-30	4.7	7.0	0.65	1.4	2.0	8.7	19	33
3B	0-15	18.0	6.8	1.21	3.6	4.6	12.3	157	101
	15-30	3.2	7.0	0.91	1.4	3.7	7.0	22	44
4B	0-15	22.7	6.6	1.26	3.9	6.4	9.8	153	103
	15-30	8.3	6.5	0.92	1.7	2.2	7.3	24	74
5B	0-15	15.2	6.5	1.98	4.7	11.1	12.8	210	165
	15-30	7.3	6.5	1.40	1.8	6.6	7.8	33	124
	30-60	1.7	6.8	0.75	1.2	0.1	6.8	12	39
	60-90	2.8	7.4	0.96	0.9	0.1	7.0	10	56
	90-120	3.7	7.4	0.67	0.8	0.2	7.2	10	34
6B	0-15	22.8	6.7	1.61	5.2	10.3	11.8	198	204
	15-30	4.8	6.6	1.24	2.3	2.6	8.3	31	93
	30-60	2.2	7.3	0.57	1.2	0.3	7.8	12	18
	60-90	3.5	7.3	0.51	1.1	0.1	7.3	11	15
	90-120	3.8	7.4	0.48	1.1	0.2	7.3	11	11

(....continued)

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
7B	0-15	11.9	7.0	1.33	3.6	5.4	12.0	185	99
	15-30	3.1	6.9	0.94	1.6	1.5	7.3	22	50
	30-60	1.9	7.3	0.50	0.9	0.3	7.7	13	13
	60-90	2.9	7.6	0.43	1.1	0.2	7.0	11	16
	90-120	3.7	7.3	0.44	1.3	0.0	8.3	10	11
8B	0-15	19.5	6.6	0.98	3.2	24.8	12.3	149	38
	15-30	6.1	6.8	0.69	1.5	8.4	9.0	30	24
Significance		N.S.	N.S.	*	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.				0.65					

Statistical treatments applied to 0-15 cm depth only.

TABLE 17

Analysis of Soil Samples from a Seeded and Fertilized Tailings Sand Dike, September, 1977 - Fertilizer Rate C

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
1C	0-15	28.3	6.2	2.14	8.3	140.1	21.3	413	39
	15-30	5.8	6.5	1.21	3.4	22.4	10.3	37	51
	30-60	3.0	7.1	0.56	1.7	2.1	8.5	18	15
	60-90	4.2	7.3	0.52	0.9	1.3	7.3	15	13
	90-120	4.7	7.3	0.44	1.0	0.3	6.8	12	11
2C	0-15	25.6	6.1	1.84	8.0	99.7	23.9	394	59
	15-30	6.2	6.3	1.42	2.7	22.4	13.3	32	79
3C	0-15	22.5	6.3	2.03	13.5	96.4	34.2	431	55
	15-30	4.4	6.4	1.21	2.6	18.2	11.0	40	33
4C	0-15	19.9	6.2	2.40	5.3	92.9	23.3	412	83
	15-30	9.5	6.5	1.77	3.6	36.3	10.0	71	79
5C	0-15	13.3	6.6	3.44	6.6	100.5	21.8	464	164
	15-30	4.1	6.7	1.67	3.2	29.3	10.7	39	49
	30-60	2.1	7.2	0.72	1.3	7.7	7.7	20	18
	60-90	3.2	7.2	0.64	1.3	2.9	7.8	17	17
	90-120	3.6	7.2	0.46	0.9	2.1	7.5	14	12
6C	0-15	20.9	6.7	3.30	11.1	105.7	17.8	508	192
	15-30	7.7	6.5	2.53	6.0	48.5	10.0	136	173
	30-60	3.1	7.3	1.18	0.6	3.2	8.3	20	26
	60-90	3.6	7.3	0.87	1.0	1.1	7.3	14	19
	90-120	3.9	7.4	0.70	0.8	0.7	7.5	14	17

(... continued)

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
7C	0-15	21.9	6.5	3.02	8.8	143.1	23.5	593	139
	15-30	6.2	6.5	2.01	4.8	38.2	11.8	114	82
	30-60	2.0	6.8	1.32	1.3	3.1	8.2	16	34
	60-90	3.1	7.0	1.12	0.9	1.2	7.7	12	33
	90-120	3.7	6.9	1.36	1.3	1.7	7.8	15	42
8C	0-15	10.8	6.6	1.39	2.9	43.5	17.3	218	36
	15-30	3.3	6.8	1.21	1.5	14.8	8.7	28	25
Significance		N.S.	N.S.	***	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.				0.88					

Statistical treatments applied to 0-15 cm depth only.

4.3 Observations

The experimental area was visited in early May.

The oats had not reseeded from the previous year. Grasses and legumes were growing actively through the remains of the oat straw which seemed to provide an excellent moisture conserving mulch for the smaller plants.

Considerably superior growth occurred on Treatment C, which had received an addition of fertilizer during the previous August. Soil samples taken at this time indicated that from between 50 and 60 Kg/ha of plant available nitrogen was present. Growth on Treatments A and B was healthy at this time but deficiencies of nitrogen and potassium began to appear at the beginning of June.

In May, the plants on the fall seeded plots were between 3 and 6 cm in height. The distribution of seed was poor, presumably caused by washing off during snow melt, and the plots had a patchy appearance.

The quality of growth on all plots improved after the addition of fertilizer in June. However, by July, Treatment A was again showing mild symptoms of nitrogen and potassium deficiency on some of the grass foliage. By August, similar mild symptoms were evident on some grasses on Treatment B.

In addition to the quality of growth, difference in species composition between the three fertilizer treatments was very noticeable. Treatment A contained the greatest diversity and appeared to have most of the original species well represented. However, very few Lupine plants had survived the winter. Treatment B supported fewer legumes and a higher proportion of Brome Grass. Treatment C was almost entirely composed of the larger grasses (Brome and the Wheatgrasses) and contained very few legume plants.

A semiquantitative assessment was made in September (see Table 18). Neither Kentucky Blue Grass nor Canada Blue Grass and Streambank Wheatgrass nor Slender Wheatgrass were distinguished from each other in the assessment. Few differences were observed between Treatments 1, 5, 6 and 7 in species composition. Hard Fescue seemed to tolerate the peat amendment more readily than overburden possibly due to the lower soluble salt content of the peat.

Smooth Brome provided about 34% of the cover at the lower fertilizer rate, 47% at rate B and an average of 62% at the highest fertilization rate. The three wheatgrass species (Slender, Streambank and Pubescent Wheatgrass) were dominant members of the mix at the lower rates of fertilizer addition and showed a slight reduction at the highest rate.

Of the legume species tested, Cicer Milk Vetch and Alfalfa Rhizoma were prominent where low fertilization was employed. They each supplied about 1% cover at the medium fertilizer rate (B) but were seldom present at the high rate (C).

TABLE 18

Percentage Cover Estimates for Plant Species in Seed Mix Used to Revegetate a Tailings Sand Dike

Plant Species	Fertilizer Treatment		
	A	B	C
	(% Mean)	(% Mean)	(% Mean)
Smooth Brome	34	47	62
Hard Fescue	6	4	1
Kentucky and Canada Blue Grass	8	9	4
Streambank and Slender Wheatgrass	21	18	14
Pubescent Wheatgrass	22	20	17
Red Top	<1	<1	<1
Altai Wild Rye	<1	<1	<1
Cicer Milk Vetch	6	1	<1
Alfalfa Rhizoma	3	1	0
Sainfoin	<1	<1	0
Lupine*			
Pendek Oats*			

Values are averages of three replicates from Treatments 1, 5, 6 and 7.

* always <0.1% cover (Treatment 1)

The growth of Lupine had been good the first year (taking into account the low seed count). However, few plants could be detected on any plots during 1977.

Sainfoin was found in Treatments A and B but seldom made a significant contribution to the total cover.

The smaller grasses, especially Hard Fescue and Canada and Kentucky Blue Grass, were prominent in the sward at the two lower fertilizer rates. At the high rate they seemed unable to compete effectively with the larger Smooth Brome Grass and Wheatgrasses.

There were few obvious differences between the various sub-treatments examined. The small number of plots that were poorly covered in 1976 all showed good regrowth in 1977. Treatment 1 (peat tilled into 15 cm), Treatment 4 (Bitumuls conditioner) and Treatment 7 (light rate of overburden tilled into peat and tailings) seemed to provide the best surface cover. Treatment 5 (overburden on surface) still possessed a very tough surface when dry and, although plant growth was as good as elsewhere, plant cover at ground level was often inferior to the other treatments.

Some disease was noted on isolated plants. Disease did not appear to be related to any particular fertilization program or surface amendment. A small proportion of Brome Grass and Wheatgrass plants were affected by Powdery Mildew (*Erysiphe graminis*) on the leaves. Wheatgrasses were occasionally affected by head smut (*Ustilago bullata*). The diseased heads were brown and black in color. Both diseases were not widespread enough to cause concern in 1977, although a careful check on diseases should be made in 1978.

4.4 Plant Productivity and Nutrient Uptake

In the first year of plant growth, the oat nurse crop made up about 85-93% of the total above ground plant biomass. Total yield of plant tops in September, 1976, varied from 0.147 to 0.393 Kg/m^2.

No significant differences in yield between sub-treatments within the same fertilizer treatment were noted for plants harvested in June, 1977 (Table 19). However, increases in the extent of fertilizer applied in 1976 did result in significant differences when overall results within Treatments A, B and C were compared. Treatment A varied between 0.096 and 0.183 Kg/m^2; Treatment B, 0.133 to 0.227 Kg/m^2 and Treatment C, 0.276 to 0.351 Kg/m^2. A similar pattern was observed with the September cut. Treatment A produced a mean yield of 0.273 Kg/m^2, Treatment B, 0.341 Kg/m^2 and Treatment C, 0.428 Kg/m^2.

Yield differences between the three different fertilizer levels with fall seeding were not statistically significant. This shows a similarity to the first year's plant growth which also indicated that little response can

TABLE 19

Yield of Plant Material from a Seeded and Fertilized Tailings Sand Dike 1977

Treatment	Yield (Kg/m^2)	
	June 1977	September 1977
1A	0.107	0.268
2A	0.128	0.282
3A	0.112	0.268
4A	0.139	0.282
5A	0.183	0.283
6A	0.096	0.265
7A	0.102	0.259
8A		0.204
Significance	N.S.	N.S.
L.S.D.		
1B	0.157	0.303
2B	0.133	0.267
3B	0.135	0.326
4B	0.200	0.378
5B	0.211	0.415
6B	0.227	0.336
7B	0.197	0.362
8B		0.264
Significance	N.S.	***
L.S.D.		0.065
1C	0.289	0.393
2C	0.312	0.438
3C	0.276	0.433
4C	0.333	0.449
5C	0.277	0.435
6C	0.351	0.423
7C	0.336	0.426
8C		0.235
Significance	N.S.	N.S.
L.S.D.		

Statistical analysis of September plant material does not include Treatment 8.

be expected above a fertilizer rate similar to rate A.

Table 20 shows the nutrient concentration in plant tops harvested in June, 1977. Differences in nutrient concentration were generally not significant at the sub-treatment level. Highly significant differences were however detected between main fertilizer treatments in total nitrogen, phosphorus, potassium and nitrate concentrations. Total nitrogen, phosphorus and nitrate were all significantly higher in treatments receiving fertilizer rate C. All fertilizer levels were significantly different from each other in potassium concentration in plant vegetative tissues.

The analysis of samples taken in September provided some comparable results (Table 21). Overall total nitrogen concentrations in plants from Treatments B and C were not significantly different but were greater than recorded for Treatment A. A similar trend was observed in sulfur concentrations. Total phosphorus concentrations in plants from Treatment C were significantly higher than for the two lower rates of fertilizer addition. This relationship was also found for nitrate concentrations. Nitrate values for Treatment C plant tops varied between 0.10 and 0.46%. Nitrate concentrations of 0.5% are considered undesirable for animal feed and 1.5% is considered toxic. Calcium concentrations were marginally higher in Treatment B than in either Treatment A or C.

Roots from Treatments 1A, 5A, 6A, 1C, 5C and 6C were

TABLE 20

Analysis of Plant Material from a Seeded and Fertilized Tailings Sand Dike - June, 1977

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Calcium (%)	Nitrate (%)
1A	2.13	0.12	2.16	0.18	0.44	0.00
2A	1.62	0.12	2.24	0.27	0.40	0.05
3A	1.02	0.13	2.20	0.06	0.42	0.02
4A	1.19	0.11	1.99	0.07	0.41	0.01
5A	1.18	0.12	2.09	0.18	0.58	0.04
6A	1.06	0.12	2.08	0.08	0.47	0.03
7A	1.08	0.14	2.05	0.11	0.52	0.05
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.						
1B	1.08	0.16	2.21	0.12	0.42	0.03
2B	1.70	0.18	2.77	0.16	0.48	0.04
3B	1.32	0.12	2.26	0.22	0.40	0.03
4B	1.12	0.12	2.35	0.14	0.37	0.03
5B	1.36	0.12	2.27	0.13	0.39	0.07
6B	1.12	0.12	2.90	0.08	0.44	0.03
7B	1.13	0.11	2.54	0.10	0.44	0.02
Significance	*	N.S.	N.S.	***	N.S.	N.S.
L.S.D.	0.37			0.06		
1C	1.73	0.19	3.84	0.16	0.56	0.09
2C	2.23	0.20	3.81	0.19	0.60	0.33
3C	1.80	0.22	3.71	0.14	0.52	0.12
4C	1.72	0.18	3.07	0.08	0.36	0.04
5C	2.11	0.18	3.61	0.15	0.44	0.11
6C	1.76	0.16	3.88	0.14	0.43	0.15
7C	1.72	0.18	3.86	0.12	0.41	0.12
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.						

TABLE 21

Analysis of Plant Material from a Seeded and Fertilized Tailings Sand Dike - September, 1977

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Calcium (%)	Nitrate (%)
1A	1.92	0.18	2.26	0.24	0.64	0.03
2A	1.53	0.14	2.07	0.22	0.63	0.03
3A	1.59	0.14	1.97	0.20	0.53	0.04
4A	2.16	0.17	2.51	0.20	0.57	0.02
5A	1.59	0.12	2.08	0.19	0.63	0.02
6A	2.08	0.16	2.50	0.24	0.59	0.02
7A	1.77	0.14	2.06	0.19	0.58	0.02
8A	2.21	0.15	2.06	0.26	0.77	0.03
Significance	*	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.	0.43					
1B	2.40	0.17	2.55	0.26	0.64	0.04
2B	2.59	0.21	2.92	0.28	0.71	0.11
3B	2.25	0.16	2.27	0.27	0.74	0.09
4B	1.87	0.13	2.23	0.21	0.69	0.05
5B	2.50	0.19	3.03	0.21	0.58	0.06
6B	1.89	0.11	1.88	0.23	0.58	0.05
7B	2.32	0.16	2.85	0.24	0.65	0.16
8B	2.67	0.15	3.10	0.26	0.91	0.13
Significance	*	*	N.S.	N.S.	*	N.S.
L.S.D.	0.46	0.17			0.10	
1C	2.27	0.22	2.17	0.27	0.60	0.11
2C	2.33	0.20	2.45	0.25	0.58	0.43
3C	2.34	0.25	2.92	0.24	0.57	0.37
4C	2.37	0.23	2.52	0.23	0.63	0.37
5C	2.46	0.22	2.79	0.22	0.65	0.32
6C	2.49	0.20	2.16	0.25	0.56	0.27
7C	2.67	0.25	2.41	0.27	0.58	0.46
8C	3.19	0.34	2.77	0.25	0.78	0.31
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.						

Statistical analyses do not include Treatment 8.

recovered to determine yield and nutrient uptake. The results are presented in Tables 22 and 23. We have noted that there was no regrowth of oats in 1977. By analogy to the species distribution in 1976, we may assume that root biomass in that year was composed of about 85-93% material derived from oats. A small part of the root tissues recovered in 1977 are likely to be partially decomposed oat roots from the previous year.

The yield of roots in 1977 was within the range found in 1976. In 1976, the total root biomass to 30 cm varied between 0.157 to 0.281 Kg/m^2 in the treatments studied. In 1977, it amounted to between 0.181 to 0.281 Kg/m^2 to a depth of 60 cm. No significant differences were found between treatments at the different depths. Some increased root penetration was noted since the proportion of roots in the surface 15 cm varied between 83.2% and 92.5% in 1977 compared to 87.3% to 94.9% in 1976.

Analysis of the roots showed that significantly higher nitrogen and phosphorus contents were found in tissues from the higher fertilizer treatment (C) (Table 23). Potassium, sulfur and calcium were not significantly different.

A summary of total nutrient uptake on a Kg/ha basis is shown in Table 24. This provides a comparison of the efficiency of fertilizer use in the different treatments studied.

Although there was generally increased uptake of N,

TABLE 22

Yield of Plant Roots from Selected Soil Treatments on a Seeded and Fertilized Tailings Sand Dike - September 1977

Treatment	Yield (Kg/m^2)				Percentage Distribution		
	0-15 cm	15-30 cm	30-60 cm	Total	0-15 cm	15-30 cm	30-60 cm
1A	0.260	0.015	0.006	0.281	92.5	5.3	2.2
5A	0.173	0.032	0.003	0.208	83.2	15.4	1.4
6A	0.210	0.032	0.005	0.247	85.0	13.0	2.0
1C	0.234	0.023	0.004	0.261	89.7	8.8	1.5
5C	0.158	0.020	0.004	0.181	87.3	11.0	1.7
6C	0.185	0.025	0.002	0.212	87.3	11.8	0.9
Significance L.S.D.	N.S.	N.S.	N.S.				

TABLE 23

Analysis of Plant Roots from Selected Soil Treatments on a Seeded and Fertilized Tailings Sand Dike - September, 1977

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Calcium (%)
1A	1.23	0.09	0.27	0.33	1.07
5A	1.19	0.07	0.26	0.28	0.97
6A	1.24	0.09	0.35	0.27	0.69
1C	1.60	0.13	0.35	0.33	0.93
5C	1.58	0.13	0.43	0.28	0.65
6C	1.55	0.14	0.28	0.27	1.10
Significance	**	***	N.S.	N.S.	N.S.
L.S.D.	0.30	0.03			

Composite samples from 0-60 cm.

TABLE 24

Total Nutrient Uptake into Plant Material from a Seeded and Fertilized Tailings Sand Dike - September, 1977

Treatment	Plant Tops (Kg/ha)					Plant Roots (Kg/ha)				
	N	P	K	S	Ca	N	P	K	S	Ca
1A	51	4.8	61	6.4	17	35	2.5	7.6	9.3	30
2A	43	3.9	58	6.2	18					
3A	43	3.8	53	5.4	14					
4A	61	4.8	71	5.6	16					
5A	45	3.4	59	5.4	18	25	1.5	5.4	5.8	20
6A	55	4.2	66	6.4	16	31	2.2	8.6	6.7	17
7A	46	3.6	53	4.9	15					
8A	45	3.1	42	5.3	16					
1B	73	5.2	77	7.9	19					
2B	69	5.6	78	7.5	19					
3B	73	5.2	74	8.8	24					
4B	71	4.9	84	7.9	26					
5B	104	7.9	126	8.7	24					
6B	64	3.7	63	7.7	19					
7B	84	5.8	103	8.7	24					
8B	70	4.0	82	6.9	24					
1C	89	8.6	85	10.6	24	42	3.7	9.1	8.6	24
2C	102	8.8	107	11.0	25					
3C	101	10.8	126	10.4	25					
4C	106	10.3	113	10.3	28					
5C	107	9.6	121	9.6	28	29	2.4	7.8	5.1	12
6C	105	8.5	91	10.6	24	33	3.0	5.9	5.7	23
7C	113	10.7	103	11.5	25					
8C	75	8.0	65	5.9	18					

P, K, S and Ca into plant tops with increased addition of fertilizer, the differences were smaller in relation to the nutrients added at each different rate. For instance, the nitrogen uptake into plant tops had means of 49, 79 and 100 Kg/ha for Treatments A, B and C, while the amount added as fertilizer in 1977 amounted to 80, 150 and 300 Kg-N/ha respectively. A similar trend may be noted for potassium uptake. Phosphorus uptake showed a good response at the highest fertilizer rate. Additions of P in 1977 amounted to 35, 40 and 80 Kg-P/ha for A, B and C, respectively, while mean uptake values were 4.0, 5.3 and 9.4 Kg-P/ha, respectively.

Despite the high overall sulfate status of the soil, there was an increase in sulfur uptake with increased fertilizer application. The overburden treated plots, which have a naturally high sulfate status, did not show a significantly greater uptake of sulfur into plant tissues.

Calcium uptake was slightly higher in Treatments B and C which were amended with calcium carbonate in 1976.

Total uptake of nutrients in roots were generally lower than recorded for the above ground tissues. A comparison of nutrient uptake into roots with fertilizer addition in 1977 is not totally valid since a proportion of the tissues analyzed may have been produced in the previous year.

Nitrogen, phosphorus and potassium were generally taken up in the greatest amounts at the highest fertilizer rate.

In 1976, approximately 90-110 Kg-N; 8-12 Kg-P; 85-135 Kg-K; 10 Kg-S and 30-40 Kg-Ca per hectare were taken up into plant tissues in the period between seeding and September. Most was contained in the oats. In 1977, about 70-140 Kg-N; 5-15 Kg-P; 65-130 Kg-K; 10-20 Kg-S and 35-50 Kg-Ca per hectare were taken up in plant growth.

The tentative balance sheet presented in Table 25 shows how these values may be related to fertilizer additions and fluctuations in available nutrients in the soil.

The fertilizer rate A maintained moderate amounts of mineral nitrogen in the surface 30 cm in June but inadequate supplies of plant available phosphorus and potassium. The June fertilizer application was insufficient to maintain adequate supplies of mineral nitrogen until the fall. In September, the phosphorus status was moderately good while levels of potassium varied from moderate to low.

Fertilizer Treatment B contained a smaller amount of mineral nitrogen in June and low amounts of available P and K. The addition of fertilizer in June resulted in a better nutrient status in September than was found at the lower rate A, although nitrogen was rather low.

In June, the fertilizer treatment C still showed the residual effect of the fertilizer addition made the previous August. Addition of fertilizer in June and August, 1977, resulted in a very high available nutrient status in September.

TABLE 25

An Approximate Balance Sheet for Nitrogen, Phosphorus and Potassium in Soil and Plants on a Seeded and Fertilized Tailings Sand Dike, 1977

	Treatment											
	1A	5A	6A	7A	1B	5B	6B	7B	1C	5C	6C	7C
Fertilizer Nutrients Added												
(Kg/ha)												
1976												
N	80	80	80	80	150	150	150	150	300	300	300	300
P	35	35	35	35	40	40	40	40	80	80	80	80
K	75	75	75	75	150	150	150	150	300	300	300	300
1977												
N	80	80	80	80	150	150	150	150	300	300	300	300
P	35	35	35	35	40	40	40	40	80	80	80	80
K	75	75	75	75	150	150	150	150	300	300	300	300
Available Nutrients in Soil												
(Kg/ha 0-30 cm)												
June, 1977												
N	21	18	26	29	16	19	19	10	46	28	35	50
P	1	3	3	3	1	3	1	4	9	11	16	9
K	34	74	57	51	54	92	77	56	108	89	125	98

(...continued)

	1A	5A	6A	7A	1B	5B	6B	7B	1C	5C	6C	7C
	Treatment											
Available Nutrients in Soil												
(Kg/ha 0-30 cm)												
September, 1977												
N	4	7	7	6	15	26	20	12	158	139	186	191
P	25	28	26	23	24	24	24	22	35	36	31	39
K	68	164	110	108	186	217	207	179	377	418	626	650
Nutrients in Plant Tissues												
(Kg/ha)												
Tops												
N	51	45	55	46	73	104	64	84	89	107	105	113
P	5	3	4	4	5	8	4	6	9	10	9	11
K	61	59	66	53	77	126	63	103	85	121	91	103
Roots												
N	35	25	31						42	29	33	
P	3	2	2						4	2	3	
K	8	5	9						9	8	6	

Data calculated using a bulk density of 0.5 g/cc and 1.2 g/cc for the 0-15 cm and 15-30 cm depths respectively.

This high content of nutrients late in the summer is probably responsible for the inefficient use of the added fertilizer.

4.5 Runoff Losses

It was noted in 1976 that surface water runoff was sufficiently high to cause some erosion especially where plants had not become rapidly established and channeling could develop. The average amount of soil lost varied from 0.19 to 1.77 cm in the seven treatments that were studied. Losses of nitrogen added in fertilizers from surface water runoff was estimated to vary between 0.5 and 6.4 Kg-N/ha at the highest fertilizer rate (300 Kg-N/ha).

Movement of soil downslope was negligible in 1977. This was largely due to the excellent stability provided by the growing plants. In addition, only one severe rainstorm was experienced during the summer on August 10-11th when 27.9 mm were recorded within 24 hours (complete precipitation data are provided in the Appendix).

Table 26 shows the analysis of runoff water and rainfall collected between June and September, 1977. Table 27 summarizes the data.

Only 1.0% to 2.1% of the intercepted rainfall was collected as surface water runoff. Most of this could be accounted for as direct interception by the collecting funnel.

Nitrogen losses in runoff were much less than last year

TABLE 26

Runoff Water Collected Between June and September, 1977

Treatment		Volume (ℓ/m^2)	pH	Conductivity (mmhos/cm)	NH_4-N (mg/m^2)	NO_3-N (mg/m^2)
June	1C	0.3	7.0	0.14	all	all
	2C	0.3	7.2	0.13	below	below
	3C	0.5	7.7	0.18	0.1	0.1
	4C	0.4	7.8	0.14		
	5C	1.2	8.8	0.45		
	6C	0.8	8.2	0.28		
	7C	0.4	7.5	0.28		
	Rainfall	40.9	6.5	0.05	0.62	0.00
July	1C	0.3	6.8	0.52	0.9	0.0
	2C	0.5	7.8	0.40	8.9	3.9
	3C	0.5	7.5	0.53	7.2	8.4
	4C	0.5	7.2	0.82	8.8	7.2
	5C	1.4	7.8	1.43	55.0	38.4
	6C	0.5	6.8	1.38	4.0	26.1
	7C	0.6	7.5	1.40	42.7	38.3
	Rainfall	56.3	5.7	0.03	0.49	0.00
August	1C	0.1	7.1	0.20	all	all
	2C	0.2	7.0	0.15	below	below
	3C	0.4	9.0	0.15	0.1	0.1
	4C	0.3	7.7	0.40		
	5C	0.2	8.5	0.26		
	6C	0.2	7.8	0.23		
	7C	0.5	8.5	0.49		
	Rainfall	26.8	6.5	0.03	1.53	1.74
September	1C	0.3	6.4	0.95	1.5	0.7
	2C	0.3	6.6	0.70	2.4	1.5
	3C	1.0	6.2	0.97	5.5	1.1
	4C	0.6	6.7	0.75	2.9	2.0
	5C	0.6	6.7	1.86	6.1	4.3
	6C	0.4	6.3	1.33	5.0	4.5
	7C	0.7	6.4	1.73	15.6	15.5
	Rainfall	39.0	6.2	0.03	1.56	1.46

TABLE 27

Total Runoff and Nitrogen Losses During June to September, 1977

Treatment	Total Runoff (mm)	Mineral Nitrogen Lost (Kg/ha)
1C	1.0	0.03
2C	1.3	0.20
3C	2.4	0.20
4C	1.8	0.20
5C	3.4	1.00
6C	1.9	0.40
7C	2.2	1.10
Rainfall	163.0	0.07

ranging from 0.03 to 1.1 Kg-N/ha. In general, the highest amounts of runoff, soluble salts and mineral nitrogen were found with Treatment 5. This was also noted last year and was believed to result from poorer infiltration of rainfall on the hardened overburden surface.

4.6 *Summary*

1. A study into revegetating a tailings sand slope of 23-30° was initiated in 1976 using a randomized latin square experimental design with three main fertilized treatments and eight material amendment treatments.

   In 1977, the area had been stabilized by an excellent growth of grasses and legumes. Wind and water erosion were minimal.

2. Considerable differences in species composition were noted with the different fertilizer programs used. A seed mix containing nine grass species, four legume species and oats was employed. The first year's growth had been dominated by oats but no reseeding of oats was observed in the second year.

   With the lowest fertilizer rate (80 Kg-N, 35 Kg-P, 75 Kg-K and 20 Kg-S per hectare) most of the grasses and three of the legumes from the original mix were growing well. Brome Grass and three Wheatgrass species were dominant. Increased fertilizer applications up to 300 Kg-N, 80 Kg-P, 300 Kg-K and 40 Kg-S per hectare resulted in loss of legumes and poor growth of the smaller grasses. Smooth Brome was the dominant species present.

3. Yield of vegetation showed a positive correlation to increase in fertilizer application. The greater yields in June and September were obtained in treatments that were fertilized both in June and August.

4. Yield of root tissues was less affected by fertilization.

5. Slight increases in rooting depth over the previous year were noted.

6. Uptake of N, P and K was increased by increasing the fertilizer rate. Results indicated that fertilizer was most efficiently used at the two lower fertilizer rates and less efficiently when two applications were made during the summer.

7. Soils contained low to very low amounts of available N, P and K in June prior to the addition of fertilizer. Significantly higher amounts of available nutrients occurred in treatments that had been fertilized in August, 1976.

8. Addition of 80 Kg-N, 35 Kg-P, 75 Kg-K and 20 Kg-S per hectare in June was generally not sufficient to supply adequate N and K throughout the summer. Addition of 150 Kg-N, 40 Kg-P, 150 Kg-K and 40 Kg-S per hectare in June improved soil nutrient status throughout most of the summer. However, nitrogen and potassium were in low supply by September. Addition of a similar amount both in June and August resulted in an excess of N, P, K and S in September and caused lower efficiency of fertilizer use.

9. In September, at the highest fertilizer rate employed, the soil electrical conductivity was moderately high (3.0 to 3.4 mmhos/cm) in the surface 15 cm of overburden treated plots. This is considered high enough to affect the growth of salt sensitive plants.

10. Surface soil pH values varied between 6.1 and 6.7 during 1977. The acidifying effect of the heaviest fertilizer application was offset by the addition of lime in 1976.

11. Comparison of spring seeding and fall seeding methods showed that in fall seeded plots the distribution of seed was uneven, presumably due to spring snow melt. Early growth was good but some bare patches existed which could become eroded during any heavy spring rainfall.

12. Powdery Mildew on Brome Grass and Wheatgrasses and head smut on Wheatgrasses was noted towards the end of the summer. The proportion of plants affected was so small that diseases were not considered a serious problem at this time.

5.0 STUDIES TO PROMOTE DEEPER ROOTING OF PLANTS ON REVEGETATED TAILINGS SAND SLOPES - EXPERIMENT III

5.1 Introduction

Our previous observations and research[1] indicated that rapid establishment of cover on tailings sand slopes was necessary to reduce soil erosion. The vegetative cover reduces erosion by intercepting raindrops and by stabilizing the subsurface through rooting. Where peat has been used as a surface amendment, the plant roots are restricted to the peaty layer which contains more moisture and nutrients relative to the tailings material below. Thus the depth of incorporation of any surface amendment like peat will likely affect the depth of rooting and successful stabilization of the slope. In 1976, an experiment was set up to study this aspect of reclamation by incorporating peat or peat and mine overburden to a depth greater than the 15 cm that had previously been used. The various treatments were as follows:

1. Overburden added at 750 Tonnes/ha and tilled into the peat/tailings sand surface to a depth of 30 cm.
2. Extra peat added to give a depth of about 20 cm on the surface and the peat incorporated into the tailings sand to a depth of 30 cm.
3. Overburden added at 1500 Tonnes/ha and tilled into

the peat-tailings sand surface to a depth of 30 cm.

4. Peat (about 10-15 cm) tilled into the tailings sand surface to about 15 cm (i.e. as Treatment 1, Experiment II).

Fertilizers were added to Treatments 1, 2 and 3 at the same rate as used in B of Experiment II (i.e. 150 Kg-N, 40 Kg-P, 150 Kg-K and 20 Kg-S per hectare, added in June with 5 Tonnes per hectare of lime added in 1976). Treatment 4 received rate A fertilizer from Experiment II (i.e. 80 Kg-N, 35 Kg-P, 75 Kg-K and 20 Kg-S per hectare). Each treatment was replicated three times. The plot size was 5 m x 4 m. The experimental design is shown in Figure 3. The same seed mix was used as in Experiment II.

Each plot was sampled to a depth of 30 cm in June, 1977, and to a depth of 120 cm in September. During 1977, plant samples were taken only in September. Root cores were taken at depths of 0-15 cm, 15-30 cm and 30-60 cm. Each depth was analyzed separately for N, P, K, S and Ca content.

5.2 Analysis of Soil Samples

Analyses of soil samples taken in June, 1977, are presented in Table 28. The surface pH in Treatment 4 was significantly lower than the other treatments. This difference was a reflection of the lime addition to Treatments 1, 2 and 3 in 1976. There were also significantly higher conductivity values

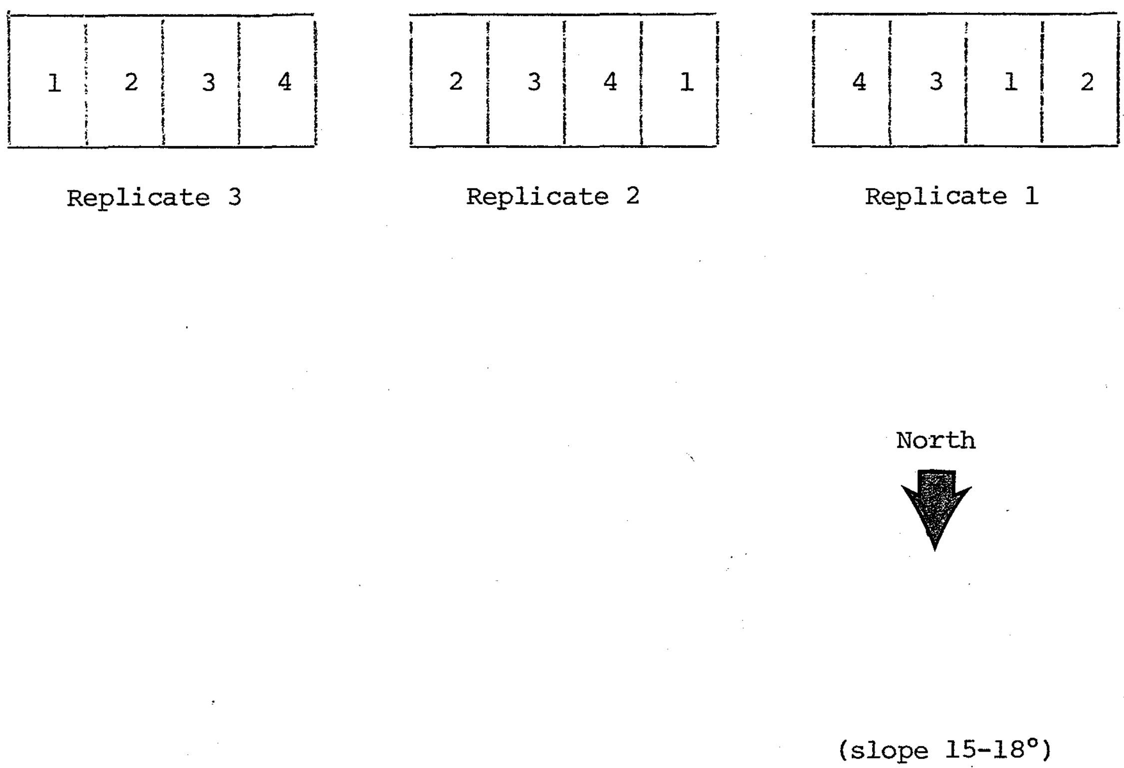


FIGURE 3. Field Plan of Experiment on an Unvegetated Area on a Tailings Sand Dike at the G.C.O.S. Plant Site at Fort McMurray, Alberta (Experiment III).

TABLE 28

Analysis of Soil Samples from an Experiment to Study Deep Rooting of Plants on a Tailings Sand Dike - June, 1977

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
1	0-15	6.7	6.8	1.93	6.5	7.1	17.9	43	134
	15-30	3.3	6.4	1.23	3.5	2.0	7.2	25	80
2	0-15	9.7	6.5	1.08	11.4	9.3	7.5	24	88
	15-30	3.3	6.4	0.77	3.3	3.2	4.8	17	44
3	0-15	7.8	6.8	1.99	9.0	8.6	15.5	49	161
	15-30	3.2	6.6	1.11	3.1	1.7	5.2	26	81
4	0-15	8.8	6.0	1.05	15.2	15.3	7.7	15	81
	15-30	6.8	6.0	0.60	3.7	2.5	1.5	11	36
Significance		N.S.	***	***	N.S.	N.S.	N.S.	***	N.S.
L.S.D.			0.4	0.52				15	

Statistical analysis applied to 0-15 cm depth only.

Conversions to Kg/ha noted in the text used bulk densities of 0.5 and 1.2 g/cm^3 for the 0-15 cm and 15-30 cm depths respectively.

in the surface 15 cm where the moderately saline overburden had been used. Available nutrients were of similar magnitude to those found for similar fertilizer treatments in Experiment II. Mineral nitrogen ranged from 18 to 35 Kg/ha, phosphorus between 7 and 20 Kg/ha, potassium between 26 and 90 Kg/ha and sulfate sulfur always above 100 Kg-S/ha in the surface 30 cm. Significantly higher amounts of potassium were found in the 0-15 cm and 15-30 cm depths of the overburden treated plots.

Results from the September set of soil samples (Table 29) were also comparable to similar fertilizer treatments from Experiment II. Mineral nitrogen was in low supply while available phosphorus had generally increased during the summer. Potassium levels were significantly higher in Treatments 1, 2 and 3 which had received a higher rate of fertilization relative to Treatment 4.

Electrical conductivity was highest in the overburden treated plots. A maximum value of 1.98 mmhos/cm was recorded for the 0-15 cm depth of Treatment 1. The deeper incorporation of the overburden in Treatments 1 and 3 had resulted in the distribution of soluble salts to a greater depth. The results suggested that some leaching of the native overburden salts had occurred to a depth of 90-120 cm. However, the concentration of soluble salts never reached a level that would be considered detrimental to plant growth. In addition, there was no evidence of significant leaching of N, P or K from the

TABLE 29

Analysis of Soil Samples from an Experiment to Study Deep Rooting of Plants on a Tailings Sand Dike - September, 1977

Treatment	Depth (cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	Mineral Nitrogen (ppm) NH_4-N	Mineral Nitrogen (ppm) NO_3-N	P (ppm)	K (ppm)	SO_4-S (ppm)
1	0-15	8.1	7.1	1.98	2.4	2.4	18.5	268	224
	15-30	3.4	6.5	1.77	2.2	5.4	10.8	80	160
	30-60	2.7	6.0	1.00	1.4	3.1	9.0	20	59
	60-90	4.0	6.1	0.94	1.5	1.7	8.7	15	60
	90-120	4.1	6.6	0.68	1.5	1.6	8.5	15	41
2	0-15	16.4	6.6	1.18	3.5	10.9	14.6	215	69
	15-30	6.2	6.3	1.01	1.8	4.0	10.7	23	81
	30-60	2.0	6.6	0.51	1.5	1.4	9.0	15	22
	60-90	3.8	6.8	0.36	1.4	0.6	8.2	12	11
	90-120	4.6	6.9	0.40	1.5	0.5	9.0	11	13
3	0-15	11.6	6.9	1.66	2.6	8.1	18.4	365	203
	15-30	3.9	6.6	1.38	1.5	2.7	10.3	122	147
	30-60	2.6	6.4	0.63	1.0	0.7	9.0	22	36
	60-90	3.6	6.6	0.50	1.2	0.7	9.0	13	29
	90-120	4.0	6.7	0.52	1.2	0.4	8.0	16	27
4	0-15	14.8	6.0	0.92	4.7	3.2	14.0	129	106
	15-30	4.8	6.1	0.78	1.8	0.9	9.8	22	51
	30-60	2.6	6.6	0.42	1.1	0.6	9.0	12	17
	60-90	3.4	6.5	0.36	2.3	1.2	8.5	11	16
	90-120	4.2	6.7	0.31	1.7	0.5	8.3	11	12
Significance		N.S.	***	*	N.S.	N.S.	N.S.	**	*
L.S.D.			0.3	0.74				134	117

fertilizers added in June.

The soil pH had not changed significantly during the summer.

5.3 Plant Yield and Nutrient Analysis

The oat plants grown the previous year did not reseed in 1977. The distribution of plant species from the original seed mix of grasses and legumes seemed to be similar to that noted in Experiment II. Treatments 1, 2 and 3, which had received more fertilizer, contained fewer legumes and a greater proportion of Smooth Brome than Treatment 4. A few of each different type of legume (except Lupine) were dug up and the roots examined. Most plants were nodulated.

The yield of above ground vegetation (Table 30) was not significantly different between the four treatments studied. Overall yields were higher than was recorded for the first year of growth in 1976.

Nutrient contents of the foliage were not significantly different except for calcium which was marginally higher in Treatment 2 which had received extra peat.

Root yields were up to 100% higher than was recorded last year. Yields from the 0-15 cm depth were significantly greater with Treatments 1 and 2 (see Table 31). Differences in the lower depths were not significant. However, the distribution of roots below 15 cm was greater where the surface

TABLE 30

Yield and Analysis of Plant Material from an Experiment to Study Deep Rooting on a Tailings Sand Dike - September, 1977

Treatment	Yield (Kg/m^2)	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Calcium (%)	Nitrate (%)
1	0.333	2.22	0.22	2.58	0.23	0.49	0.11
2	0.334	2.50	0.19	2.26	0.24	0.64	0.07
3	0.352	2.21	0.17	2.21	0.25	0.57	0.10
4	0.290	2.05	0.18	2.64	0.25	0.56	0.01
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.
L.S.D.						0.09	

TABLE 31

Yield and Analysis of Plant Roots from an Experiment to Study Deep Rooting on a Tailings Sand Dike - September, 1977

Treatment and Depth	(cm)	Yield (Kg/m^2)	Distribution (%)	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulfur (%)	Calcium (%)
1	0-15	0.400	76.2	1.30	0.11	0.40	0.24	1.35
	15-30	0.114	21.7	1.34	0.07	0.21	0.35	1.26
	30-60	0.011	2.1	1.27	*nd*	*nd*	*nd*	*nd*
	Total	0.525						
2	0-15	0.321	79.5	1.41	0.15	0.22	0.22	1.27
	15-30	0.075	18.6	1.23	0.12	0.15	0.28	1.26
	30-60	0.008	1.9	1.25	*nd*	*nd*	*nd*	*nd*
	Total	0.404						
3	0-15	0.225	78.9	1.50	0.17	0.30	0.26	1.34
	15-30	0.055	19.3	1.26	0.13	0.22	0.23	1.26
	30-60	0.005	1.8	1.24	*nd*	*nd*	*nd*	*nd*
	Total	0.285						
4	0-15	0.243	81.5	1.34	0.15	0.29	0.24	1.16
	15-30	0.046	15.4	1.19	0.11	0.23	0.27	1.02
	30-60	0.009	3.1	1.10	*nd*	*nd*	*nd*	*nd*
	Total	0.298						

nd - Not Determined

amendments had been tilled to 30 cm. An average of between 20.5% and 23.8% of the root biomass with Treatments 1, 2 and 3 occurred below 15 cm while 18.5% was found in the control Treatment 4.

There were no significant differences in nutrient concentrations in root tissues. Due to the small amount of sample, only nitrogen was determined for the 30-60 cm depth.

Table 32 shows the total amount of nutrients in the shoot and root tissues. The nitrogen and phosphorus uptake with Treatment 4 (peat tilled to 15 cm with low fertilizer addition) was lower than for the other treatments. In relation to the amount of fertilizer added, the uptake into root and shoot tissues was quite efficient. For instance, the nitrogen contained in roots and shoots varied from 99 Kg-N/ha with Treatment 4 to 146 Kg-N/ha in Treatment 2. In 1977, 80 Kg-N/ha were added to Treatment 4 and 150 Kg-N/ha to Treatments 1, 2 and 3.

5.4 *Summary*

1. The dry weight yield of both root and shoot tissues was greater than in 1976. A great proportion of the roots occurred below a depth of 15 cm where peat or overburden and peat had been tilled in to a depth of 30 cm. The results also suggested that where deep tillage had been employed, there was a greater proportion of roots in the 0-15 cm depth as well.

2. The ratio of root to shoot biomass showed an increasing trend over 1976 as the plants became well established.

3. Available nutrient levels showed a similar trend to

TABLE 32

Total Nutrient Uptake into Plant Tissues - 1977

Treatment	Plant Tops (Kg/ha)					Plant Roots (Kg/ha)				
	N	P	K	S	Ca	N	P	K	S	Ca
1	74	7.3	86	7.6	16	68	5.8	21	12.6	71
2	84	6.3	75	8.0	21	62	6.1	9	8.8	51
3	78	6.0	78	6.0	20	43	4.8	9	7.4	38
4	59	5.2	77	7.3	16	40	4.5	9	7.2	35

that observed in Experiment II when equivalent fertilizer rates were compared. Generally, towards the end of the summer, nitrogen and potassium were in short supply.

4. Plant species from the original seed mix were well distributed except for Lupine and Oats. Several legumes examined had well nodulated root systems.

5. Some downward movement of soluble salts was noted in overburden treated plots. However, there was no evidence of significant leaching of fertilizer nutrients in those soils.

6.0 PROGRESS REPORT OF LYSIMETER STUDY

6.1 Introduction

In 1976, a series of double pail lysimeters were set up on main treatments A, B and C and Sub-treatments 1, 3, 4, 5, 6 and 7 of Experiment II. The experiment was designed to provide a more accurate material balance for nutrient cycling than could be provided by the main experiment.

The sampling of leachate and soil was continued in 1977. In 1978, the experiment will be terminated after three years' growth with a final soil sampling and separate harvesting of plant roots and shoots.

Soils were sampled in September, 1977, at depths of 0-15 cm and 15-30 cm (to the bottom of the pail). Samples of leachate water were obtained from below the lysimeter at monthly intervals.

6.2 Leachate Analysis

Table 33 shows the amount of leachate collected and the quantity of mineral nitrogen lost in the leachate during the summer.

Much less leaching occurred in 1977 in comparison to 1976. This year there was a greater amount of plant growth and consequently greater water uptake by roots and transpir-

TABLE 33

Volume and Mineral Nitrogen Content of Leachate from Lysimeters - 1977

Treatment	Volume (ℓ/m^2)				Mineral Nitrogen						
					NH_4-N (mg/m^2)			NO_3-N (mg/m^2)			Total
	July	August	September	Total	July	August	September	July	August	September	(Kg/ha)
1A	2.9	0.6	2.8	6.3	24.0	0.0	0.3	9.0	0.2	0.3	0.1
3A	0.0	1.8	2.7	4.5	0.0	0.3	0.1	0.0	1.3	0.5	<0.1
4A	0.0	0.5	6.1	6.6	0.0	0.0	0.6	0.0	0.0	7.0	0.1
5A	0.4	2.4	10.2	13.0	1.1	0.2	0.9	2.0	4.5	2.3	0.1
6A	1.5	0.0	0.6	2.1	7.4	0.0	0.0	9.7	0.0	0.1	0.1
7A	0.0	0.0	4.2	4.2	0.0	0.0	0.2	0.0	0.0	1.0	<0.1
1B	0.0	0.0	3.6	3.6	0.0	0.0	1.0	0.0	0.0	0.4	<0.1
3B	3.0	1.7	2.0	6.7	150	0.1	0.2	153	1.4	2.1	1.6
4B	1.4	0.7	0.8	2.9	36.2	0.1	0.0	5.3	1.3	0.4	0.1
5B	0.0	0.5	2.0	2.5	0.0	0.0	0.3	0.0	0.1	3.1	<0.1
6B	2.6	0.0	0.5	3.1	128	0.0	0.0	231	0.0	0.1	2.3
7B	3.7	1.4	3.2	8.3	13.3	0.1	0.2	113	0.2	4.4	1.2
1C	0.7	0.5	2.9	4.1	0.9	0.1	2.0	4.2	0.3	6.2	0.1
3C	0.6	2.0	5.8	8.4	3.1	0.3	0.5	4.8	1.6	10.0	0.2
4C	0.0	0.7	0.0	0.7	0.0	0.0	0.0	0.0	1.3	0.0	<0.1
5C	1.2	0.3	2.3	3.8	29.4	0.0	0.3	4.8	0.1	1.2	0.1
6C	0.9	0.4	1.5	2.8	4.3	0.2	0.2	5.7	0.9	0.2	0.1
7C	2.3	0.3	2.9	5.5	8.1	0.1	0.2	34.4	0.1	2.0	0.4

ation through leaf surfaces. The total amount of leachate collected in 1977 was equivalent to between 0.7 and 13.0 mm of rainfall while in 1976 a range of 23.9 to 60.9 mm was encountered.

Similarly, losses of mineral nitrogen were smaller. In 1977, between 0.0 and 2.3 Kg-N/ha was lost below a depth of 30 cm. This may be compared to 1.3 to 31.2 Kg-N/ha during the first summer. A large proportion of the nutrient losses in 1977 occurred after the addition of fertilizer in June. There were no consistent differences between different sub-treatments in the experiment.

6.3 Soil Analysis

Table 34 shows the results of the analysis of soil samples taken in September, 1977. Moisture contents were consistently lower in lysimeters in comparison to the same treatment on the main plot. The lysimeters are isolated and slightly raised and so tend to dry out more readily than the surrounding soil.

Soil pH was consistently 0.5 to 0.8 units lower in Treatment A which had not been limed. The heavy application of overburden on the surface (Treatment 5) seemed to result in a relatively stable pH of about 6.5. This buffering capacity, characteristic of these particular mine overburdens, was noted before[1].

TABLE 34

Analysis of Lysimeter Soil Samples - September, 1977

Treatment and Depth	(cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	Mineral Nitrogen (ppm) NH_4-N	NO_3-N	P (ppm)	K	SO_4-S
1A	0-15	11.5	6.1	0.98	4.3	1.8	13.2	30	88
	15-30	5.0	6.1	0.75	5.1	3.0	5.7	14	49
3A	0-15	15.3	6.1	0.60	6.2	2.3	9.7	29	83
	15-30	2.8	6.0	0.61	3.5	1.1	3.0	8	38
4A	0-15	15.9	6.1	0.77	4.6	3.8	7.7	35	60
	15-30	4.3	6.3	0.49	3.9	0.6	2.8	10	31
5A	0-15	10.4	6.5	2.02	3.6	0.6	19.5	47	216
	15-30	3.1	6.4	1.19	3.7	0.9	5.0	14	95
6A	0-15	8.9	6.6	2.96	4.1	1.3	14.0	38	591
	15-30	5.0	6.7	1.31	3.8	0.3	5.3	16	96
7A	0-15	10.8	6.0	1.97	3.7	2.5	15.5	35	277
	15-30	5.1	6.4	1.26	2.6	0.9	5.2	15	88
Significance		N.S.	***	***	N.S.	N.S.	N.S.	N.S.	***
L.S.D.			0.3	0.77					148
1B	0-15	17.7	6.9	1.20	2.8	7.5	14.5	55	72
	15-30	4.3	6.8	0.94	3.1	3.4	7.0	23	42
3B	0-15	15.5	6.8	1.16	2.7	20.9	13.3	53	60
	15-30	3.7	6.4	0.68	4.3	1.8	3.3	18	27
4B	0-15	18.9	6.9	1.12	5.8	19.5	17.7	65	52
	15-30	2.8	6.4	0.66	5.7	3.7	4.5	19	25

(.... continued)

Treatment and Depth		Moisture	pH	Electrical Conductivity	Mineral Nitrogen		P	K	SO_4-S
					NH_4-N	NO_3-N			
	(cm)	(%)		(mmhos/cm)	(ppm)		(ppm)		
5B	0-15	11.3	6.4	1.74	4.1	6.4	22.3	56	187
	15-30	4.7	6.4	0.91	3.6	1.9	6.0	21	57
6B	0-15	8.6	7.1	2.19	4.5	4.4	19.2	51	326
	15-30	4.3	7.1	0.95	3.0	0.7	6.8	24	75
7B	0-15	8.1	6.9	2.20	3.8	9.7	19.5	45	327
	15-30	3.9	6.8	1.23	2.7	2.0	6.5	29	81
Significance		*	***	***	N.S.	N.S.	N.S.	N.S.	***
L.S.D.		8.0	0.1	0.46					114
1C	0-15	16.0	6.9	1.48	4.2	23.8	20.7	86	71
	15-30	5.0	6.9	0.86	4.1	6.2	8.5	29	26
3C	0-15	17.0	6.8	1.00	4.0	9.1	11.8	46	55
	15-30	3.0	6.3	0.67	2.5	0.6	3.7	20	36
4C	0-15	21.8	6.8	1.25	4.2	22.9	13.2	60	60
	15-30	3.3	6.4	0.65	3.4	2.7	4.0	19	25
5C	0-15	8.0	6.5	2.05	3.9	10.2	26.7	65	220
	15-30	2.8	6.7	0.98	4.0	4.9	7.0	31	65
6C	0-15	11.6	7.2	2.30	4.1	8.3	21.0	67	279
	15-30	3.2	6.9	1.06	2.9	0.9	5.5	29	60
7C	0-15	8.8	7.0	2.00	4.0	19.0	11.3	53	298
	15-30	3.6	6.8	1.14	5.5	4.0	4.8	31	65
Significance		N.S.	**	***	N.S.	**	N.S.	N.S.	***
L.S.D.			0.4	0.77		11.0			109

Electrical conductivity was highest where overburden had been added but the salt concentration was not high enough to harm plant growth.

In September, mineral nitrogen levels were quite low, particularly at the lowest fertilization rate. Most of the nitrogen occurred as nitrate but little leaching of nitrate into the 15-30 cm depth seemed to have occurred.

Moderate amounts of available phosphorus were detected but potassium was low even in the treatments receiving the two highest fertilizer rates.

Sulfate sulfur was adequate for plant growth in every treatment.

7.0 NITROGEN MINERALIZATION AND NITRIFICATION

Inadequate supply of mineral nitrogen has been one of the major factors limiting plant yield on the tailings sand dike. It has been noted both this year and last year that plant growth on Experiment I, which has been vegetated for over six years, is often deficient in nitrogen even though there are moderate levels of organic nitrogen present as humified organic matter from the peat, plant roots and microbial biomass.

A more detailed soil testing program was carried out during 1977 to study the mineral nitrogen status of selected treatments on an older vegetated area (Experiment I) and on the area seeded in 1976 (Experiment II). Treatments T_0, T_2, T_4 and T_5 were studied from Experiment I to provide a comparison between areas which had not been fertilized since 1974 and those that had received varying amounts of fertilizer since 1975. Treatments 1A, 6A, 1B, 6B, 1C and 6C were studied from the recently seeded area to show the presence of residual fertilizer-N from applications made in 1976 and to indicate the rate of mineral nitrogen use by plants during 1977. Samples were taken at monthly intervals between May and September at depths of 0-15 cm and 15-30 cm. The results are summarized in Table 35. Unfortunately, without the use of the

TABLE 35

A Comparison of Mineral Nitrogen Contents in Soil of the 0-30 cm Depth in a 6 Year Revegetated Area and a 2 Year Revegetated Area

Treatment	Mineral Nitrogen [NH_4-N + NO_3-N] in the 0-30 cm Depth (kg/ha)				
	May	June	July	August	September
Experiment I - 6 Year Area					
T_0	7.0	38.9	35.4	40.7	4.2
T_2	14.2	18.8	51.3	37.1	25.9
T_4	11.1	23.4	147.7	77.6	32.8
T_5	6.9	14.4	30.8	30.3	7.7
Experiment II - 2 Year Area					
1A	7.1	18.8	33.7	23.9	3.3
6A	3.3	12.7	22.9	19.5	5.9
1B	6.5	14.6	59.2	56.8	13.9
6B	14.8	16.7	52.6	71.5	19.0
1C	60.0	40.9	83.6	116.2	150.0
6C	54.1	33.1	90.0	86.0	169.4

In 1977, the following rates of nitrogen fertilizers were added:

T_0	0 Kg/ha	1A, 6A	80 Kg/ha (June)
T_2	80 Kg/ha (June)	1B, 6B	150 Kg/ha (June)
T_4	160 Kg/ha	1C, 6C	300 Kg/ha (June, August)
T_5	38 Kg/ha		

Fertilizers were added after the June or August soil samples were taken.

Bulk densities used for conversions were 0.5 g/cm^3 for the 0-15 cm depth and 1.2 g/cm^3 for the 15-30 cm depth.

labelled N^{15} isotope, it is not possible to show the relative rates of mineralization, nitrification, denitrification and plant microbial immobilization with any precision.

The results concerning Treatment T_0 do indicate that a moderate amount of mineralization does occur in the spring and early summer. The very poor growth of plants on Treatment T_0 during 1977 is rather surprising in view of the apparent excess of mineral nitrogen present over much of the summer period. We might conclude that this effect may be due to poor supplies of available potassium.

Additionally, in view of the large amount of undecomposed litter present, it is likely that mineral nitrogen is being tied up in the microbial decomposition of these residues. Apparently, between August and September, at least 35 Kg-N/ha was immobilized.

The remaining treatments (T_2, T_4 and T_5) show a more easily explainable pattern. Between May and June, a slight increase in net mineral nitrogen was noted which reflects lower plant and microbial fixation relative to the mineralization rate. A large percentage of the fertilizer-N that was added in June, 1977, was still present in July. Treatments T_2, T_4 and T_5 received 75 Kg, 150 Kg and 35 Kg-N/ha respectively. Fertilizer nitrogen was largely consumed by September in Treatment T_5. However, Treatments T_2 and T_4 still contained an excess at that time. The small difference between the mineral nitrogen present in Treatments T_2 and T_4 in September and the relative amounts of nitrogen uptake in plant tissue (see previous sections) seems to indicate a much lower efficiency in fertilizer-N use when added at 150 Kg/ha. Lower efficiency is probably due to higher denitrification losses or possibly to increased immobilization by microorganisms involved in the decomposition of carbon-rich plant residues in the soil.

The results from Experiment II indicate that some net mineralization occurred between the spring thaw and June. Available nitrogen present in fertilizer treatments A and B prior to the June application of fertilizers was quite low. It was, in fact, low enough to produce some nutrient deficiency symptoms on the plants at that time.

The addition of fertilizer to Treatment C in August, 1976, resulted in a good nitrogen supply in the early spring and summer. However, since 150 Kg-N/ha were added, the results indicate that this good available nitrogen status was gained at the expense of poorer efficiency in use of the fertilizer nutrients.

With Treatment B, the fertilizer-N added in June was sufficient to maintain adequate supplies of available nitrogen throughout most of the summer growth period. In Treatments 1A and 6A, the levels of available nitrogen varied between only 13 to 34 Kg-N/ha and dropped to very low values (3 to 6 Kg-N/ha) in September. In contrast, Treatment C always contained a good excess of mineral nitrogen. The addition of extra nitrogen in August, 1977, was not considered necessary from a plant nutrition standpoint. A significant amount of the mineral nitrogen remaining at the end of the summer (150 - 169 Kg-N/ha in September) may be lost through denitrification reactions and possibly by some leaching of nitrate.

A comparison of the relative amounts of ammonium-N and nitrate-N present (see Appendix) shows that nitrification was quite active in these soils despite the mildly acidic reaction of the soil.

There were no evident differences in the nitrogen status of peat amended relative to peat + overburden amended soils.

In conclusion, the results indicate that, although mineralization and nitrification seem to be active in six-year old revegetated areas, there is still liable to be poor growth and/or deficiencies of nitrogen during the mid to late summer unless fertilizer nitrogen is added. However, this does not mean that fertilizers should be added under these circumstances. The continued addition of fertilizer may only increase problems by increasing growth and reducing the amount of nitrogen available for plants the next year by creating more intensive microbial immobilization of nitrogen as last year's litter is decomposed.

Although two moderate additions of fertilizers seem warranted in the first year, the results presented here indicate that no more than 150 Kg-N/ha are required during the second year of growth.

8.0 DECOMPOSITION OF PLANT RESIDUES

8.1 Introduction

The decomposition of plant residues is the main route for recycling nutrients in the soil. Plant tissues typically contain 15-60% cellulose, 10-30% hemicellulose, 5-30% lignin, 2-15% proteins and nucleic acids, 5-30% aliphatic acids, 1-25% lipids and 1-13% mineral ash[7]. The first constituents to be removed by microbial decomposition and leaching are water soluble substances such as salts and sugars. After this, more complex materials such as proteins and certain carbohydrates like starch are decomposed followed by cellulose and lignin. The half life of cellulose may be under six months under favorable field conditions while lignin may persist for several years. The rate achieved will depend upon the following factors: the presence of specific organisms capable of the decomposition; pH; moisture; temperature, and the supply of additional nutrients, especially nitrogen.

Where disturbed areas are to be revegetated, it is most important that the fertilizer nutrients added are used efficiently and are steadily recycled within the soil system. In time, decomposition processes will be such that the rates of mineralization and uptake of mineral nutrients reach an equilibrium and the area becomes self-sustaining and largely maintenance free.

The objectives of this experiment were to provide an estimate of the rate of decomposition of plant litter and roots and to indicate what effect previous and current additions of fertilizers have on the decomposition process, especially where nitrogen is concerned.

The same treatments were used as in the mineralization study, viz. T_0, T_2, T_4 and T_5 from Experiment I and 1A, 6A, 1B, 6B, 1C and 6C from Experiment II.

Litter decomposition was studied directly. Samples of plant litter were collected in May, 1977, and the material was air dried in the laboratory. Weighed amounts were placed into nylon net bags which were replaced onto the respective plots in June. Three identical litter bags were prepared so that one sample could be recovered from each replicate every month until September to give exposure times of one, two and three months. The recovered litter was again air dried, weighed and ground for a total nitrogen determination.

It is more difficult to study the decomposition of plant roots so that an indirect method involving the *in situ* decomposition of cellulose was used.

Washed cellulose strips (unbleached cotton) each weighing about 0.5 g were enclosed in nylon mesh and buried to a depth of 10 cm in the soil. Three strips were buried on each plot studied so that one sample could be recovered at monthly intervals between June and September. In addition to the ten treatments in Experiments I and II, strips were also buried in unfertilized overburden and weathered tailings sand. After the strips were dug up they were carefully washed to remove any soil particles, dried at 110°C and reweighed to determine the loss in weight.

8.2 Litter Decomposition

The losses in weight observed are shown in Figures 4 and 5. With Experiment I, the treatments that had either not been fertilized (T_0) or had received fertilizer at a low rate (T_5) showed a progressive but slow decomposition over the three month period (see Figure 4). Where higher rates of fertilizer were employed (T_2 and T_4), the weight loss was more rapid between June and August but no additional weight loss was observed between August and September. The progressive decomposition pattern was shown with the treatments studied from Experiment II. However, the initial rate of decomposition was significantly slower than for the treatments studied from Experiment I. Peat amended tailings sand showed about 25% decomposition between June and September at the lowest fertilizer rate (1A) while at the higher rates (1B and 1C) slightly above 35% decomposition was recorded. The same trend was observed with the overburden plus peat amended soil (Treatment 6) but the amount of decomposition was always less

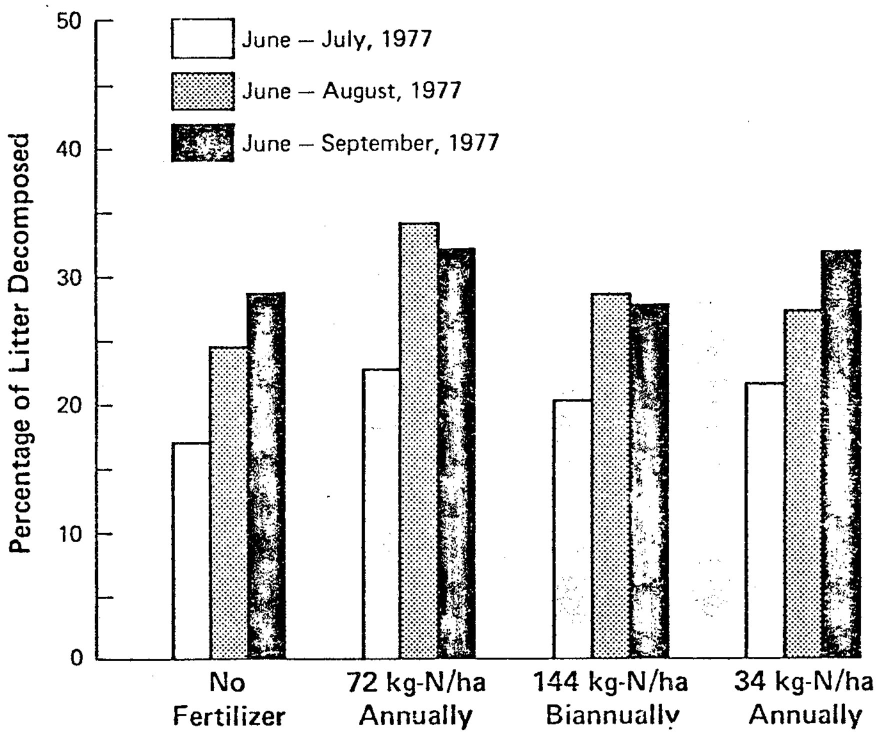


FIGURE 4. Decomposition of Plant Litter Between June and September, 1977, on Treatments T_0, T_2, T_4 and T_5, Experiment I.

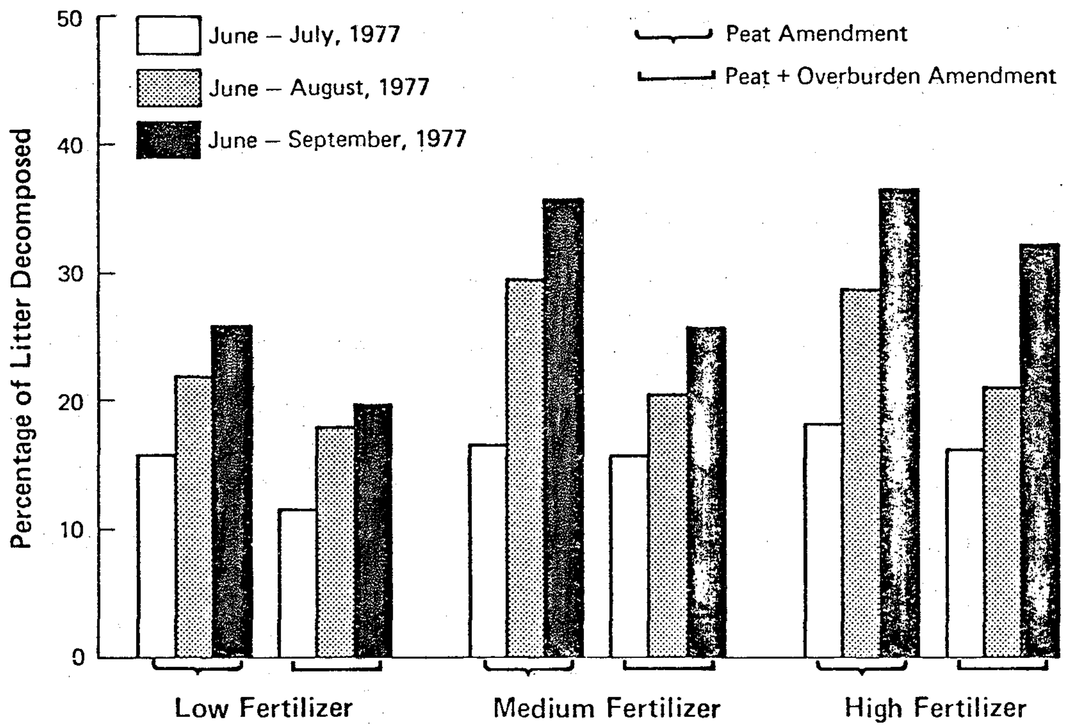


FIGURE 5. Decomposition of Plant Litter Between June and September, 1977, on Treatments 1A, 6A, 1B, 6B, 1C and 6C, Experiment II.

than with tailings sand amended with peat alone. At present, we do not have any explanation for this observation. Changes in nitrogen content of the litter were likewise difficult to explain. The results in Table 36 show the nitrogen content of plant material harvested in September, 1976, the litter at the start of the experiment and at the three sampling times. For material from Experiment I, we can not assume that the material collected as litter in May, 1977, was of the same origin as that harvested in September, 1976. The litter collected is probably a combination of residues from 1975 and 1976. The litter collected from Experiment II primarily originated from oats grown in 1976.

Most treatments showed a slight increase in the percentage of nitrogen content between May and September. However, over this period a net loss in weight was also incurred so that overall generally a small loss in total nitrogen was experienced.

In October, 1977, a second series of litter bags were placed on the same plots. This will extend the study over an entire year and hopefully provide a more complete picture of litter decomposition.

8.3 Cellulose Decomposition

Cellulose is one of the major constituents of plant tissues. Its decomposition in the soil is carried out by a

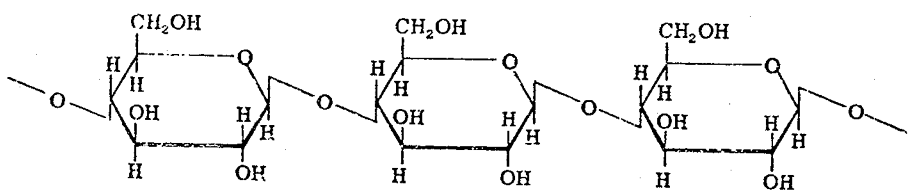
TABLE 36

Changes in Total Nitrogen Content of Plant Litter Decomposing on Site During 1977

Treatment	Total Nitrogen Content (%)				
	September, 1976	Litter as Added May, 1977	May to June 1977	May to July 1977	May to August 1977
Experiment I					
T_0	0.93	1.44	1.36	1.68	1.60
T_2	2.61	1.89	2.14	2.15	2.27
T_4	1.38	1.46	1.72	1.85	1.80
T_5	1.80	1.62	1.78	1.85	2.00
Experiment II					
1A	1.93	1.17	1.60	1.53	1.62
6A	2.05	1.20	1.33	1.35	1.00
1B	2.15	1.23	1.81	1.54	1.60
6B	1.96	1.18	1.48	1.53	1.32
1C	2.29	1.46	1.75	1.85	1.86
6C	2.27	1.52	1.56	1.57	1.48

Values are means of three replicates.

large variety of fungi, actinomycetes, and aerobic and anaerobic bacteria. Protozoa and certain soil animals are probably involved in the later stages of decomposition. Generally, cellulolytic fungi are more predominant in acidic soils while bacteria are the main cellulose decomposers under more alkaline conditions. In addition to the availability of cellulolytic organisms and soil pH, the rate of cellulose decomposition will depend upon moisture, aeration, temperature and particularly the presence of available nitrogen. The cellulose molecule is composed of glucose units bonded together by β 1, 4-linkages as shown below.



β-D-(1,4)-Linked glucopyranosyl residues in cellulose

Each molecule may contain up to several thousand glucose units (8). The cellulose molecule itself contains no nitrogen. However, the microorganisms that decompose cellulose must obtain nitrogen to fabricate new cellular tissue. This nitrogen is either obtained from other components of the plant residue, from other soil sources or from fertilizers.

Generally, the decomposition of cellulose in residues with a C:N ratio above 20 will be slow unless extra nitrogen is added.

Figures 6 and 7 show the decomposition of cellulose strips in Experiments I and II respectively, while Figure 8 shows the decomposition observed for tailings sand and overburden.

There were no large differences between the decomposition of cellulose strips in Experiments I and II. On the average, a weight loss of between 40 to 53% was measured in the first month and up to 75% by the third month. The data for September did indicate that there was a significant response to the addition of fertilizer, particularly when Treatments A, B and C were compared in Experiment II.

The most significant differences were observed where cellulose strips had been buried in tailings sand or overburden. Less than 10% weight loss was recorded for the first month and 28-33% loss in weight after three months. These results could be explained by the low nutrient status of these two materials but it seems more likely that the effect is due to a lack of cellulolytic organisms.

8.4 *Summary*

The decomposition of organic residues with C:N ratios above 20:1 will be slow unless nitrogen is supplied. The

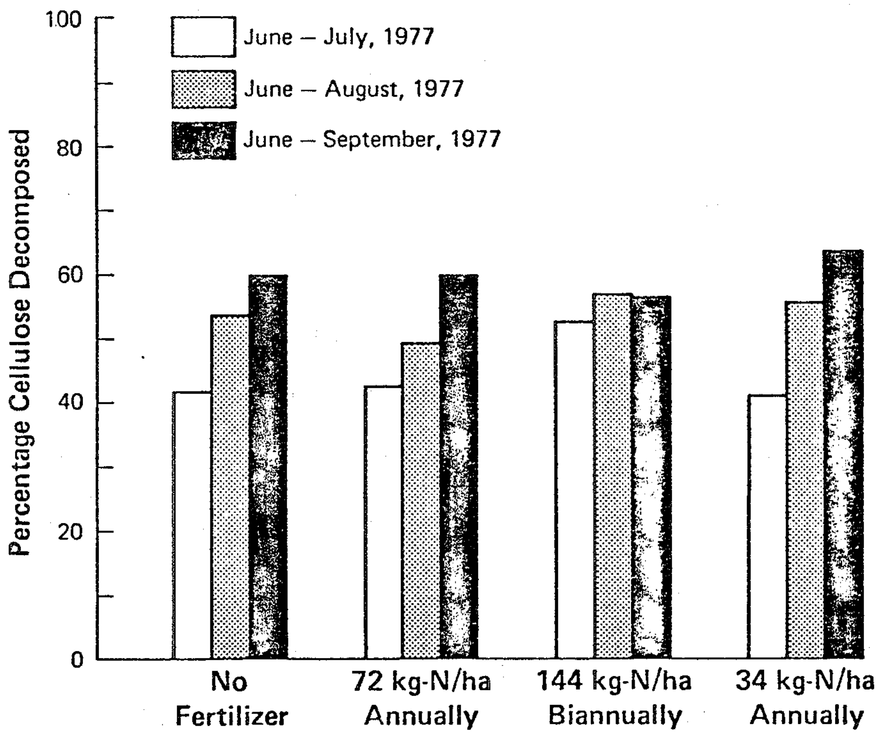


FIGURE 6. Decomposition of Cellulose Strips Added to Treatments T_0, T_2, T_4 and T_5 of Experiment I, 1977.

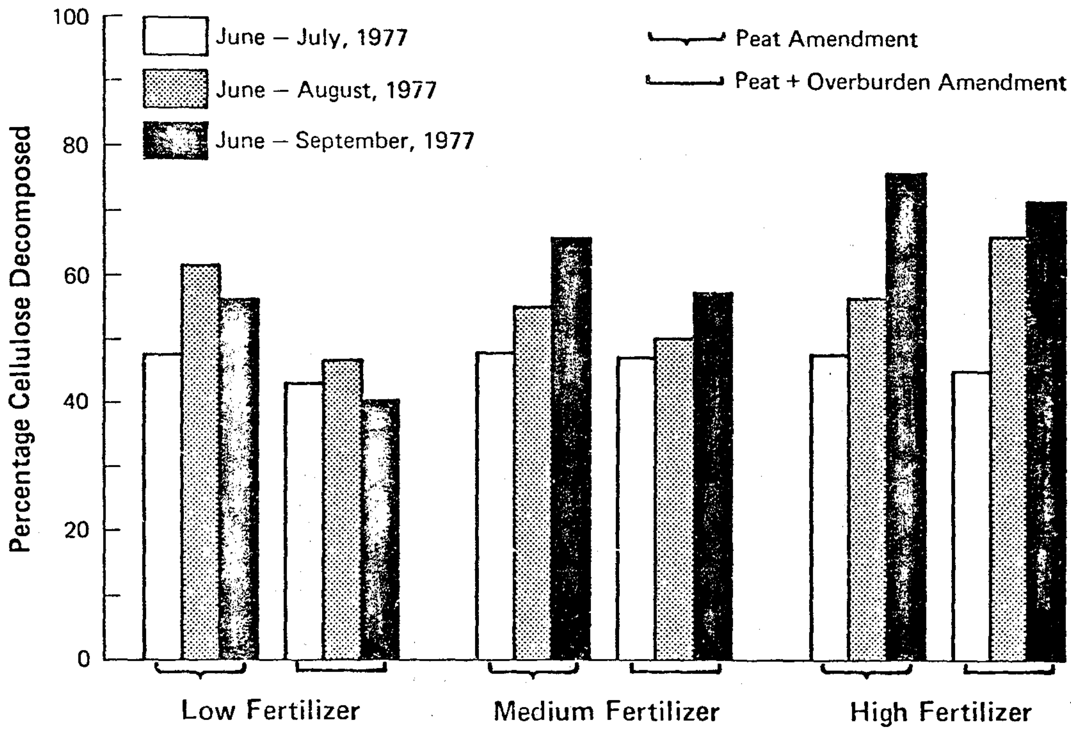


FIGURE 7. Decomposition of Cellulose Strips Added to Treatments 1A, 6A, 1B, 6B, 1C and 6C of Experiment II, 1977.

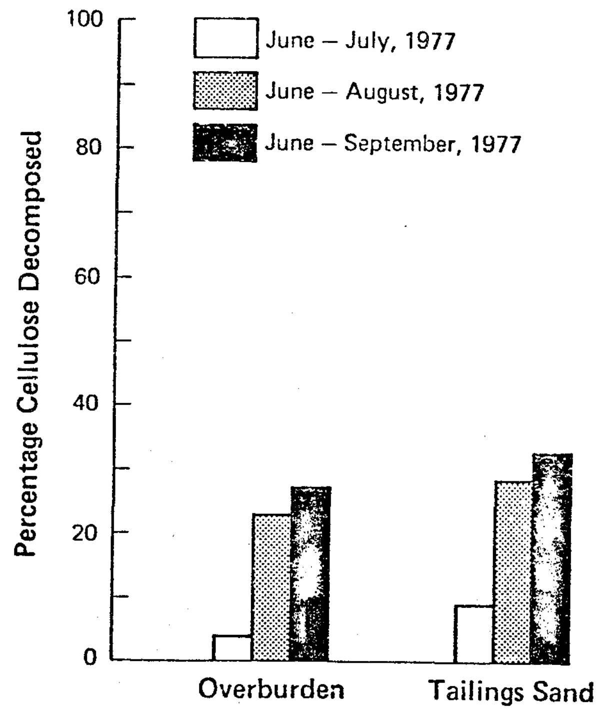


FIGURE 8. Decomposition of Cellulose Strips in Unfertilized Mine Overburden and Weathered Tailings Sand, 1977.

plant litter used in this study was estimated to have a C:N ratio between 25:1 and 40:1. The C:N ratio of plant root tissues on the tailings sand dike probably varies between 30:1 and 55:1. Therefore, decomposition could be expected to result in immobilization of nitrogen and to benefit from addition of nitrogen containing fertilizers.

From the litter study we may conclude that the turnover of litter is stimulated by the application of fertilizers. Similarly, from the data obtained from the decomposition of buried cellulose strips, there is evidence to suggest that root turnover would also be stimulated. This stimulation is a desirable feature since an increase in nutrient turnover means more rapid reuse by plants of the added fertilizer nutrients.

9.0 MICROBIOLOGICAL STUDIES

9.1 Microorganisms and Soil Respiration Rates

A comparison of biological activity in the 0-15 cm depth was again made between the older revegetated area (Experiment I) and the area that was seeded in 1976 (Experiment II). The results are presented in Table 37.

Significantly more aerobic bacteria were present in the older revegetated area than on the newly seeded area of the dike. However, within each area there were no significant differences between the experimental treatments under study. The total numbers of bacteria were within the same range measured last year and varied between 3.4×10^7 and 53.5×10^7 bacteria/g.

Fungal counts were not statistically different between the two areas but were generally one order of magnitude greater than last year.

Soil respiration was also not significantly different between the two areas although the values for Experiment II were slightly higher than last year.

The numbers of bacteria and fungi as well as soil respiration were very low in samples of fresh tailings sand and vegetated tailings sand. In comparison to the two experimental areas, numbers of bacteria were 10-100 times lower,

TABLE 37

Bacterial and Fungal Counts and Total Respiration Rates of Surface Soils from a Revegetated Tailings Sand Slope, 1977

Treatment	Bacteria $\times 10^7$/g	Fungi $\times 10^5$/g	Soil Respiration (mg CO_2-C/100g/hour)
Experiment I			
T_0	44.7	6.8	0.120
T_2	53.5	12.5	0.241
T_4	38.8	19.6	0.217
T_5	44.4	4.9	0.169
Experiment II			
1A	13.0	6.3	0.212
5A	5.0	3.6	0.091
6A	5.7	6.6	0.076
7A	5.8	6.8	0.105
1C	3.4	8.1	0.133
5C	20.0	4.9	0.078
6C	33.3	13.1	0.129
7C	4.3	14.9	0.130
Fresh Tailings Sand	0.30	0.23	0.020
Vegetated Tailings Sand	0.52	0.11	0.028

fungi were 30-200 times lower and soil respiration 3-10 times less. These results conclusively show the beneficial effect of peat or overburden in providing a large inoculum of microbial types to the soil.

9.2 Characteristics of Isolated Bacteria

The previous results indicated that fresh and vegetated tailings sands have considerably lower biological activity than vegetated soils where peat or overburden had been added to the tailings sand. Further studies were conducted to determine whether the bacterial populations differed not only numerically but in physical and biochemical characteristics. The latter feature has considerable practical significance in terms of nutrient cycling capabilities. It has already been demonstrated that the cellulose decomposing abilities of unamended tailings sands and overburdens are rather limited.

Many of the observations and tests that were made on the bacterial isolates were similar to those that would be made to type or classify the organisms. However, classification was not the main objective of this study.

About seventy bacterial colonies were randomly isolated from each treatment. Bacterial growth was aseptically transferred from the dilution plates onto nutrient agar slants. The slants were incubated for seven days at 22°C, flooded with sterile liquid paraffin and the cultures stored under refrigeration at 4°C.

Organisms from fresh tailings sand, vegetated tailings sand and from Treatment T_0, 1C and 6C were compared. The various testing methods used have already been discussed in the methodology section. A summary of the results is given in Table 38. The two tailings sand samples were generally similar as were the bacterial populations from the amended and vegetated treatments T_0, 1C and 6C. The pure tailings sands contained predominantly Gram negative short rods or cocco-bacilli. They were less frequently catalase positive than bacteria from the experimental plots. They showed a poor ability to grow in the presence of high sodium chloride concentrations or 0.1% phenol. These results are rather surprising in view of the high sodium content and high levels of naphthenic acid type compounds present in fresh tailings sand slurries. These bacteria also showed a limited ability to degrade gelatin or starch or use citrate as a sole source of carbon. These latter characteristics may indicate that these organisms would demonstrate a poor ability to use many of the common classes of compounds in plant residues.

Some differences were observed between the fresh and vegetated tailings sands that indicate that the vegetated sand has some similarities to the bacterial populations from peat and overburden. For instance, a greater ability to degrade starch and gelatin and use citrate was shown by the vegetated

TABLE 38

Characteristics of Bacteria Isolated from Fresh and Vegetated Tailings Sand and from Peat-Overburden-Tailings Sand Mixes

	Fresh Tailings Sand	Vegetated Tailings Sand	T_0, Peat, 6 Year Growth	1C, Peat 1 Year Growth	6C, Peat-Overburden 1 Year Growth
Total No. Isolates	68	66	65	49	67
Gram + (%)	13	13	25	29	42
Gram - (%)	71	67	46	59	33
Gram Variable (%)	16	20	29	12	25
Rods (%)	12	11	12	16	5
Cocco-bacilli and short rods (%)	86	86	57	69	89
Cocci (%)	2	3	31	15	6
Motile (%)	91	85	88	84	91
Catalase + (%)	66	64	88	90	96
Growth at pH 9.5 (%)	81	83	89	96	90
Growth on 10% NaCl (%)	22	38	75	71	78
Liquification of gelatin (%)	32	59	78	80	88
Growth on starch (%)	26	50	34	41	63
Tolerance to 0.1% phenol (%)	37	35	77	65	79
Tolerance to phenol with pigment production (%)	4	9	32	16	25
$NO_3 \rightarrow NO_2$ (%)	44	21	32	55	60
Citrate sole-C (%)	18	38	66	65	72
Production of spores (%)	10	11	8	12	5
Color: white or cream (%)	74	64	92	71	82
yellow (%)	20	34	8	25	18
orange (%)	3	0	0	2	0
purple (%)	3	2	0	2	0

sand. The fresh tailings sand contained a greater percentage of isolates that produced nitrite from nitrate, a characteristic which is probably linked to the water saturated and anaerobic nature of the sand around the tailings pond.

Samples that included peat or peat and overburden contained more bacteria that were Gram positive. They were also generally catalase positive and could grow at high pH and tolerate salts and phenol. A greater proportion of the isolates could use citrate as a sole source of carbon for growth. Most of the variations encountered between isolates from Treatments T_0, 1C and 6C involved the ability to grow on starch and the relative abundance of cocci to rods and short rods.

The number of organisms that produced spores after fourteen days' growth on soil extract agar was quite low (5-12%) in the five samples studied.

In terms of specific bacterial types, the tailings sand samples seemed to contain mainly *Pseudomonas* sp. while both *Pseudomonas* sp. and *Arthrobacter* sp. were commonly found in the peat and peat plus overburden amended soils. *Bacillus* sp. did not seem to exceed 10% in any of the samples studied. *Pseudomonas* sp. and *Arthrobacter* sp. are generally the dominant types found in soils. *Pseudomonas* sp. are often more common in the rhizosphere around plant roots.

10.0 GENERAL CONCLUSIONS

10.1 Fertilizer Requirements

The research has had two main objectives. The first is the short term objective of erosion control which requires the rapid establishment of vigorously growing plant cover. The second is a long term objective which concerns the maintenance of an adequate plant cover in such a way that the area can be left as a self-sustaining and maintenance-free unit.

The work during 1975 indicated that tailings sand amended with peat, overburden, or mixtures of peat and overburden could provide a rich enough growth medium if fertilizer nutrients were also added.

The field work in 1976 demonstrated that the addition of fertilizers at or above a rate of 80 Kg-N; 35 Kg-P; 75 Kg-K; and 20 Kg-S per hectare were adequate to produce an erosion -free cover of plants during the first year.

This year's work shows that this cover can be maintained at an acceptable quality to avoid erosion by the addition of only 80 Kg-N; 35 Kg-P; and 75 Kg-K in the second year. Plant growth becomes mildly nutrient deficient at times but the plant species growing represent a good balanced distribution from the original grass-legume seed mix.

A much better cover can be obtained by adding either one or two applications of fertilizer at a higher rate (e.g. 150 Kg-N; 40 Kg-P; 150 Kg-K/ha in June or in June and August). However, in this case, the legumes and smaller grasses tend to compete less favorably with the high yielding Brome and Wheat-grasses.

Is a real benefit obtained from the legumes other than the adequate cover produced at the low fertility regime?

How does the fertilizer program affect the time taken for the area to become a self-sustaining unit? For example, does adding greater amounts of fertilizers during the first few years increase nutrient uptake into the plant-soil system? Will this potential for increased nutrient cycling enable the area to become self-sustaining at an earlier time than the low fertility grass-legume area?

At the present time we can tentatively propose two fertilizer schemes to provide good erosion control on tailings sand dikes that have been amended with peat or mine over-burdens. One will result in a grass-legume cover while the other will produce a dense grass cover.

	BALANCED GROWTH OF GRASSES AND LEGUMES		GRASS GROWTH
Year 1	May - Seed - Add 75 Kg-N, 40 Kg-P, 75 Kg-K per ha.	Year 1	May - Seed - Add 150 Kg-N, 40 Kg-P, 150 Kg-K per ha. July - Add 100 Kg-N, 100 Kg-K per ha.
Year 2	June - Add 75 Kg-N, 40 Kg-P, 75 Kg-K per ha.	Year 2	June - Add 150 Kg-N, 150 Kg-K per ha.
Year 3	Eliminate or reduce fertilizers.	Year 3	Eliminate or reduce fertilizers.

10.2 Fertilizer Losses

Results indicate that once plant growth is established, fertilizer losses are very small even where comparatively large additions of fertilizer are made. Fertilizer losses by water runoff and leaching were reduced to about one-tenth of those occurring in 1976.

An August application of fertilizer at a rate equivalent to 150 Kg-N/ha does not seem necessary or efficient. When high levels of nitrate accumulate, there is a high potential for losses of nitrogen by denitrification reactions even in well aerated soils.

10.3 Nutrient Cycling

The results of soil analysis in early spring showed that in both revegetated areas mineralization of soil organic matter containing nitrogen was occurring. Preliminary work on litter and cellulose decomposition seems to indicate that the addition of fertilizer is effective in accelerating decomposition. Where fertilizers have been added, the residues have a lower C:N ratio and hence are more readily decomposed by soil microorganisms. Additionally, the nutrients in the added fertilizer can be used directly by the microbes to decompose the plant residues. This, of course, means less nutrient uptake by plants but so far, at the fertilizer rates used, no severe immobilization of nutrients has been noted. This may not be the case in subsequent years when fertilizers may be reduced or cut off entirely.

10.4 Benefit of Deep Rooting

Encouraging results from the deep rooting study indicate that deeper penetration of roots is obtained by increasing the depth of incorporation of peat and overburden to 30 cm. In addition, an overall improvement in total root yields is obtained. Subsequent work should indicate how this affects overall stability and whether this is worthwhile in view of the additional materials handling and tillage required.

10.5 Development of Normal Soil Biological Characteristics

Most of the biological parameters measured in 1977 were not greatly different from the previous year. However, comparisons of the old experimental area with the newly seeded part showed that bacterial and fungal numbers, specific bacteria species and total soil activity were becoming more similar. Both areas seemed biologically similar in respect to undisturbed soils.

Bacterial populations from fresh tailings sand and re-vegetated pure tailings sand could not be considered normal. The bacterial species in these soils had a low ability to grow on commonly occurring substances such as starch, gelatin and citrate. Pure tailings sand had a poor ability to decompose cellulose, the most common constituent of plant residues. The addition of peat to tailings sand adds useful organisms that are able to carry out transformations required for nutrient cycling in soils.

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