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REVEGETATION AND MANAGEMENT OF TAILINGS SAND SLOPES FROM TAR SAND EXTRACTION: 1978 RESULTS

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F O R E W O R D

Syncrude Canada Ltd. is producing synthetic crude oil from a surface mine in the Athabasca Tar Sands area of north-eastern Alberta. This report is the fifth in a series of reports describing revegetation experiments initiated by Syncrude Canada Ltd. on the slopes of the Great Canadian Oil Sands (now Suncor) tailings pond dyke. The previous four reports are numbered 1974-3, 1977-1, 1977-4, and 1978-5 in Syncrude's Environmental Research Monograph series.

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REVEGETATION AND MANAGEMENT OF TAILINGS SAND SLOPES FROM TAR SAND EXTRACTION: 1978 RESULTS

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SYNCRUDE CANADA LTD.

ENVIRONMENTAL AFFAIRS DEPARTMENT

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This is the fourth annual report on the study of different aspects of land reclamation in the Athabasca Tar Sand region of Alberta. The work was carried out for Syncrude Canada Ltd. under Contract No. 98-8021-CD.

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SUMMARY

The results are reported of research into the revegetation of two areas on a steeply sloping dike composed of tailings sand from tar sand extraction at the Great Canadian Oil Sand Limited plant at Fort McMurray, Alberta.

One area was seeded with three pasture grasses and two legumes in 1971 after the slope surface had been mixed with peat to a depth of 15 cm.

A second area had been amended with peat or peat and overburden and differing rates of fertilizer added. A mix containing nine grasses, four legumes, and oats, as a companion crop, was seeded in July, 1976.

The objectives of the research were to study methods for the establishment of a stable vegetative cover that would prevent erosion of the slope and, in time, might become a self maintaining unit. Tillage of soil amendments to a depth of 15 cm and 30 cm were compared in promoting deeper rooting and stabilizing of the slope.

Total precipitation at the G.C.O.S. site amounted to 539 mm in 1978 and included several periods of heavy continuous rainfall. The areas seeded in 1971 and 1976 showed little signs of erosion in 1978 and were considered stable.

The yield of above ground vegetation varied from 0.145 Kg/m^2 where no fertilizers had been added in 1978 to up to 0.588 Kg/m^2 where fertilizers had been added. Fertilizer additions significantly increased the uptake of nitrogen and potassium and to a lesser extent phosphorus and sulfur into the shoot tissues. Fertilizers had no significant effect on root mass production and less influence in uptake of specific elements.

Deeper rooting was promoted by the deeper incorporation of peat and overburden. Yet in view of the stable soil surface conditions that could be obtained by tillage to 15 cm, deeper tillage could not be justified.

Soil pH did not show any significant change over previous years. However, a reduction in soluble salt concentrations were noted, particularly where moderately saline overburden had been used as a surface amendment.

The effectiveness of different fertilizer programs was assessed in terms of biomass production, nutrient uptake and the efficiency of use

of the added fertilizer nutrients. On the older established area, an erosion-free surface still exists where no additional fertilizers have been added since 1974. However, in terms of maintaining a vigorous cover and the efficient use of fertilizers, an annual fertilizer addition of about 90 Kg-N; 25 Kg-P and 40 Kg-K per hectare is recommended.

Where peat or peat and overburden are used on the tailings sand surface, fertilizer should be added at a rate of 60-80 Kg-N; 40 Kg-P and 60-80 Kg-K per hectare in the first year to obtain the most efficient use of the fertilizers. Depending upon the species distribution required, this rate could either be increased or decreased over the next two years.

The availability of nitrogen and potassium changed over the summer. Differences were related to previous and current fertilizer additions as well as to rates of uptake by the plant cover. Phosphorus availability was more constant over the growing season.

Plant litter added in October, 1977, had a half-life of about twelve months. The initial rate of decomposition was faster on the older revegetated area than on that established in 1976.

Buried cellulose strips (added in October, 1977) had a half-life between seven and eleven months with again a more rapid rate of decomposition observable at the older site. Both litter and cellulose decomposition rates were correlated with total soil respiration and to a lesser extent with numbers of aerobic microorganisms.

Analysis of decomposing litter residues indicated different patterns in the release of the major plant nutrients. Potassium was readily leached from the litter, 60-80% being lost over the October 1977 to May 1978 period. Initially, losses in nitrogen were more gradual but a 30-70% reduction in nitrogen content had occurred over a twelve month period. Phosphorus mineralization was initially slight, equivalent to less than one-third lost between October and May, while in the total twelve month period the phosphorus content had decreased by 50-90%.

Sulfur mobilization from litter was anomalous in that gains in litter sulfur were noted until the latter part of the year when the content began to drop.

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1. INTRODUCTION

The deposits of tailings sand that result from tar sand extraction operations are particularly susceptible to wind and water erosion. The problem is most severe on tailings sand dikes where slopes of 20-25% are commonly created.

Soil stability can be improved by vegetating the slope and thereby providing a resilient intercepting surface for raindrops and a root system that anchors the soil in position.

However, a plant cover that is adequate for erosion control is not easily achieved on untreated tailings sand slopes due to their inherent low fertility, erodibility and low moisture content. Addition of materials such as peat, mine overburden, and fertilizers have proved useful amendments in the reclamation of tailings sand slopes.

This report represents the fourth year's results of a study into the establishment of vegetation on steeply sloped areas of tailings sand in the Athabasca tar sands region of Alberta.

The experimental sites that are described are located on the tailings sand dike at the Great Canadian Oil Sands Limited tar sand extraction plant 50 km north of Fort McMurray (legal location 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 after peat had been tilled into the tailings sand surface. Several fertilizer programs have been studied to assess their effectiveness in maintaining an erosion-free surface and improving nutrient availability in the soil.

In 1976, two additional experiments were started on hitherto unvegetated sand. One area was used to investigate the performance of a seed mix containing a variety of commercial pasture grasses and legumes seeded into the tailings sand amended with peat or peat plus overburden. Three different fertilizer programs were studied. The minimal fertilization program involved low rates of nutrient additions in the first two years followed by discontinuance of fertilizer additions. The medium approach involved moderately high fertilization in the first two years followed by reduced application in subsequent years. A third approach employed two applications of fertilizer during each of the first two years followed by reduced annual application in the third year. The effect of these management practices on species distribution, cover, fertilizer use and subsequent nutrient release by decomposition of plant residues are being studied, particularly in relation to whether or not such areas eventually become self-sustaining.

A second area was set aside to study the effect of deeper tillage of peat and overburden on improved plant rooting and soil stability.

2.0 ANALYTICAL METHODS

2.1 Sampling and Laboratory Preparation

Soil samples were taken with an Oakfield soil sampler. Each sample was a composite of 6-12 randomly located cores taken from each replicate of each treatment. The outside 1 m of each plot was not sampled to avoid edge effects. The soil cores were broken up by hand in the laboratory and a subsample was taken to determine the field moisture contents. Samples were air dried and ground to 2 mm and stored for analysis.

Plant samples were obtained by hand clipping one randomly located m^2 area from each replicate of each treatment to a height of about 1 cm. 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 from each replicate of each treatment. To reduce decomposition of the root tissues, 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.

Samples of plant tissue harvested in September, 1977, had been added to the plots during October, 1977. The plant litter was enclosed in fine nylon mesh bags which were recovered at intervals and reweighed. During 1978, a set of litter bags were recovered in May, July and November. Each bag was carefully cut open and the contents weighed after drying at 35°C in a forced-air oven.

In a similar study, weighed strips (about 0.5 g) of unbleached cotton enclosed in a nylon mesh bag were buried to a depth of 10 cm in the soil during October, 1977. A set of these cellulose strips were recovered during May, July and November of 1978. The undecomposed material was gently washed in a mild detergent solution to remove any soil particles. The loss in weight was determined after drying the washed strips at 100°C in a forced-air oven.

2.2 Chemical Analysis

Details of the methods used may be found in Agronomy Monograph No. 9[1] or in the Manual on Soil Sampling and Methods of Analysis[2].

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.

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* *Nitrate measured after reduction with Devarda's Alloy.*

Available phosphorus was measured using a Technicon Autoanalyzer after extraction with 0.03N ammonium fluoride/0.3N sulfuric acid solution. Sulfate was extracted with 0.001M calcium chloride and the concentration of sulfate determined using a Technicon Autoanalyzer.

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, potassium and sulfur were determined as described for the soil samples. Magnesium, calcium, iron, manganese, copper and zinc were determined by atomic absorption spectroscopy. Boron was determined using a Technicon Autoanalyzer.

Total nitrogen was determined by Kjeldahl digestion using a temperature programmable Tecator block digestor followed by steam distillation.

2.3 Biological Methods

Soil respiration rates were determined in the laboratory. The soils were allowed to incubate for two weeks at field moisture content. A 40 g sample was placed in a litre capacity polythene container in which a small vial containing sodium hydroxide was placed. The container was sealed and 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.

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

2.4 Statistical Methods

The replicated data were treated statistically to determine standard deviation about the mean and to indicate significant treatment differences using an analysis of variance. Where statistical treatment of the data was carried out, the following notations appear in the tables:-

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

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

3.0 RESULTS

3.1 Climatological Data

Table 1 shows a summary of climatological data obtained from the G.C.O.S. meteorological station during 1978.

The year was characterized by cool summer temperatures and frequent rainfall. A total of eleven days were recorded with rainfall in excess of 10 mm. A total of 402.4 mm was recorded in the May 1 to October 31 period which includes the period of most plant growth.

3.2 Experiment I - Studies on a Tailings Sand Slope Amended with Peat and Seeded in 1971

3.2.1 *Introduction*

Only a brief description of the experimental design will be given here since more detailed accounts are available in the previous papers and monographs[3-6].

The experimental site of about 0.8 hectares is situated on the east-facing slope of the Great Canadian Oil Sands Limited tailings sand dike. The tailings sand surface was amended with a layer of peat approximately 15 cm in depth which was mixed into the tailings sand surface. In May, 1971, the area was seeded with a seed mix containing 33% Brome Grass by volume, 24%

TABLE 1

Temperature and Precipitation Data for 1978

	Precipitation			Temperature		
Month	Rainfall (mm)	Snow (cm)	Equivalent Total (mm)	Mean Maximum (°C)	Mean Minimum (°C)	Mean (°C)
January		17.1	17.1	-16.0	-26.9	-21.7
February		7.7	7.7	- 7.6	-19.9	-13.7
March		15.5	15.5	no data available		
April	44.2	17.8	62.0	7.7	- 3.1	2.3
May	24.0		24.0	16.6	4.2	10.4
June	80.6		80.6	20.8	9.1	14.9
July	26.7		26.7	21.7	10.3	16.0
August	92.3		92.3	20.0	8.0	14.0
September	150.0		150.0	14.5	5.7	10.1
October	28.8		28.8	10.8	0.5	5.8
November	1.2	18.5	19.7	- 4.7	-14.6	- 9.6
December		14.4	14.4	-13.7	-29.0	-21.4
		*TOTAL**	538.8			

* *Total as snow* 91.0 cm equivalent
Total as rain 447.8 mm

Days of Heavy Rainfall

April 9	40.6 mm	Aug. 14	12.4 mm	Sept. 7	13.0 mm
April 16	32.3 mm	Aug. 25	22.1 mm	Sept. 8	49.0 mm
Aug. 10	16.2 mm	Sept. 1	19.0 mm	Sept. 22	23.6 mm
Aug. 11	13.3 mm	Sept. 3	16.2 mm		

Crested Wheatgrass, 15% Creeping Red Fescue, 14% Sweet Clover and 14% Alsike Clover. This area received six small additions of fertilizer between May 1971 and July 1974.

In June, 1975, a replicated field experiment was set up to study the effectiveness of different fertilizer programs in improving the stability of the dike surface by stimulating plant growth. Fertilizer treatments ranged from no application at all to high annual additions of nitrogen, phosphorus and potassium containing mineral fertilizers.

Figure 1 shows the experimental design while Table 2 shows the amount of fertilizer that has been added to date.

3.2.2 *Soil*

As in previous years, soil samples were taken to determine field moisture contents, pH, electrical conductivity and the concentrations of available plant nutrients. In 1978, samples were taken in September. Each treatment was sampled to a depth of 30 cm which contains over 80% of the root biomass. Selected treatments were sampled to a depth of 120 cm to assess nutrient leaching and salt movement. These selected treatments (T_0, T_2, T_4 and T_5) were also involved in a separate study concerned with monitoring nutrient availability over the entire summer (see Section 3.5). The results of the September sampling are presented in Table 3.

Soil moisture:

Due to the wet August of 1978, moisture contents later

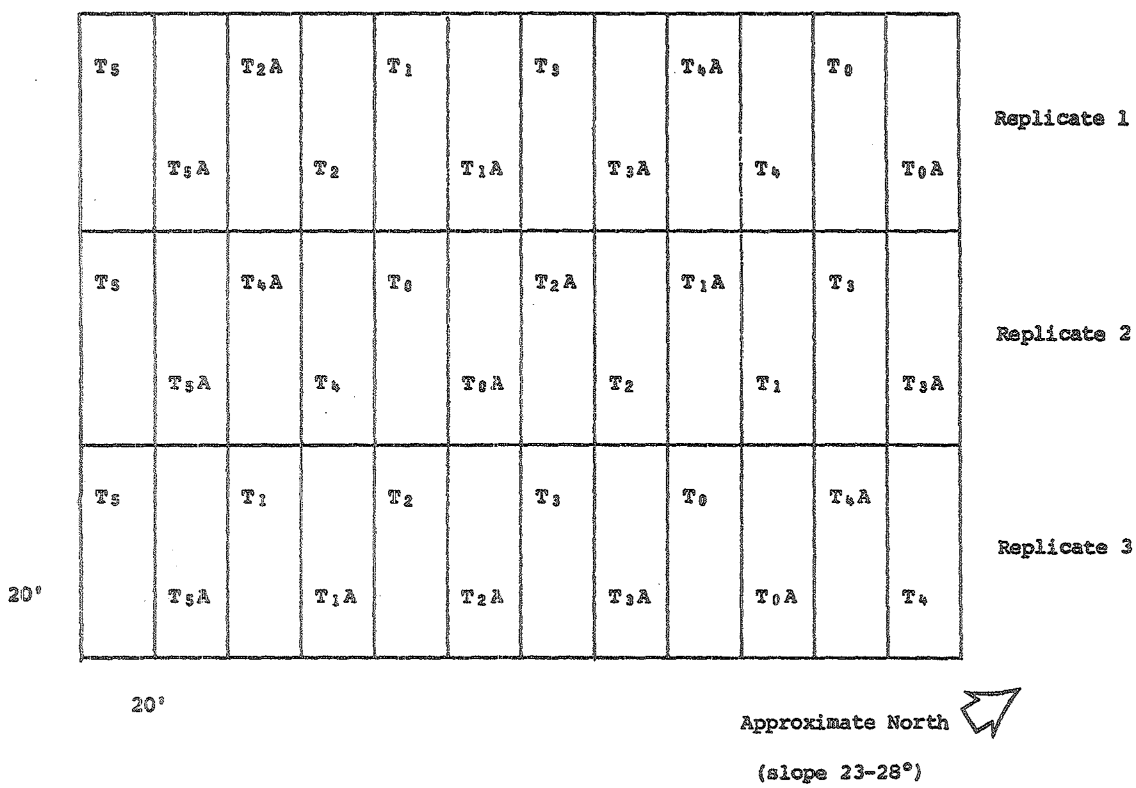


FIGURE 1. Design of Field Experiment I on a Vegetated Tailings Sand Dike at the G.C.O.S. extraction plant, Fort McMurray, Alberta.

TABLE 2

Fertilizer Addition to a Vegetated Tailings Sand Dike at the G.C.O.S. Extraction Plant at Fort McMurray, Alberta, between 1971 and 1978

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
1975												
N	0	90	90	180	90*	180*	180	360	180*	360*	41	91
P	0	0	23	23	23	23	46	46	46	46	12	12
K	0	0	90	90	90	90	180	180	180	180	22	22
S	0	9	9	18	9	18	18	18	18	18	40	40
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
1977												
N	0	90	90	180	90	180	180	360	180	360	43	112
P	0	23	23	46	23	46	46	92	46	92	11	11
K	0	90	90	180	90	180	180	360	180	360	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
1978												
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
Total												
N	279	359	639	819	639	819	639	1019	639	1019	449	568
P	138	161	230	253	230	253	230	276	230	276	183	183
K	188	278	548	638	548	638	548	728	548	728	276	276
S	0	9	9	18	9	18	18	36	18	36	67	67

* Lime added at 4.5 Tonnes/ha.

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

TABLE 3

Results of Soil Analysis for Samples Taken in September, 1978, from Experiment I

Treatment	Depth (cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	NH_4-N (ppm)	NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)
T_0	0-15	31.3	6.36	0.32	13.0	4.5	19	90	21
	15-30	11.2	6.58	0.34	5.9	1.4	6	29	18
	30-60	7.7	6.75	0.36	8.3	3.0	3	15	12
	60-90	8.3	7.53	0.39	9.6	3.3	3	19	10
	90-120	9.4	7.55	0.45	7.9	1.4	3	30	14
T_0A	0-15	39.2	6.24	0.40	18.1	3.7	28	78	20
	15-30	9.0	6.29	0.39	11.4	4.3	10	24	15
T_1	0-15	30.5	5.86	0.64	19.9	2.8	25	74	39
	15-30	8.3	6.33	0.81	10.7	3.8	8	29	43
T_1A	0-15	42.5	6.17	0.60	21.5	6.3	34	257	39
	15-30	8.4	6.63	0.65	7.1	2.0	9	31	33
T_2	0-15	45.8	6.61	0.67	16.9	5.4	27	278	31
	15-30	9.5	6.85	0.58	10.8	4.1	8	41	26
	30-60	5.4	7.05	0.57	7.3	1.1	3	17	19
	60-90	13.6	7.03	0.50	4.8	3.1	3	16	21
	90-120	6.6	7.30	0.42	5.0	3.9	3	14	13
T_2A	0-15	47.8	6.57	0.78	7.6	5.3	34	234	48
	15-30	8.1	6.83	0.80	7.2	3.7	8	36	41
T_3	0-15	40.6	6.25	0.44	11.1	5.2	36	222	28
	15-30	18.9	6.51	0.49	4.6	1.4	14	49	28
T_3A	0-15	50.7	6.27	0.43	14.6	7.7	35	249	23
	15-30	16.7	6.62	0.54	9.0	5.2	9	44	31
T_4	0-15	51.5	6.67	0.83	8.1	1.8	29	206	31
	15-30	13.0	6.75	0.59	6.5	3.3	10	61	34
	30-60	6.1	7.02	0.53	6.1	4.3	4	25	20
	60-90	7.2	7.58	0.50	2.5	1.3	3	31	13
	90-120	7.1	7.64	0.57	5.3	3.4	3	24	17
T_4A	0-15	41.8	6.73	0.73	13.1	8.2	34	296	40
	15-30	10.1	6.54	0.91	3.7	2.1	11	78	65
T_5	0-15	49.8	6.36	0.65	18.7	4.1	25	184	63
	15-30	11.2	6.84	0.53	9.6	4.7	8	43	29
	30-60	6.2	7.60	0.52	3.3	1.9	4	14	18
	60-90	6.7	7.88	0.61	5.0	3.1	4	23	19
	90-120	6.6	8.09	0.62	7.2	3.2	3	20	19
T_5A	0-15	54.0	6.30	0.57	17.5	2.7	22	174	37
	15-30	14.0	6.55	0.82	9.0	3.2	16	43	75

Results are means of 3 replicates.

in the summer were generally higher than had been recorded in previous years at a similar date. Soil moisture varied between 30.5% and 54.0% in peat-rich layers at the 0-15 cm depth and from between 5.4% and 13.6% in the tailings sand layers at a depth of 30-120 cm. No moisture stress in the plants could be expected at this time. In addition, there were no apparent differences in moisture levels between the treatments dominated by Brome Grass in comparison to those where Creeping Red Fescue was the main grass.

pH:

Surface soil pH values have not shown any large fluctuations over the past four years. Prior to treatment in 1971, the tailings sand surface had a pH of about 8.5. After the addition of the peat, the surface pH was between 5.9 and 6.8 depending upon specific fertilizer treatments or lime additions given. In September, 1978, pH in the 0-15 cm depth varied between 5.86 and 6.76. Those treatments that received lime in 1975 (T_2, T_2A, T_4 and T_4A) had surface pH's that were about 0.5 units higher than similarly fertilized unlimed treatments. Heavily fertilized, unlimed treatments, such as T_1, T_1A, T_3 and T_3A, typically exhibited the lowest surface pH values. Plants on plots with a surface pH below 6 did not show significantly poorer growth than those growing on similarly fertilized but lime-treated areas.

Soil pH increases with depth. In September, 1978, values between 7.30 and 8.09 were recorded at a depth of 120 cm.

Electrical conductivity:

Soluble salt concentrations, as indicated by electrical conductivity measurements, were well within the range tolerated by plants. Surface conductivity values varied between 0.30 and 0.83 mmhos/cm with the highest values recorded with treatments that had a history of high fertilizer additions. In general, electrical conductivities throughout the soil profile were lower than had been found in previous years. This could have resulted from greater leaching during the wet August of 1978.

Available nutrient concentrations:

The concentrations of mineral nitrogen found in the soil were generally higher than in previous years at a similar time. The amount of ammonium nitrogen was greater than nitrate nitrogen even where fertilizer had been added either in June (e.g. Treatments T_1, T_1A, T_2, T_2A and T_5) or in both June and August (e.g. T_5A). This seemed to indicate that nitrification rates had been reduced by the high soil moisture in the late summer. Leaching of nitrate may have been more intense in August than in previous years. Nitrification may also have been low during the very dry July.

No significant differences were observed in mineral nitrogen concentrations in the surface between unfertilized or poorly fertilized treatments (e.g. T_0, T_0A, T_5 and T_5A) and the other more liberally fertilized treatments. This was contrary to the previous three years' experience.

Ammonium nitrogen varied between 7.6 ppm and 21.5 ppm in the surface 0-15 cm and between 3.7 ppm and 11.4 ppm in the 15-30 cm depth. In contrast, nitrate nitrogen ranged between only 1.8 ppm and 8.2 ppm at the surface and between 1.4 ppm and 5.2 ppm in the 15-30 cm depth.

Concentrations of mineral nitrogen were higher at greater depth than generally had been found in previous years. Ammonium nitrogen varied between 2.5 ppm and 9.6 ppm and nitrate nitrogen between 1.1 ppm and 4.3 ppm in the 30-120 cm depth samples. These above normal mineral nitrogen levels at depth possibly indicate that some leaching losses of nitrogen may have occurred during August and September.

Available phosphorus concentrations showed a similar trend to previous years in that moderate amounts were present at the surface while very little occurred below a depth of 30 cm. The highest concentrations were found in treatments that had received the higher applications of phosphate fertilizers since 1975. However, results from unfertilized or poorly fertilized treatments (e.g. T_0, T_0A, T_5 and T_5A) still indicated a moderately good supply of plant available phosphorus.

Similarly, the highest available potassium concentrations were found in treatments that had received the highest rates of potassium fertilizer since 1975. Most of the available potassium was found in the surface 15 cm (74 ppm - 296 ppm). Only 14 ppm - 61 ppm was found below a depth of 30 cm.

Wide variation in sulfate sulfur concentrations were found between treatment replicates. Values were generally lower than had been recorded in previous years at a similar time of the year. Surface concentrations varied from 20 ppm to 63 ppm and indicated adequate amounts of sulfate sulfur for plant growth.

3.2.3 *Plant Growth*

The early plant cover was markedly superior to that at a similar time last year, presumably due to the good moisture status of the soil.

A complete assessment of plant cover was made during May and October, 1978, (see Appendix - Table I). A comparison of plant species distribution for four of the main treatments between 1974 and 1978 is shown in Table 4. Significant changes in the frequency of different grasses and legumes have occurred during this time in response to the different fertilization programs. Brome Grass has progressively become more dominant where fertilizers have been added. Creeping Red Fescue has competed more favorably on the unfertilized or poorly fertilized areas. Within the past two years, a noticeable increase in legume growth has occurred on the unfertilized T_0 treatment. Increased atmospheric nitrogen fixation by these legumes may have been responsible for the above anticipated mineral nitrogen status of the soil under this treatment.

Plant productivity assessments from clippings made in September (Table 5) indicated a direct relationship between above-ground biomass production and fertilizer addition. The highest top yields were generally found in treatments such as T_1, T_1A, T_2 and T_2A that had received an increment of fertilizer

TABLE 4

Assessment of Percentage Cover by Different Seeded Grasses and Legumes Between 1974 and 1978

	Species Distribution (% Cover)														
	Creeping Red Fescue					Brome Grass					Alfalfa and Alsike Clover				
Treatment	1974	1975	1976	1977	1978	1974	1975	1976	1977	1978	1974	1975	1976	1977	1978
T_0	90	100	88	88	72	9	0	9	1	5	1	0	3	11	23
T_2	90	93	50	23	1	9	7	50	77	99	1	0	0	0	0
T_4*	90	92	69	32	10	9	8	25	67	88	1	0	1	0	2
T_5	90	96	80	74	58	9	4	19	24	33	1	0	1	2	9

*T_4 contained 5% Crested Wheatgrass in 1976

1% " " in 1977

2% " " in 1978

TABLE 5

Dry Matter Yield of Plant Tissue, Experiment I, 1978

	Yield (Kg/m^2)				
	Tops	Roots			
Treatment		0-15 cm	15-30 cm	30-60 cm	Total
T_0	0.145	0.771	0.128	0.029	0.928
T_0A	0.313				
T_1	0.518				
T_1A	0.555				
T_2	0.434	0.779	0.132	0.018	0.928
T_2A	0.588				
T_3	0.436				
T_3A	0.449				
T_4	0.367	0.981	0.114	0.018	1.113
T_4A	0.436				
T_5	0.194	0.926	0.104	0.045	1.075
T_5A	0.445				
Significance	***				N.S.
L.S.D.	0.105				

Results are means of 3 replicates.

equivalent to 90 Kg-N, 23 Kg-P and 90 Kg-K per hectare in June, 1978. The residual effect of fertilizers added in June and August, 1977, were invariably noted when equivalent comparisons could be made. For instance, dry matter production from Treatment T_2A, which received fertilizer in June and August, 1977, as well as in June, 1978, was significantly higher than Treatment T_2 which did not receive the August, 1977, application.

Those treatments receiving no fertilizer (T_0) or very low amounts of fertilizer nutrients (T_5) produced significantly lower yields than all other treatments. However, notwithstanding these large differences, all the plot treatments provided an adequate surface vegetative cover to ensure that erosion of the surface did not occur. It should be noted that this was a year that included three periods of very intensive rainfall on April 9th (40.6 mm), April 16th (32.3 mm) and September 8th (49.0 mm).

During the four years in which biomass data has been collected, yields have fluctuated depending upon rainfall, temperature and fertilizer additions. The yield from the unfertilized area has varied between 0.5 and 2.4 tonnes/ha while yields up to 5.9 tonnes/ha have been recorded where fertilizers have been added. Yield data do not indicate that the sward is aging in terms of productivity as is often noted with pasture seeded to tame grasses after five or more years growth.

Root yields did not show any significant differences between the four treatments studied (see Table 5). Since measurements were started in 1976, root biomass has been progressively reducing thus indicating a more rapid decomposition of root tissue relative to production. Total root biomass has always been in excess of yearly top production. However, in this regard, it should be realized that our root recovery method does not distinguish between live roots and recently dead or partially decomposed root tissue.

The analysis of plant tissue from Treatments T_0, T_2, T_4 and T_5 revealed statistically significant differences in concentrations of nitrogen and phosphorus in plant tops and in phosphorus in plant roots (see Table 6). The higher concentrations were not always found with treatments that received the greatest amount of fertilizer. However, total nutrient uptake patterns in top materials (see Section 4.3) were generally related to fertilizer additions.

3.3 Experiment II - Studies on a Tailings Sand Slope Amended with Peat and Overburden and Seeded in 1976

3.3.1 *Introduction*

Complete details of the experimental design and the methods of site preparation are included in the 1976/77 report[4]. The plot layout and a brief description of each treatment are shown in Figure 2.

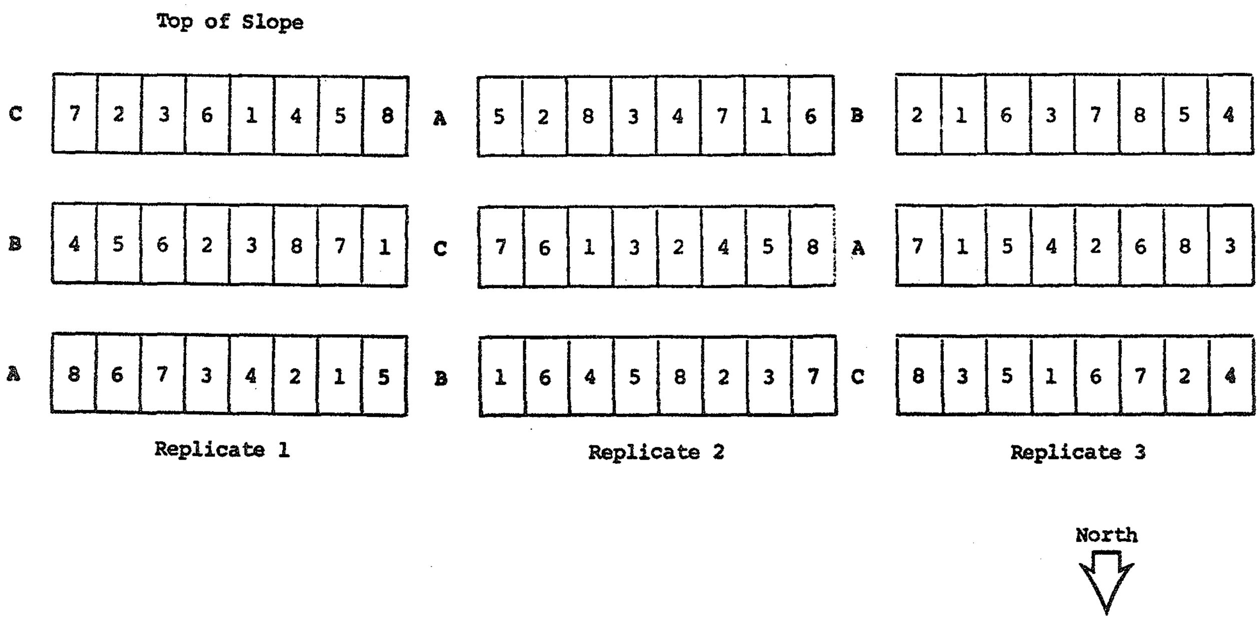
The experiment was initiated in July, 1976. Peat and overburden were incorporated into the surface of the tailings

TABLE 6

Nutrient Concentrations in Plant Tissues in Experiment I, 1978

	Tops				Roots			
	N	P	K	S	N	P	K	S
Treatment	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
T_0	1.59	0.24	2.18	0.63	0.96	0.07	0.10	0.27
T_2	1.49	0.23	2.11	0.45	1.31	0.12	0.12	0.34
T_4	1.21	0.14	1.62	0.34	1.33	0.16	0.13	0.38
T_5	1.46	0.21	2.05	0.48	1.11	0.09	0.10	0.40
Significance	***	*	N.S.	N.S.	N.S.	***	N.S.	N.S.
L.S.D.	0.19	0.06				0.04		

Results are means of 3 replicates.



1. Peat tilled to 15 cm.
2. Peat tilled to 15 cm, contour trenched.
3. Peat tilled to 15 cm, "Aquatain" soil stabilizer added.
4. Peat tilled to 15 cm, "Bitumuls" soil binder added.
5. Overburden (750 tonnes/ha) added to peat surface as 1.
6. Overburden (1500 tonnes/ha) tilled into peat surface as 1.
7. Overburden (750 tonnes/ha) tilled into peat surface as 1.
8. Peat tilled to 15 cm, seeded fall, 1976.

   A. Low fertilizer additions (see Table 7).
   B. Medium fertilizer additions.
   C. High fertilizer additions.

FIGURE 2. Design of Field Experiment II on a Vegetated Tailings Sand Dike at the G.C.O.S. extraction plant, Fort McMurray, Alberta.

sand slope and the area was seeded with the following seed mix:

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

The amounts of fertilizer added each year are shown in Table 7. The rates of addition were greatest in the first two growing seasons and since then nutrient additions have been gradually reduced.

The experiment had a short term objective in determining the effectiveness of different soil amendments, soil conditioning treatments and fertilizer applications in rapidly establishing a plant cover and thereby minimizing slope erosion. More extended study concerned the management of the revegetated area particularly in relation to the performance of different plant species under different nutrient regimes and the overall self maintenance potential of the area.

3.3.2 *Soil*

Soil sampling was reduced in 1978 to one sampling in September, which included the main soil amendment treatments (Treatments 1, 5, 6 and 7) and the fall 1976 seeded treatment

TABLE 7

Fertilizer Additions to Experiment II since July, 1976

	Fertilizer Addition (Kg/ha)																							
	1976								1977								1978							
	July				August				June				August				June				Total			
Treatment	N	P	K	S	N	P	K	S	N	P	K	S	N	P	K	S	N	P	K	S	N	P	K	S
A	80	35	75	20					80	35	75	20									160	70	150	40
B	150*	40	150	20					150	40	150	20					75	0	75	0	375	80	375	40
C	150*	40	150	20	150	40	150	20	150	40	150	20	150	40	150	20	150	0	150	0	750	160	750	80

* Lime added at 5 Tonnes/ha.

(Treatment 8), at each of the three fertilizer levels (Treatments A, B and C). In addition, Treatments 1, 5, 6 and 7 were sampled to a depth of 30 cm on a monthly basis to assess soil nutrient status. This study is discussed in Section 3.5. The results of the September soil sampling are presented in Tables 8, 9 and 10.

Soil moisture:

As a result of the wet summer, soil moisture levels in September were high in all cases. A comparison with data from September, 1977, shows that the moisture content in the surface 15 cm was generally double that found at the same time last year (range of 10.8 - 28.3% in 1977 and a range of 19.3 - 70.9% in 1978). Even larger differences were found below a depth of 30 cm in the tailings sand layer (1.7 - 4.7% in 1977; 5.2 - 8.3% in 1978). This data indicates that plant moisture stress is unlikely but that there may have been losses of nutrients from the root zone by leaching.

pH:

Soil acidity has changed very little over the three years of study. In 1976, pH in the surface 15 cm varied between 6.3 and 7.0 in unlimed treatments (i.e. Sub-treatment A) and between 6.6 and 7.3 when lime had been added (i.e. Sub-treatment B and C). This year, surface pH values were between 6.3 and 6.9 for unlimed plots and between 6.7 and 7.1 in limed treatments. Average pH values below the surface 15 cm were similar to those of previous years and ranged between 6.4 and 7.9 at depths below 30 cm.

TABLE 8

Results of Soil Analysis for Samples Taken in September, 1978, from Experiment II

Treatment	Depth (cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	NH_4-N	NO_3-N	P	K	SO_4-S
					(ppm)				
1A	0-15	27.7	6.30	0.40	7.3	2.7	9	59	17
	15-30	7.6	6.85	0.42	7.1	2.1	4	10	11
	30-60	6.3	6.87	0.45	6.8	1.8	3	9	17
	60-90	8.0	7.07	0.42	6.7	2.4	2	9	13
	90-120	7.4	7.19	0.41	6.8	2.5	3	9	20
5A	0-15	36.0	6.57	0.86	13.3	1.6	11	148	54
	15-30	12.3	6.28	0.90	10.3	2.6	3	23	64
	30-60	6.4	7.00	0.81	6.6	1.6	3	11	34
	60-90	6.1	7.19	0.66	5.6	1.3	3	11	22
	90-120	7.2	7.12	0.68	7.7	1.4	3	8	23
6A	0-15	21.0	6.93	0.98	6.1	1.6	15	112	45
	15-30	10.8	7.03	0.98	6.8	1.3	5	35	45
	30-60	6.5	7.52	0.81	6.4	1.0	3	12	28
	60-90	6.3	7.37	0.63	5.3	1.2	3	10	22
	90-120	6.5	7.47	0.70	6.1	1.2	3	9	25
7A	0-15	28.6	6.75	0.64	8.5	1.7	11	129	39
	15-30	8.3	6.74	1.09	4.8	1.7	4	23	48
	30-60	6.4	7.05	0.68	4.6	1.6	4	13	28
	60-90	7.2	7.17	0.53	3.8	1.8	3	9	18
	90-120	8.3	7.28	0.59	3.4	2.2	3	10	16
8A	0-15	44.1	6.41	0.37	10.2	2.1	7	74	18
	15-30	9.4	6.75	0.76	7.3	1.7	3	23	20

Results are means of 3 replicates.

TABLE 9

Results of Soil Analysis for Samples Taken in September, 1978, from Experiment II (continued)

Treatment	Depth (cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	NH_4-N (ppm)	NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)
1B	0-15	70.9	6.75	0.54	7.4	2.6	10	229	22
	15-30	8.2	6.56	0.61	4.8	2.4	3	24	29
	30-60	5.6	6.95	0.44	3.2	2.2	2	11	20
	60-90	6.4	7.15	0.44	2.5	2.3	2	11	13
	90-120	7.2	7.26	0.50	4.2	2.5	2	17	15
5B	0-15	34.8	6.76	0.69	8.6	3.3	7	260	48
	15-30	14.8	6.73	0.80	5.6	2.5	2	52	61
	30-60	5.2	6.56	1.12	4.1	2.7	2	20	74
	60-90	5.8	7.42	1.02	4.8	3.0	1	23	71
	90-120	5.9	6.36	1.37	6.6	2.6	1	21	86
6B	0-15	47.6	6.75	1.01	12.6	4.0	2	219	79
	15-30	18.0	6.48	0.71	7.9	3.1	1	37	81
	30-60	6.3	6.95	0.72	4.9	2.7	1	16	31
	60-90	7.0	7.13	0.70	4.4	3.3	1	15	37
	90-120	6.8	7.24	0.80	3.7	3.1	0	13	33
7B	0-15	29.4	7.02	0.65	7.9	3.2	6	145	28
	15-30	10.0	7.07	0.69	6.5	2.9	2	30	31
	30-60	5.4	7.31	0.57	6.1	3.4	1	19	21
	60-90	5.9	7.34	0.47	5.6	3.2	1	12	16
	90-120	6.5	7.27	0.44	5.4	3.0	1	14	17
8B	0-15	37.9	6.69	0.52	9.2	3.8	11	122	21
	15-30	14.9	6.80	0.55	7.5	3.0	2	29	26

Results are means of 3 replicates.

TABLE 10

Results of Soil Analysis for Samples Taken in September, 1978, from Experiment II (continued)

Treatment	Depth (cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	NH_4-N (ppm)	NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)
1C	0-15	53.6	6.65	0.66	12.8	11.8	26	418	23
	15-30	12.5	6.68	0.76	7.2	7.9	5	65	41
	30-60	6.8	6.76	0.69	8.0	7.1	3	23	29
	60-90	8.0	7.38	0.73	6.1	7.3	3	23	20
	90-120	6.7	7.23	0.72	5.7	7.5	3	19	19
5C	0-15	24.7	6.81	0.89	13.3	14.9	30	274	55
	15-30	15.8	6.58	1.51	8.9	10.5	7	53	81
	30-60	6.7	7.11	1.03	7.4	10.2	3	25	43
	60-90	6.0	7.31	0.79	7.5	7.2	3	18	27
	90-120	5.6	7.61	0.71	6.8	6.3	3	18	21
6C	0-15	43.0	6.70	1.32	14.5	17.5	23	324	93
	15-30	19.7	6.54	1.30	11.0	15.1	7	79	90
	30-60	7.1	6.96	1.15	9.2	6.7	4	25	43
	60-90	7.3	6.73	0.97	9.0	5.3	3	20	40
	90-120	5.8	6.75	1.05	9.7	6.2	2	18	34
7C	0-15	54.3	7.11	0.86	15.3	9.7	23	326	36
	15-30	12.8	6.79	0.97	14.6	8.2	5	64	44
	30-60	7.0	6.69	1.17	7.5	5.5	3	24	36
	60-90	6.1	6.77	1.21	5.8	5.6	2	18	40
	90-120	6.2	6.91	1.05	4.3	7.2	2	23	36
8C	0-15	19.3	6.65	0.38	10.9	5.2	22	200	18
	15-30	7.9	6.72	0.44	6.7	5.3	4	34	17

Results are means of 3 replicates.

Electrical conductivity:

Electrical conductivity values were lower in the surface 15 cm than in previous years, especially in overburden containing treatments. The range in electrical conductivity in the 0-15 cm depth was 0.40 - 1.32 mmhos/cm in 1978 compared to 0.60 to 3.44 mmhos/cm in the two previous years. Electrical conductivity at depth was largely unchanged in non-overburden containing treatments. However, where overburden had been added as a surface amendment, generally higher electrical conductivities were found at a depth between 30 and 120 cm. This would indicate that during 1978 some leaching of the surface salts had occurred and that this had occurred more readily from the moderately saline overburden material. This seems to be supported by the higher sulfate concentrations that were found at depth in 1978.

Available nutrient concentrations:

In respect to available nutrient concentrations, the differences between fertilizer treatments were less noticeable than in previous years since the amount of nutrients added in fertilizers had been reduced considerably in 1978. For example, mineral nitrogen concentrations were only slightly higher in Treatment C whereas in previous years, when an extra application of fertilizer had been made in August, there had been a large excess of nitrate in Treatment C in September. Also, there was evidence that nutrients taken up into plant tissues in previous years were being recycled into the available nutrient pool. Treatment A was unfertilized in 1978 yet contained more mineral nitrogen and generally more available potassium than at a similar time in previous years.

Levels of available phosphorus and potassium were still significantly higher in Treatment C which had received the largest amounts of fertilizer since 1976.

Mineral nitrogen and sulfate sulfur concentrations at depth in the soils were higher than had been recorded in the first two years of study. The above average precipitation during the summer seemed to have caused some leaching of soluble nutrients below the region of great root accumulation.

The concentrations of potassium in the 30-120 cm region were still low and largely unchanged from previous years.

Most of the available phosphorus was concentrated in the surface 30 cm. Concentrations in the 0-15 cm depth varied between 2 ppm and 30 ppm with the highest values found in the high fertilizer rate treatment (C) and the lowest values occurring with the medium fertilizer treatment (B). Concentrations of available phosphorus in the 30-120 cm depth varied between 2 and 4 ppm which was under half that found in the previous September.

3.3.3 *Plant Growth*

An assessment of ground cover by seeded grasses and legumes was made in October in a similar way to the assessment made in 1977.

The complete data for Treatments 1, 5, 6, 7 and 8 with Sub-treatments A, B and C may be found in the Appendix (Table II). Since there were no significant differences between Main-treatments 1, 5, 6 and 7 with each different fertilizer treatment, the data from both 1977 and 1978 is compared in Table 11 on the basis of means of each fertilizer treatment. No bare ground or weed cover measurements were made in 1977.

In 1977, considerable differences were found in the relative proportion of ground cover provided by the different grass and legume species depending upon winter survival and the particular fertilizer program. At the lowest rate of fertilizer addition (Treatment A), most of the different grasses and legumes that had been seeded were found. Brome Grass and the three wheatgrasses were the dominant species present. Under increased fertilization, Brome Grass dominated the sward and a reduction in growth of the legumes and smaller grasses was noted.

In 1978, this trend continued with even larger differences evident. At the high fertilizer rate (C), vegetative cover of the surface was complete while 4% and 1% of the surface was bare with fertilizer rates A and B, respectively. At rate C, Brome Grass provided 99% cover and the wheatgrasses 1%. Hard Fescue, Kentucky Blue Grass and Canada Blue Grass were detectable on most "C" plots while the remaining grasses and legumes from the original seed mix were absent.

TABLE 11

Assessment of Percentage Ground Cover by Seeded Grass and Legume Species in 1977 and 1978

	Fertilizer Treatment (% mean*)					
	A		B		C	
Plant Species	1977	1978	1977	1978	1977	1978
Brome Grass	34	36	47	81	62	99
Wheat Grasses (Streambank, Pubescent, Slender)	51	26	38	9	31	1
Blue Grasses (Canada, Kentucky)	8	22	9	6	4	<1
Hard Fescue	6	7	4	4	1	<1
Cicer Milk Vetch	6	<1	1	0	<1	0
Alfalfa	3	5	1	<1	0	0
Sainfoin	<1	0	<1	0	0	0
Red Top	<1	0	<1	0	<1	0
Altai Wild Rye	<1	0	<1	0	<1	0
Bare Ground	n.d.	4	n.d.	1	n.d.	0

Approximate Cover 1976:		
	Pendek Oats	88.7% by weight
	Grasses	9.7% by weight
	Legumes	1.6% by weight

Pendek Oats and Lupine have been absent since 1977.

n.d. Not Determined

* Mean of Treatments 1, 5, 6 and 7.

At the medium rate of fertilizer addition (rate B), the Brome Grass had become more prevalent over the previous year. In 1978, some 81% of the ground cover was provided by Brome Grass and only 9%, 6% and 4% by the wheatgrasses, blue grasses and Hard Fescue, respectively. Of the remaining legumes and grasses seeded, only Alfalfa Rhizoma could be detected in significant amounts.

Under the lowest fertilization program (Treatment A), which did not receive any fertilizer nutrients in 1978, the cover provided by Brome Grass was almost unchanged over the previous year (36%). The wheatgrasses had reduced in percentage cover while the blue grasses had become more prevalent. Cover by Hard Fescue was almost unchanged. Of the legumes tested, only Alfalfa Rhizoma had made significant gains since 1977 and showed signs of becoming well established in the sward. Cicer Milk Vetch could be found on most of the "A" plots but rarely did it account for over 1% of the cover. Sainfoin was found infrequently and then only on the "A" plots.

No evidence of Red Top, Altai Wild Rye, Lupine or Oats could be found in 1978.

The fall seeded plots (Treatment 8) provided several interesting observations. Bare ground percentages were always higher than found on the summer seeded plots and were always in the order >A>B>C. Mean values of 4% were recorded with Treatment 8A, which was considered high enough to give some concern of surface erosion since channels can develop readily under heavy rainfall. The relative proportions of the different plant species seeded were similar to those encountered on the summer seeded plots except with Treatment 8A, which contained considerably more Brome Grass and less wheatgrasses and blue grasses than the other "A" treated plots. In addition, weed species added in the peat tended to be more prevalent than on the summer seeded plots.

Despite the wide differences in species composition between fertilizer treatments, only the fall seeded plots at the lowest fertilizer application rate (8A) gave any concern as to the likelihood of surface erosion.

Plant productivity assessments were made in September by clipping and weighing the above ground plant material (see Table 12). With Treatments 1, 5, 6 and 7, legumes were separated from the grasses. Root biomass was determined at three depths (0-15, 15-30 and 30-60 cm) for Treatments 1, 5 and 6 as in previous years.

As may be anticipated from the ground cover data, significant differences in biomass of legumes were found with each fertilizer treatment. In terms of the legume biomass as a percentage of the total plant biomass, the ground cover data was in considerably close agreement with the data from the biomass clippings.

Total dry matter yields from the low fertilization program were significantly less than from either the medium (B) or high fertilizer rate (C). Small but significant differences

TABLE 12

Dry Matter Yield of Plant Tissue, Experiment II, 1978

	Yield (Kg/m^2)						
	Tops		Roots				
Treatment	Legumes	Total	0-15 cm	15-30 cm	30-60 cm	Total
1A	0.0064	0.143	0.458	0.074	0.027	0.559
2A		0.174				
3A		0.167				
4A		0.171				
5A	0.0123	0.170	0.514	0.100	0.023	0.637
6A	0.0108	0.160	0.398	0.098	0.043	0.539
7A	0.0122	0.136				
8A		0.174				
1B	0.0012	0.351				
2B		0.258				
3B		0.232				
4B		0.291				
5B	0.0009	0.278				
6B	0.0006	0.295				
7B	0.0009	0.269				
8B		0.350				
1C	0	0.394	0.549	0.069	0.023	0.641
2C		0.321				
3C		0.394				
4C		0.393				
5C	0	0.371	0.425	0.088	0.033	0.546
6C	0	0.385	0.602	0.100	0.014	0.716
7C	0	0.397				
8C		0.395				
Significance	***	***				N.S.
L.S.D.	0.0062	0.071				

Results are means of 3 replicates.

were normally found between respective B and C treatments. No consistent differences could be detected within each fertilizer treatment in relation to the original soil amendment or soil stabilization treatment imposed.

Above-ground biomass yields in this experiment have not shown the large year-to-year variations that were noted in Experiment I. The initial year, 1976, was typified by good growth of the oat nurse crop. Yields varied from 0.147 - 0.393 Kg/m^2 but could not be related to surface treatment of fertilizer additions. In the second year, when the grasses and legumes were becoming established, yields varied between 0.204 and 0.449 Kg/m^2 and were directly related to the addition of fertilizer nutrients. In 1978, individual variation from treatment to treatment and between replicates of the same fertilizer treatment was generally less than in previous years as the overall growth became more uniform. Yields varied from 0.136 - 0.174 Kg/m^2 where no fertilizer was added in 1978 to 0.321 - 0.397 Kg/m^2 where fertilizer was added at a rate of 150 Kg-N/ha and 150 Kg-K/ha.

Root yields show a different pattern. No significant differences were detected between high and low fertilizer regimes in terms of total root tissue production. Also, root yields have increased since 1976 and are beginning to approach the root biomass recovered from Experiment I. In 1976, root biomass varied from 0.157 - 0.281 Kg/m^2; in 1977, 0-181 - 0.281 Kg/m^2 was recovered; while in 1978, biomass reached

0.539 - 0.716 Kg/m^2 as the new grass growth became well established.

Nutrient concentrations in the plant tissues, and particularly in the above ground tissues, are assuming large differences related to current and previous fertilizer additions (see Table 13). For instance, significantly higher concentrations of nitrogen were noted in plant tops at the highest rate of fertilizer addition (rate C) than for either of the lower rates. Similar trends were noted for phosphorus, potassium and sulfur.

Differences in nutrient concentrations in the roots were less. Significantly high concentrations were noted for nitrogen at fertilizer rate C while only marginally significant differences were obtained for phosphorus. Neither potassium nor sulfur concentrations showed any statistically significant differences between the low (rate A) and high (rate C) fertilizer regimes.

Since the rate of fertilizer application was considerably reduced in 1978, the large differences in nutrient concentrations in the plant tops are believed to be in large part due to differences in the rate of mineralization of available nutrients added as fertilizers and immobilized in plant tissues in previous years. In other words, there is good evidence for active nutrient cycling occurring in the heavily fertilized soil treatments.

TABLE 13

Nutrient Concentrations in Plant Tissues in Experiment II, 1978

	Tops				Roots			
	N	P	K	S	N	P	K	S
Treatment	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1A	1.15	0.11	1.27	0.38	1.19	0.09	0.14	0.37
5A	1.35	0.15	1.77	0.49	1.30	0.09	0.22	0.47
6A	1.18	0.12	1.21	0.33	1.00	0.08	0.22	0.36
7A	1.24	0.12	1.19	0.29				
1B	1.58	0.22	2.88	0.52				
5B	2.11	0.21	3.42	0.66				
6B	1.80	0.20	3.15	0.44				
7B	1.96	0.21	3.01	0.45				
1C	2.91	0.35	4.49	0.76	1.40	0.10	0.20	0.47
5C	3.11	0.39	5.19	0.73	1.49	0.14	0.20	0.55
6C	3.23	0.35	4.79	0.74	1.78	0.12	0.17	0.59
7C	3.37	0.35	4.71	0.68				
Significance	***	***	***	***	***	*	N.S.	N.S.
L.S.D.	0.48	0.07	0.91	0.16	0.29	0.04		

Results are means of 3 replicates.

3.3.4 *Lysimeter Studies*

In July of 1976, small lysimeters were set up on Main-treatments A, B and C of Sub-treatments 1, 3, 4, 5, 6 and 7. The treatments were the same as were used in the main experimental design but gave an added advantage that the analysis of the individual lysimeter, in terms of changes in plant growth and soil characteristics, provided a more accurate picture of nutrient transformations and losses than could be obtained from analyses of the main plot experiment.

In September, 1978, soil and plant samples were taken and then all the lysimeters were transported back to our Edmonton laboratory. The root tissues were recovered from the entire lysimeter and weighed to determine biomass production.

Tables 14, 15 and 16 show the results of soil analysis, plant biomass production and the nutrient concentrations in the root and shoot tissues, respectively.

Soil analysis:

The differences between the results obtained from the analysis of lysimeter soil and samples taken from the main plot were generally quite small except in the concentration of extractable potassium.

Soil pH at a depth of 0-15 cm varied between 6.2 and 6.6 in the low fertilizer treatment (rate A) with the higher values being related to the presence of overburden. With treatments B and C, where lime and greater amounts of fertilizer had been added, the surface pH ranged from 6.6 to 7.2. The

TABLE 14

Analysis of Lysimeter Soil Samples, September 1978

Treatment	Depth (cm)	pH	Electrical Conductivity (mmhos/cm)	NH_4-N (ppm)	NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)
1A	0-15	6.28	0.97	4.8	2.1	10	66	110
	15-30	6.19	0.96	2.6	2.2	7	25	69
3A	0-15	6.36	0.35	4.1	1.7	7	47	12
	15-30	6.73	0.41	2.8	1.9	4	20	12
4A	0-15	6.27	0.32	6.6	1.8	12	86	14
	15-30	6.44	0.32	5.7	2.1	5	28	13
5A	0-15	6.53	0.78	6.7	2.3	15	93	69
	15-30	6.16	0.81	5.6	2.0	5	18	67
6A	0-15	6.63	1.56	4.2	2.8	13	84	172
	15-30	6.61	1.30	3.3	1.3	4	18	94
7A	0-15	6.33	1.37	6.3	2.5	12	51	145
	15-30	6.40	1.23	4.1	1.8	5	34	76
1B	0-15	6.91	0.61	8.8	5.1	6	120	19
	15-30	6.64	0.91	4.3	1.8	3	22	26
3B	0-15	6.75	0.53	8.9	3.8	5	113	18
	15-30	6.36	0.60	5.5	2.3	3	16	19
4B	0-15	6.73	0.90	11.1	3.6	15	107	68
	15-30	6.83	0.82	7.7	2.8	4	24	41
5B	0-15	6.63	0.82	6.1	2.6	13	115	57
	15-30	6.50	1.38	2.8	2.4	5	32	100
6B	0-15	7.23	1.58	10.9	3.3	14	87	112
	15-30	7.29	1.23	4.3	2.5	4	26	69
7B	0-15	7.09	1.18	9.7	3.0	17	105	95
	15-30	6.77	1.29	4.3	1.6	5	27	89
1C	0-15	6.94	0.77	8.0	4.6	8	117	55
	15-30	6.87	0.97	3.4	2.0	3	29	63
3C	0-15	7.07	0.52	4.8	2.6	11	93	25
	15-30	6.75	0.56	2.5	1.7	4	20	14
4C	0-15	6.98	0.51	4.6	3.2	10	110	10
	15-30	6.79	0.58	2.7	2.3	4	27	16
5C	0-15	6.61	0.91	3.8	3.2	15	117	65
	15-30	6.83	1.06	3.1	2.2	7	35	48
6C	0-15	7.21	1.93	5.1	3.2	13	99	176
	15-30	7.15	1.58	1.4	1.5	5	56	106
7C	0-15	7.04	1.43	6.9	3.3	7	92	125
	15-30	6.90	1.48	3.0	2.1	4	35	91

Results are means of 3 replicates.

TABLE 15

Dry Matter Yields from Lysimeters Harvested in September, 1978

Treatment	Dry Matter Yields (Kg/m^2) Tops	Roots
1A	0.341	0.724
3A	0.154	0.415
4A	0.185	0.618
5A	0.305	0.534
6A	0.276	0.575
7A	0.297	0.574
1B	0.596	1.000
3B	0.379	0.663
4B	0.447	0.691
5B	0.417	0.441
6B	0.315	0.675
7B	0.319	0.714
1C	0.486	0.509
3C	0.436	0.621
4C	0.427	0.614
5C	0.386	0.740
6C	0.469	0.536
7C	0.441	0.685
Significance	***	N.S.
L.S.D.	0.373	

Results are means of 3 replicates.

TABLE 16

Nutrient Concentrations in Lysimeter Plant Tissues, September 1978

	Tops				Roots			
	N	P	K	S	N	P	K	S
Treatment	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1A	1.25	0.12	1.15	0.31	0.90	0.08	0.08	0.28
3A	1.16	0.10	0.73	0.25	0.96	0.08	0.09	0.30
4A	1.21	0.10	0.89	0.27	0.79	0.06	0.08	0.47
5A	0.96	0.10	0.66	0.26	0.80	0.08	0.09	0.32
6A	1.04	0.09	0.75	0.24	0.94	0.08	0.11	0.35
7A	1.01	0.08	0.63	0.27	0.80	0.04	0.08	0.40
1B	1.39	0.12	2.14	0.32	1.08	0.08	0.10	0.43
3B	1.32	0.11	1.51	0.21	0.99	0.06	0.08	0.41
4B	1.56	0.13	1.63	0.35	1.08	0.09	0.11	0.31
5B	1.34	0.13	1.52	0.29	0.89	0.06	0.09	0.41
6B	1.51	0.14	1.52	0.25	0.95	0.08	0.12	0.41
7B	1.43	0.14	1.67	0.31	0.90	0.08	0.11	0.39
1C	2.53	0.26	3.42	0.54	1.32	0.08	0.09	0.40
3C	2.13	0.19	3.06	0.33	1.17	0.08	0.09	0.43
4C	2.24	0.20	2.78	0.35	1.06	0.08	0.10	0.45
5C	2.23	0.27	3.05	0.51	1.10	0.09	0.10	0.46
6C	1.97	0.21	2.10	0.51	1.13	0.07	0.11	0.44
7C	1.79	0.15	1.76	0.25	1.20	0.06	0.09	0.53
Unamended Tailings Sand	0.89	0.11	0.88	0.32	n.d.*	n.d.	n.d.	n.d.

* n.d. Not Determined.

Results are means of 3 replicates.

presence of overburden did not have a significant effect on the pH of the soil.

Electrical conductivity was generally higher than was recorded in 1978 from the main plot. Values varied between about 0.4 mmhos/cm in the peat/tailings sand mixes (Treatments 1, 3 and 4) to a maximum of 1.9 mmhos/cm in the mixes containing overburden (Treatments 5, 6 and 7). As was found with samples from the main experiment, this was a reduction from 1977. Values above 4 mmhos/cm are generally taken to indicate potential salt hazard to plant growth.

Mineral nitrogen was very low in all the samples taken in September and ranged from about 7 ppm to 11 ppm in the surface 0-15 cm (NH_4-N + NO_3-N). No significant differences existed between the three fertilizer treatments studied.

Similarly, no differences were found in available phosphorus between fertilizer treatments. Values between 5 ppm and 17 ppm were recorded in the surface 15 cm. On the main plot, similar figures were recorded for the two lower fertilizer treatments but higher values between 22 ppm and 30 ppm were found in the surface 15 cm in Treatment C.

Surface potassium concentrations were considerably lower than were found on the main plots. This was especially noticeable at the highest fertilization rates. For instance, lysimeter values varied between 92 - 117 ppm-K in the 0-15 cm depth for fertilizer rate C while results varied between 200 and 418 ppm on the main plot. Differences in soil compaction, leaching and plant uptake of potassium within the lysimeters may have been the cause of such differences.

Plant growth:

Plant top biomass measurements showed greater variability than on the main plot. The results obtained from the lysimeters were generally slightly higher than from the main experiment. Top biomass increased with greater applications of fertilizer. Root biomass was generally within the range that was found on the main plot. Root production was not significantly affected by fertilizer additions.

Nutrient concentrations in both root and shoot tissues were lower than had been found for plants growing on the main experimental area. However, generally similar trends were noted when results with the three fertilization programs were compared. Top nitrogen and potassium concentrations showed the larger increases with greater application of fertilizers. Increases in phosphorus and sulfur were less, though it should be noted that differences in P and S addition as fertilizers are also smaller than for N and K applications (see Table 7, page 25).

As with root tissues from the main experiment, it was found that differences in nutrient concentrations were largely unaffected by the differing rates of nutrient addition in fertilizers.

3.4 Experiment III - Studies on a Tailings Sand Slope Amended with Deeply Tilled Peat and Overburden and Seeded in 1976

3.4.1 *Introduction*

In addition to Experiment II, a second smaller experiment was started in 1976 to study the effect of incorporating surface amendments to a depth greater than 15 cm on the subsequent stabilization of the tailings sand slope. Previous studies[3] indicated that where tailings sands are mixed with peat, plant roots are largely restricted to the peat/sand mixture and that deep penetration into layers of pure tailings sand is rather poor. The establishment of a deep and laterally creeping root system by seeded grasses and legumes together with the rapid covering of the soil surface with foliage are the most important factors in the stabilization of steeply sloping sand dikes.

Figure 3 shows the experimental design and a brief summary of each treatment studied.

3.4.2 *Soil*

Soil samples were taken in September as in previous years to a depth of 120 cm. The results are presented in Table 17.

As was noted in Experiments I and II, the moisture held in the surface 15 cm of the soil was 50-100% greater than had been recorded in previous years and represented ample

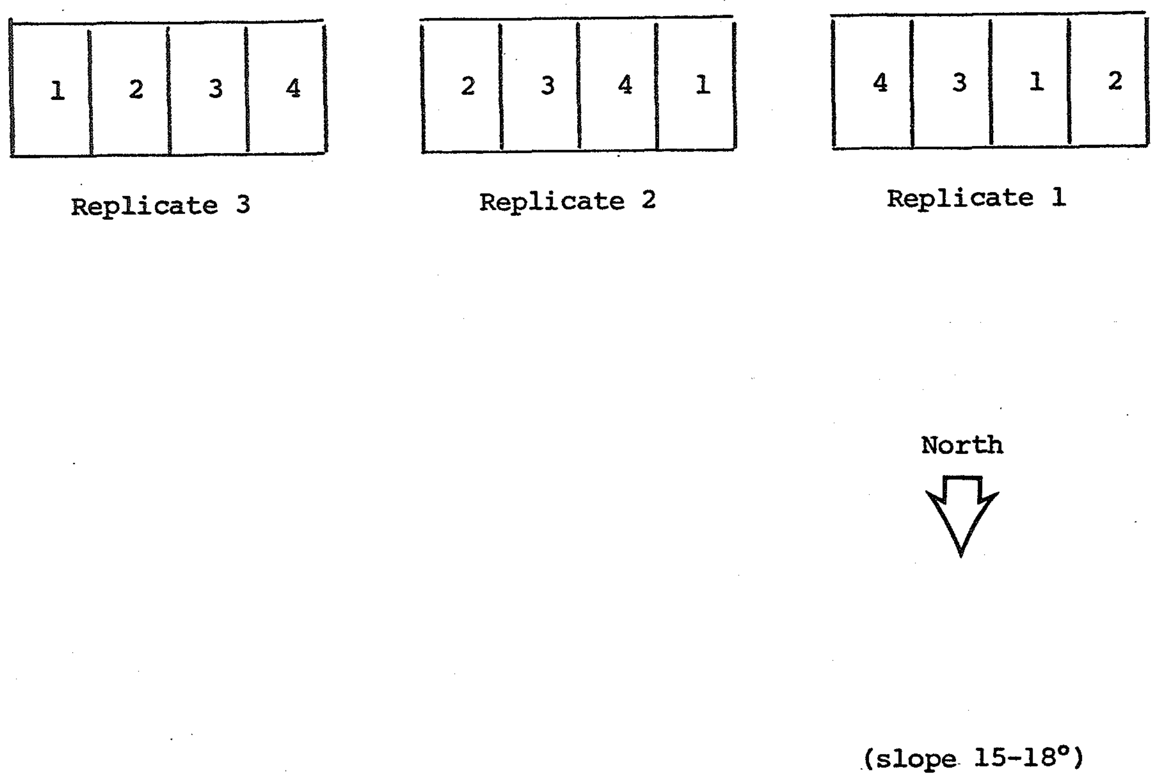


FIGURE 3. Design of Field Experiment III to Study Deep Rooting on a Vegetated Tailings Sand Dike at the G.C.O.S. Extraction Plant, Fort McMurray, Alberta.

A short summary only of the experimental design is given here. Four treatments were studied:

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 to a depth of 30 cm.
3) Overburden added at 1500 tonnes/ha and tilled into the peat-tailings surface to a depth of 30 cm.
4) Peat (10-15 cm) tilled into the tailings sand surface to a depth of 15 cm (This is identical to Treatment 1 in Experiment II).

Fertilizers were added to Treatments 1, 2 and 3 at rate B as in Experiment II while rate A was added to the control, Treatment 4. Each treatment was replicated three times.

TABLE 17

Results of Soil Analysis for Samples Taken in September, 1978, from Experiment III

Treatment	Depth (cm)	Moisture (%)	pH	Electrical Conductivity (mmhos/cm)	NH_4-N (ppm)	NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)
1	0-15	16.1	6.65	1.55	4.0	2.7	19	155	111
	15-30	8.8	6.75	1.54	2.5	0.2	7	37	108
	30-60	5.6	6.81	0.77	6.4	3.1	4	17	31
	60-90	6.2	6.95	0.68	2.7	5.7	3	15	25
	90-120	7.1	7.14	0.64	2.1	0.2	3	15	22
2	0-15	28.1	6.59	0.79	8.2	2.0	11	139	37
	15-30	8.4	6.34	0.95	3.1	2.4	2	29	56
	30-60	5.5	6.78	0.60	3.8	1.8	1	13	22
	60-90	5.4	7.04	0.54	2.6	1.2	1	8	16
	90-120	7.1	7.06	0.48	4.0	1.4	1	10	13
3	0-15	25.8	6.84	1.42	6.7	1.0	16	169	95
	15-30	11.2	6.36	1.27	6.0	2.0	4	44	67
	30-60	5.7	6.53	0.80	5.8	1.3	3	11	34
	60-90	6.8	7.05	0.64	4.1	0.7	2	10	28
	90-120	7.5	6.97	0.70	7.1	1.6	3	19	31
4	0-15	31.7	6.05	0.44	7.3	2.1	14	65	34
	15-30	10.0	6.17	0.67	4.6	0.7	3	16	30
	30-60	5.5	6.40	0.65	5.3	0.8	2	9	27
	60-90	6.5	6.62	0.48	5.1	2.2	2	8	15
	90-120	6.5	6.75	0.51	4.7	0.8	2	8	19

Results are means of 3 replicates.

supplies of plant available moisture at this time.

Soil pH in the surface 0-15 cm varied from 6.1 to 6.8 with the lower value recorded for Treatment 4 which was unlimed in 1976. Also as noted in other experiments, a reduction in salt content in the rooting zone was found in 1978. The overburden amendments in Treatments 1 and 3 provided a significant though not particularly hazardous soluble salt load. A maximum value of 1.52 mmhos/cm was recorded in 1978, well below the arbitrary value of 4.00 mmhos/cm which is generally used to indicate potential salt damage to growing plants.

Available nitrogen was low (7-10 ppm of NH_4-N + NO_3-N in the surface 0-15 cm) but showed no significant differences between the soil mixes or fertilizer application rates employed.

Phosphorus concentrations varied between 11 ppm and 19 ppm in the surface 15 cm which is within the range measured at the same time last year.

Potassium concentrations were moderate in Treatments 1, 2 and 3 which were fertilized at rate B (75 Kg-N/ha and 75 Kg-K/ha in June, 1978). The potassium concentrations varied between 139 ppm and 169 ppm in the surface 15 cm while only 65 ppm was detected in Treatment 4 which received no fertilizer in 1978.

Available sulfate sulfur continued to be in adequate supply for plant growth although approximately half the concentration (34 ppm to 111 ppm) was measured in relation to that found last year (69 ppm to 224 ppm).

3.4.3 *Plant Growth*

The plant cover produced was sufficient to prevent any erosion on the plots. A significantly lower plant top biomass was recorded for Treatment 4 which only involved tillage of peat to 15 cm and no fertilizer additions in 1978 (see Table 18). Total yield of plant roots showed no significant differences between the four treatments. However, as noted in previous years, the depth of rooting was improved by the deeper incorporation of the soil amendments. Some 16-20% of the root biomass was recovered at a depth of 15-30 cm where amendments had been tilled to 30 cm while only 11% was found where peat was tilled to 15 cm. A comparison with the previous year's results indicates that deep tillage has also resulted in a progressively higher percentage of roots reaching 30-60 cm than is the case with tillage to 15 cm. On the other hand, the percentage of roots in the 15-30 cm zone is approximately constant. A comparison with rooting studies in other experiments is discussed later in Section 4.2.

The nutrient concentrations in the plant tissues (Table 19) show a similar trend to that noted in Experiment II. Additional fertilization (Treatments 1, 2 and 3 versus Treatment 4) increased the total nitrogen, phosphorus and potassium concentrations in the plant tops. No significant differences for the roots were found.

TABLE 18

Dry Matter Yield of Plant Tissues, Experiment III, 1978

	Yield (Kg/m^2)							
	Tops	Roots				Percentage Distribution of Roots		
Treatment		0-15 cm	15-30 cm	30-60 cm	Total	0-15 cm	15-30 cm	30-60 cm
1	0.316	0.542	0.103	0.040	0.684	79	16	5
2	0.332	0.550	0.117	0.039	0.706	78	17	5
3	0.324	0.549	0.145	0.023	0.717	77	20	3
4	0.205	0.510	0.067	0.015	0.591	86	11	3
Significance	***				N.S.			
L.S.D.	0.065							

Results are means of 3 replicates.

TABLE 19

Nutrient Concentrations in Plant Tissues in Experiment III, 1978

	Tops				Roots			
	N	P	K	S	N	P	K	S
Treatment	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1	1.93	0.25	3.29	0.54	1.33	0.09	0.20	0.36
2	1.83	0.24	2.89	0.50	1.32	0.09	0.19	0.27
3	1.79	0.25	3.51	0.39	1.36	0.10	0.17	0.34
4	1.36	0.13	1.45	0.32	1.29	0.09	0.19	0.31
Significance	**	***	***	N.S.	N.S.	N.S.	N.S.	N.S.
L.S.D.	0.31	0.05	0.71					

Results are means of 3 replicates.

3.5 Study of Available Nutrient Supply During 1978

3.5.1 *Introduction*

A low supply of nitrogen and potassium in particular is one of the major factors limiting plant growth on the tailings sand dike.

The intensive soil testing program that was started in 1977 for mineral nitrogen was continued in 1978 and expanded to include available phosphorus and potassium monitoring as well.

Soil samples were taken as bulk samples of the 0-30 cm depth during May, June, July, August and October from selected treatments for Experiments I and II. The specific treatments and fertilizer additions in 1978 are shown below:

	Fertilizer Addition (Kg/ha)			
Treatment	N	P	K	S
Experiment I:				
T_0	0	0	0	0
T_2	90	23	90	0
T_4	0	0	0	0
T_5	43	11	22	9
Experiment II:				
1A/5A/6A/7A	0	0	0	0
1B/5B/6B/7B	75	0	75	0
1C/5C/6C/7C	150	0	150	0

The September results for the 0-15 cm and 15-30 cm depths were recalculated to include them in this comparison.

The data has been summarized in the form of histograms in Figures 4-7. Bulk densities used in the calculations were as follows:

Experiment I:	0-15 cm	0.6 g/cm^3
	15-30 cm	1.4 g/cm^3
Experiment II:	0-15 cm	0.8 g/cm^3
	15-30 cm	1.3 g/cm^3

It will be noted in comparison to bulk densities used in previous years, that in the new experiment as a result of compaction and decomposition of the added peat, bulk densities were increased. It is estimated that settling and compaction of the tilled surface resulted in lowering of the soil surface by 2-3 cm.

3.5.2 *Results*

If we discuss the results from the older revegetated area first (Experiment I, Figure 4), we see that, as a consequence of nitrogen mineralization, plant uptake and fertilizer additions, levels of available mineral nitrogen fluctuate throughout the summer. Levels are generally quite low (15-20 Kg/ha range) at the start of the growing season in May and decrease due to higher plant uptake relative to mineralization so that levels are generally lowest in July. The effect of fertilizer nitrogen additions in-between the June and July measurements

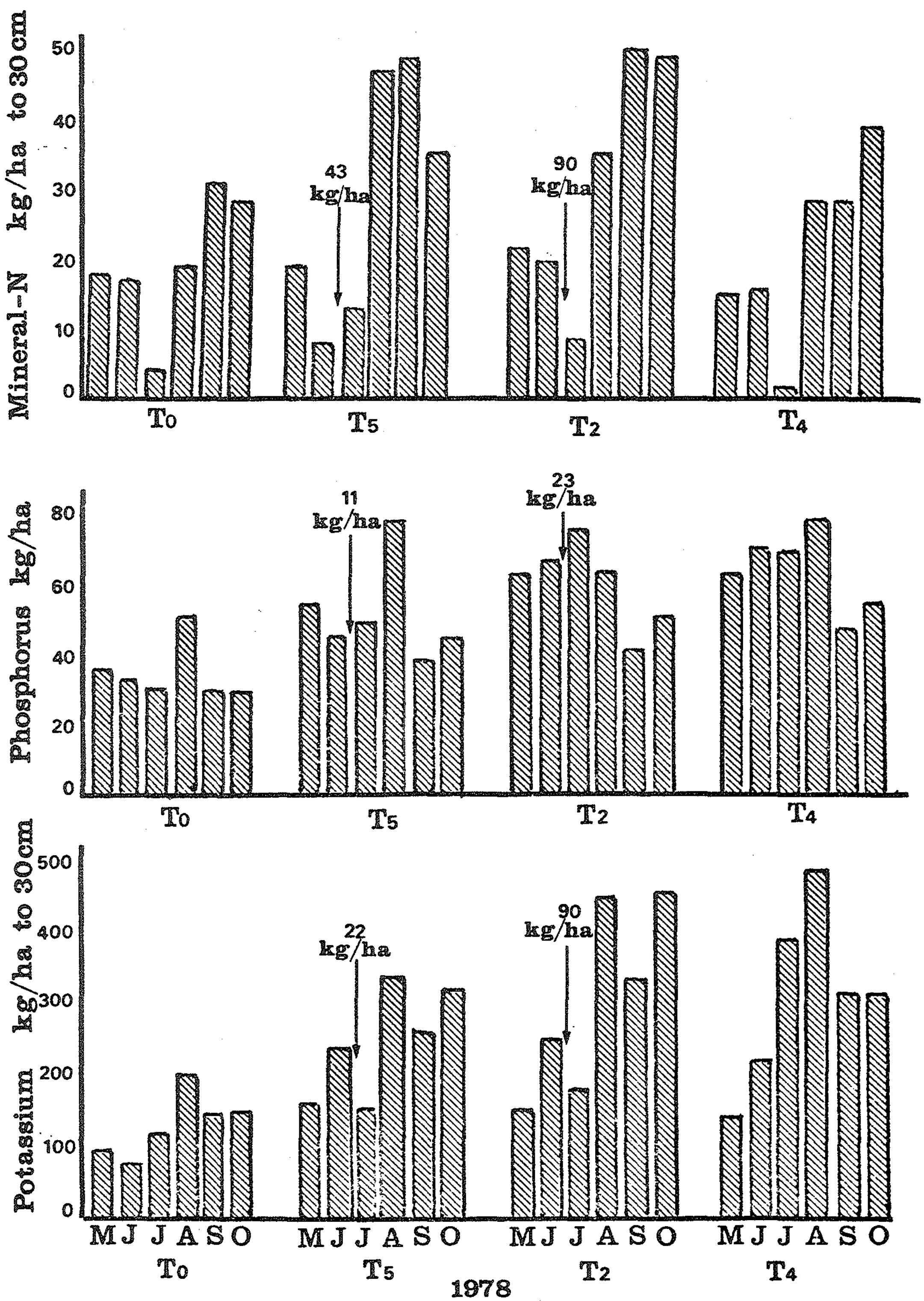


FIGURE 4. Changes in Available Nitrogen, Phosphorus and Potassium in the Surface 30 cm in Experiment I During 1978.

was a flush in uptake rather than supplying a surplus of mineral nitrogen in the soil in July.

All treatments, regardless of whether they were fertilized or not, showed an increase in mineral nitrogen during the August to October period as a result of greater mineralization of soil nitrogen relative to plant uptake. In October, between 30-50 Kg-N/ha existed in the soil to a depth of 30 cm.

In contrast to nitrogen, the content of phosphorus remained almost constant throughout the summer at a level generally between 30 and 70 Kg-P/ha. Those treatments with a history of fertilizer additions since 1971 (Treatments T_2, T_4 and T_5) had higher phosphorus levels during the summer compared to Treatment T_0 which had been unfertilized since 1971. However, phosphorus supply was always adequate for plant growth and never showed the stresses typical of nitrogen supply during the mid-summer period.

The additions of phosphorus fertilizer to Treatments T_2 and T_5 in June, 1978, were not reflected in a high available phosphorus index in July. The added phosphorus was either taken up by the plants or fixed in an unavailable form in the soil.

Fluctuations in available potassium showed some similarities to those found for mineral nitrogen. In the unfertilized treatment, potassium varied between 80 and 200 Kg-K/ha in the surface 30 cm which was considered marginal for healthy plant growth. Treatments with a history of fertilizer additions since 1971 showed greater available potassium contents in May (about 150 Kg-K/ha). Potassium increased slightly or remained constant until August when the content increased presumably in response to reduced plant uptake. Again the addition of fertilizer potassium in June could not be detected in the July analyses. Visual observations and plant analyses seem to indicate that uptake of both nitrogen and potassium was high during the summer where fertilizers were added.

A generally similar pattern in available nitrogen, phosphorus and potassium was observed during 1978 in Experiment II (Figures 5, 6 and 7). Previous and current additions of fertilizer as well as the different uptake of nutrients into plant tissues during the year resulted in significant differences between the three fertilizer treatments.

Differences in soil Treatments 1, 5, 6 and 7 were small in relation to those between the fertilizer treatments (see Tables III, IV and V in the Appendix). Consequently the histograms have been constructed from mean values at each fertilizer level. It should be noted that Treatment A received no fertilizer in 1978 while B and C received only nitrogen and potassium. The previous data from 1976 and 1977 indicated that deficiencies of phosphorus and sulfur were unlikely.

Mineral nitrogen contents in May ranged between only 10 and 30 Kg-N/ha in the surface 30 cm. Thus supplies of nitrogen to the plants were low in all treatments. The concentration of mineral nitrogen remained very low in Treatment A until August when about 40 Kg-N/ha existed in the 30 cm depth until October.

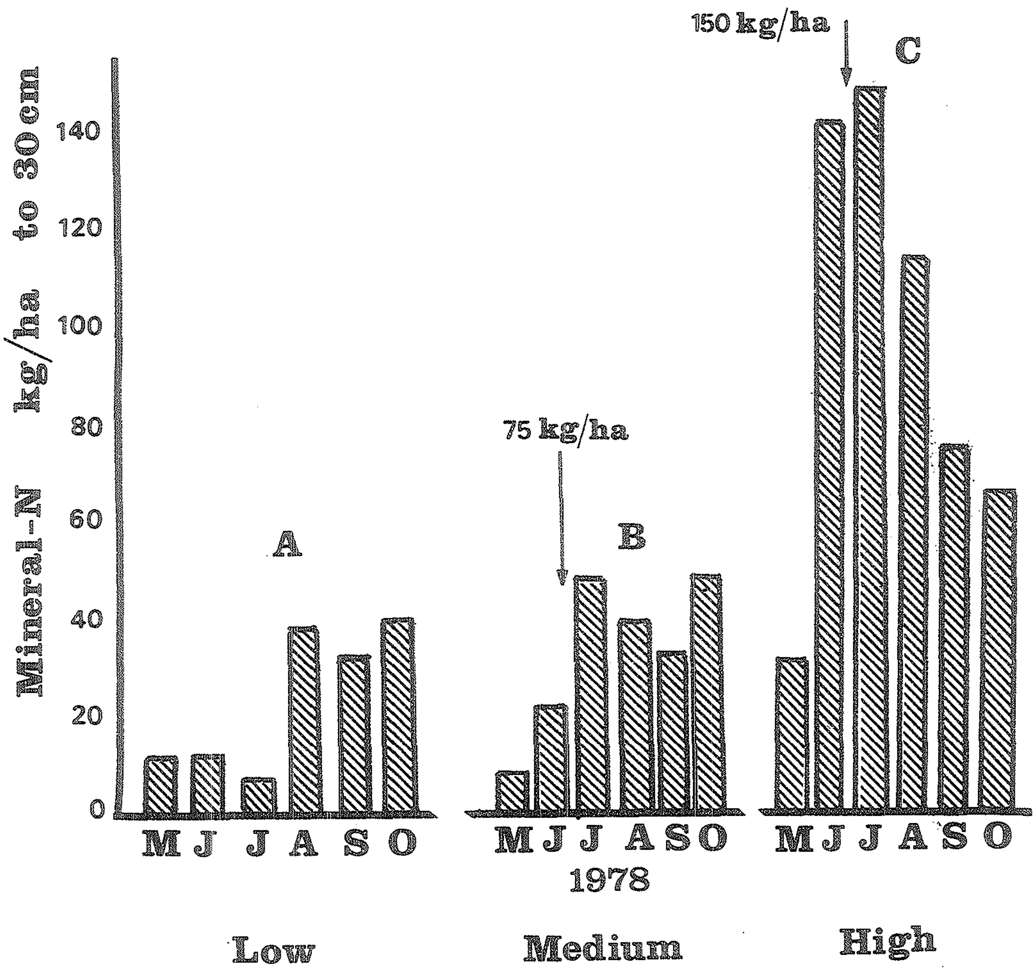


FIGURE 5. Changes in Mineral Nitrogen in the Surface 30 cm in Experiment II During 1978.

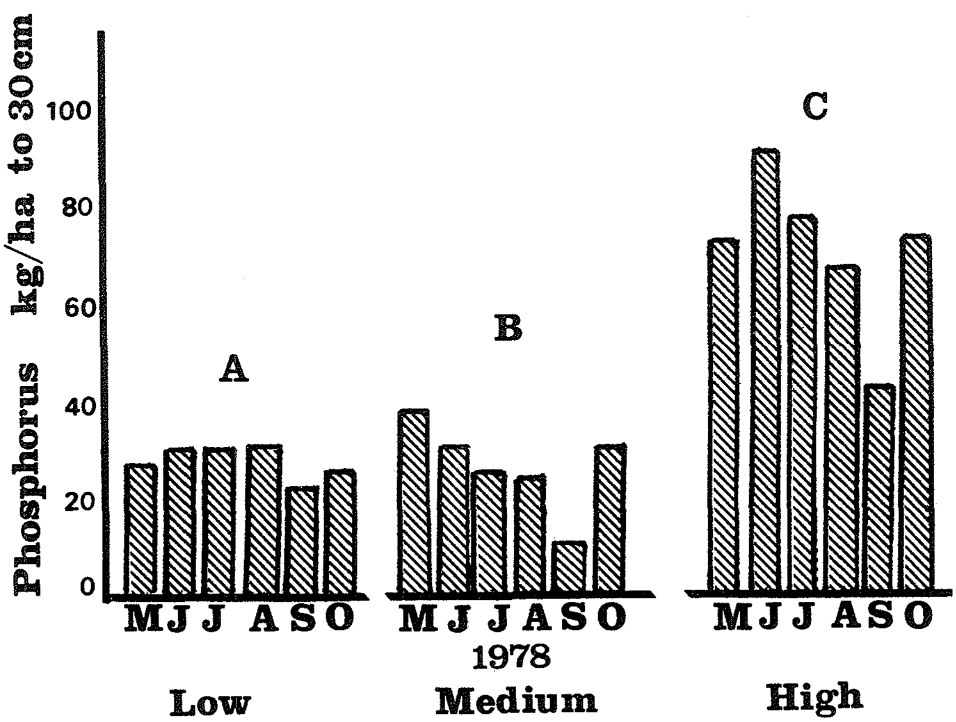


FIGURE 6. Changes in Available Phosphorus in the Surface 30 cm in Experiment II During 1978.

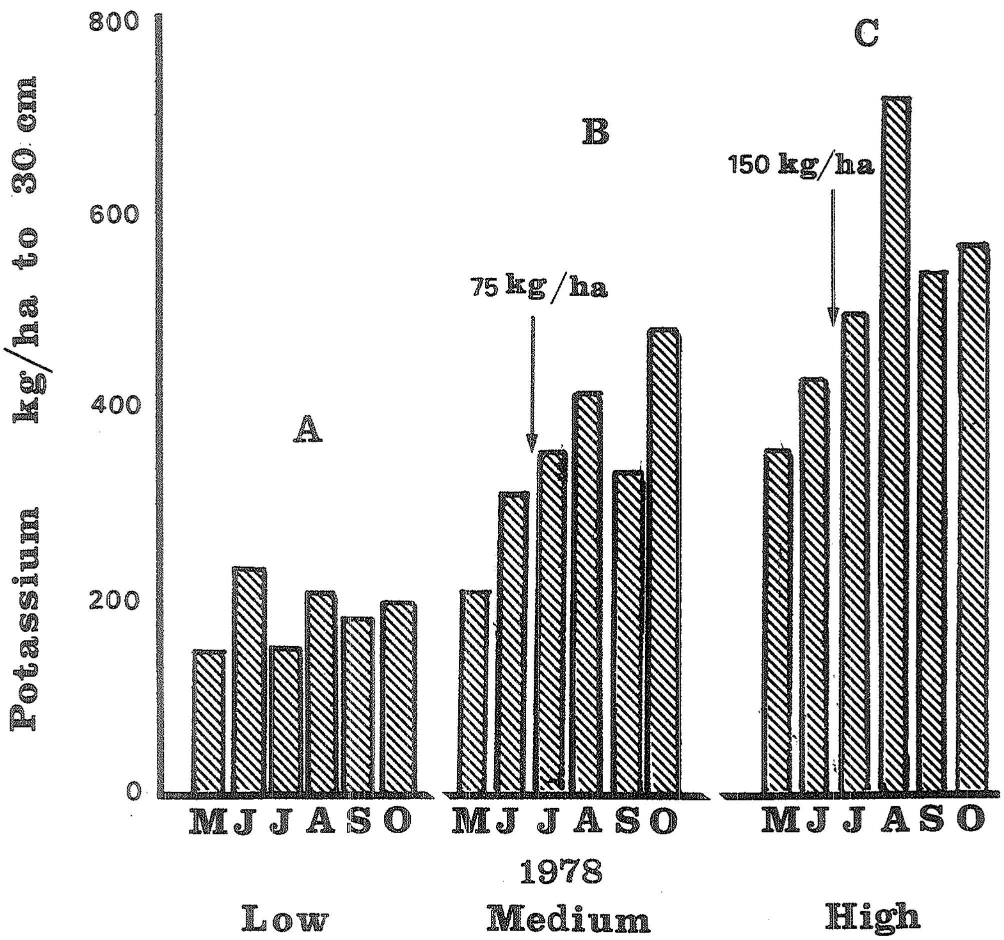


FIGURE 7. Changes in Available Potassium in the Surface 30 cm in Experiment II During 1978.

Where previous fertilizer additions had been made (i.e. Treatments B and C), the concentration of mineral nitrogen increased into June and July. The effect was most evident in Treatment C where nitrogen mineralization relative to plant uptake and other soil losses was so intense that 140 Kg-N/ha existed in the 0-30 cm depth in June. This contrasts to the older area (Experiment I) which showed a gradual decrease in mineral nitrogen until August. This data seems to suggest a very rapid mineralization of nitrogen during the third growing season where high amounts of fertilizer were added in the initial two years to establish the plant cover.

In common with the results from Experiment I, the addition of fertilizer nitrogen between the June and July samplings did not significantly increase the available nitrogen status of the soil one month after the application of fertilizer. By the end of the summer, the differences in mineral nitrogen content in the three fertilizer treatments was not large. Treatment A contained 40 Kg-N/ha; Treatment B, 50 Kg-N/ha and Treatment C was slightly above 60 Kg-N/ha. Thus the differences in nitrogen status between treatments should be evident as increased uptake into plant tissues and possibly in increased losses of nitrogen by denitrification and leaching.

Phosphorus showed a relatively constant pattern over the summer. Under Treatment A, a value of about 30 Kg-P/ha was recorded over the six-month period between May and October. Phosphorus was initially at a level of almost 40 Kg-P/ha in

Treatment B but declined to about 10 Kg-P/ha in the surface 30 cm by September. It should be noted that differences in phosphorus addition as fertilizer in Treatments A and B are quite small. Since 1976, Treatment A has received a total equivalent to 70 Kg-P/ha while 80 Kg-P/ha has been added to Treatment B. However, greater overall biomass production has occurred with Treatment B due to larger additions of nitrogen and potassium. Thus plant growth has placed a greater stress upon the available phosphorus supply than has been noted for Treatment A.

Since 1976, Treatment C has received equivalent to 160 Kg-P/ha. This has always resulted in a greater supply of available phosphorus than in other treatments. Again the phosphorus supply was relatively constant throughout the summer ranging from a high of about 90 Kg-P/ha in June to just over 40 Kg-P/ha in September.

Potassium supply under fertilizer regime A was relatively constant at between 170 and 220 Kg/ha in the 0-30 cm depth. This could be expected to maintain the potassium demand of the plant cover through the summer at the growth rate observed.

Both Treatments B and C showed a progressive rise in available potassium between May and August. During this time, plant uptake of potassium was obviously high since the addition of potassium fertilizer after the June sampling did not result in greatly increased available potassium in July. In addition, the concentration of potassium in the plant foliage indicated that a luxury consumption of potassium occurred during 1978. Over the summer, available potassium ranged from 200 Kg-K/ha in May to 500 Kg-K/ha in October in Treatment B. A minimum of 380 Kg-K/ha was recorded in May and a maximum of 700 Kg-K/ha in August for Treatment C. Both Treatments B and C contained an excess of available potassium in relation to plant requirements.

Continued measurements of this nature are required during the next few years to fully document the long-term effects of the fertilizer additions of the 1976-1978 period.

3.6 Decomposition of Plant Residues

3.6.1 *Introduction*

As indicated by the results of available nutrient contents over the summer, the mineralization of organic constituents either in the form of added peat or dead plant residues is an active process that supplies available nutrients for plant growth.

In 1977, an experiment was started to study the relative rates of plant residue decomposition under the management practices being investigated in both old and newly revegetated areas on the tailings pond dike. Two different techniques were employed, namely the measurement of weight loss of plant litter exposed on plot surfaces and the measurement of the rate of decomposition of cellulose strips buried in the soil.

Litter and cellulose strips were added in May of 1977 and data collected until the fall of that year. This work only provided information related to decomposition during the summer period. In 1977/1978, the experiments were repeated to cover one entire year. In addition, during 1978, the nutrient concentration of the residual plant litter was determined to show the total release and rate of release of nitrogen, phosphorus, potassium and sulfur from last year's dead above-ground tissues.

3.6.2 *Litter Decomposition*

Litter bags containing material harvested from the plots in September, 1977, were placed on the plots in October, 1977. Replicate bags were recovered during May, July and October, 1978, and the loss in weight determined (see Table 20). Ground samples of the litter were analyzed for Total N, P, K and S concentrations (see Table VI, Appendix). Using this data and the yield measurements for 1977, it was possible to estimate the expected release of nitrogen, phosphorus, potassium and sulfur into the soil from the decomposition of the plant litter (see Table 21).

The results indicated that litter decomposition was more intense at the older site (Experiment I) than in the more recently revegetated area (Experiment II). The differences in terms of percentage decomposition between the two sites declined as the summer progressed but was still evident in November when losses with Experiment I litter ranged from 47.6 - 56.2% while 43.0 - 51.7% was recorded for Experiment II material. No relationship between the decomposition rate and the initial nutrient concentration was evident.

No relationship was found between past or current fertilization practice and the overall rate of litter decomposition. For example, Treatment C litter, which contained a higher concentration of nitrogen, showed no greater decompo-

TABLE 20

Percentage Loss in Weight of Plant Litter Added in Litter Bags to Plot Surfaces in October 1977

Treatment	October 1977 to May 1978	October 1977 to July 1978	October 1977 to October 1978
Experiment I			
T_0	21.3	39.8	47.6
T_2	19.8	36.0	53.1
T_4	22.6	37.1	56.2
T_5	24.7	37.2	53.4
Experiment II			
1A	12.2	34.4	46.3
6A	12.7	28.1	43.0
1B	13.3	27.5	43.8
6B	12.5	23.3	43.8
1C	10.3	24.1	51.7
6C	15.3	32.7	45.8
Significance	***	***	***
L.S.D.	4.8	8.5	5.8

TABLE 21

Changes in Nutrient Content of Plant Litter on Selected Treatments from Experiments I and II between October 1977 and October 1978

	Nutrients Remaining in Litter (Kg/ha)															
	Nitrogen				Phosphorus				Potassium				Sulfur			
Treatment	Added Oct 1977	May 1978	July 1978	Oct 1978	Added Oct 1977	May 1978	July 1978	Oct 1978	Added Oct 1977	May 1978	July 1978	Oct 1978	Added Oct 1977	May 1978	July 1978	Oct 1978
Experiment I																
T_0	7	5	5	5	1.9	0.8	0.5	0.3	11	2	1	2	1.4	2.2	1.8	1.8
T_2	69	45	41	35	11.7	5.4	4.4	1.3	81	15	10	8	6.3	8.3	13.5	9.2
T_4	72	42	47	35	6.2	5.5	3.9	1.5	72	18	12	5	7.0	13.4	14.1	9.4
T_5	27	21	22	18	3.3	2.9	2.5	1.5	33	10	5	4	2.6	7.8	8.6	3.8
Experiment II																
1A	51	36	33	25	4.8	4.2	2.8	2.0	61	22	6	5	6.4	14.1	11.4	7.8
6A	55	30	33	23	4.2	3.2	2.9	1.8	66	13	7	4	6.4	9.7	10.1	6.8
1B	73	38	42	26	5.2	4.2	3.3	1.7	77	25	9	5	7.9	15.8	12.3	10.0
6B	64	43	43	32	3.7	4.4	3.9	1.9	63	21	17	6	7.7	12.3	13.1	11.7
1C	89	59	54	29	8.6	6.7	3.6	1.9	85	22	13	6	10.6	20.1	17.6	12.4
6C	105	62	60	42	8.5	7.2	4.3	2.5	91	34	11	7	10.6	16.5	16.2	14.0

Results are means of 3 replicates.

sition than Treatment A litter. There were also no differences in litter decomposition between the sub-treatments studied from Experiment II, namely Treatment 1 (peat + tailings sand) and Treatment 6 (peat + overburden + tailings sand).

As a whole, the data indicated a half-life of plant litter of about twelve months.

In terms of the nutrient release characteristics of the litter, the data was more instructive. Table 21 shows the nutrient content of litter during the 1977/1978 period studied. The calculations used to produce these figures assume that last year's above-ground biomass was dead at the time of the September harvest and decomposed in similar fashion to the litter bags that were placed on the plots in October, 1977.

The data indicates that potassium, being largely soluble, was very rapidly lost from the litter. In general, a total of 60-80% of the original potassium was lost by May, 1978. This ranged from a release equivalent to 9 Kg-K/ha with Treatment T_0 to a maximum of 63 Kg-K/ha in Treatment 1C. Further losses during the summer were more gradual and resulted in the potassium content in the residual litter stabilizing at equivalent to about 2-8 Kg-K/ha or 8-18% of that originally present. Obviously, the release of potassium from plant litter is a significant contribution to the available potassium pool, especially early in the growing season.

Loss of nitrogen was initially rapid but between May and November, 1978, was quite slow. This is probably due to the release of water soluble nitrate and some early mineralization of organic nitrogen in late fall and early spring. Mineralization of less labile nitrogen compounds presumably occurs at a slower rate during the summer and may be limited by the supply of nitrogen and other mineral elements to the decomposer organisms.

Loss of nitrogen from litter between October, 1977, and May, 1978, ranged from a maximum of 43 Kg-N/ha in Treatment 6C to a minimum of only 2 Kg-N/ha in Treatment T_0. The magnitude of the release is related largely to the initial content of nitrogen in litter and to a certain extent to the current supply of nitrogen in fertilizers. By October, 1978, the litter residues had lost 30-70% of their original nitrogen content.

Phosphorus mineralization was even more gradual than was found for nitrogen. Generally, less than one-third of the phosphorus content was lost between October, 1977, and May, 1978. By October, 1978, between 49% and 89% of the original phosphorus had been lost from the litter. A maximum release of 10.4 Kg-P/ha was recorded for Treatment T_2 while only 1.6 Kg-P/ha was lost from Treatment T_0 during the twelve month period. Both the largest and most rapid phosphorus mineralization was associated with litter that initially contained a high concentration of phosphorus and had been fertilized during 1978 though, not necessarily with phosphate fertilizers.

Sulfur transformations in the litter showed an anomalous pattern in that total sulfur contents generally increased until May or July, 1978, and then showed a slight decline between July and October, 1978. A small increase, such as 1 or 2 Kg-S/ha, could be explained through the deposition of extraction plant emissions. The remainder must have resulted from the immobilization of soil sulfate by the decomposing organism. However, the residues did seem to contain adequate sulfur in relation to nitrogen, phosphorus and potassium to allow for mineralization of sulfur to occur without immobilization.

3.6.3 *Cellulose Decomposition*

Cellulose is one of the major constituents of plant tissues. The decomposition of pure cellulose in the soil has been used to study the potential rate of plant residue decomposition and to provide an index of soil microbial activity[7].

Results from 1977[6] indicated that cellulose strips buried in tailings sand mixed with peat or peat and overburden in May were decomposed 40-53% in one month and up to 75% by the third complete month of burial. The decomposition rate was significantly less where peat was not added; pure tailings sand or pure overburden gave only 28% and 33% decomposition, respectively, between May and the end of July.

In 1977/78, a similar experiment was carried out but over a complete year. Strips were buried in October, 1977, and replicates recovered in May, July and November, 1978. The results are presented graphically in Figures 8 and 9.

No significant differences were found between Treatments T_0, T_2, T_4 and T_5 from Experiment I. These four treatments included a wide range in fertilizer rates and differences in plant cover that varied from almost pure Creeping Red Fescue to entire cover by Brome Grass. The half-life of cellulose varied between seven and eight months, which included the winter period. The most rapid rate in decomposition occurred between May and July which would have included the periods of highest soil temperature.

Although no consistently significant differences were observed between the fertilizer treatments A, B and C in Experiment II, there were overall differences in the rate of decomposition between cellulose in peat + tailings sand mixes and in peat + overburden + tailings sand mixes. As a generalization, early cellulose decomposition in the overburden mix lagged behind that in the peat + tailings sand mix. However, the differences were slight by October, 1978, when decomposition was almost complete in all treatments. The addition of nitrogen and phosphorus containing fertilizers in Treatments B and C seemed to reduce the retarding effect of the overburden treatment. Thus, cellulose decomposition may be initially slow in the peat + overburden + tailings sand system due to nitrogen and/or phosphorus deficiencies rather than by low moisture or other

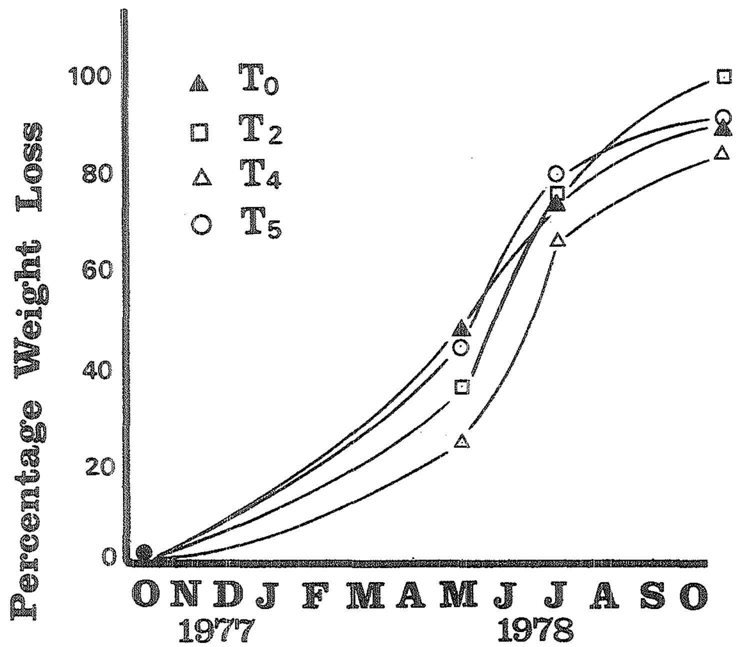


FIGURE 8. Decomposition of Cellulose Strips Buried to a Depth of 15 cm on Treatments T_0, T_2, T_4 and T_5 in Experiment I During October 1977 to October 1978.

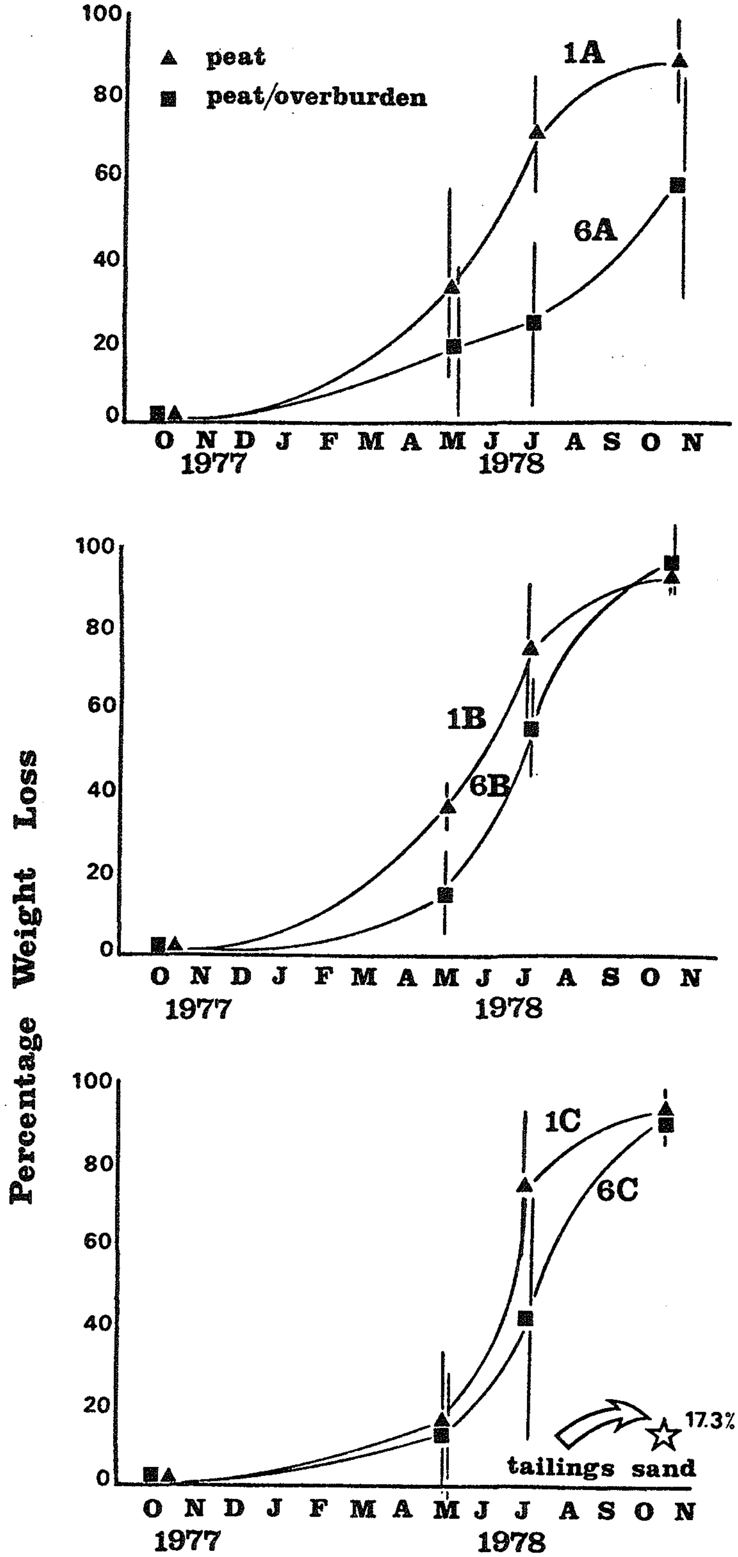


FIGURE 9. Decomposition of Cellulose Strips Buried to a Depth of 15 cm on Selected Treatments in Experiment II During October 1977 to October 1978.

soil characteristics.

The half-life of cellulose in Experiment II was between eight and eleven months and was, therefore, slightly longer than found in the older revegetated area.

3.7 Trace Element Concentrations in Plant Tissues

3.7.1 *Introduction*

Tailings sands arising from tar sand extraction contain only small amounts of the major plant nutrients. Their ability to supply trace elements required for healthy plant growth is also liable to be limited.

In September, 1978, the concentrations of iron, manganese, copper, zinc and boron in green tissues were determined for plants harvested from both old and newly revegetated areas on the tailings sand dike as well as in plants growing on unamended tailings sand. This allowed a comparison of plant uptake of trace elements from tailings sand amended with peat (Experiment I, Treatments T_0, T_2, T_4 and T_5 and Experiment II, Treatments 1A, 1B and 1C), tailings sand + peat + overburden (Experiment II, Treatments 5A, 5B and 5C), and pure tailings sand. In addition, the effect of heavy, medium and light fertilization could be assessed by comparing Treatments A, B, and C from Experiment II.

3.7.2 *Results*

The plants growing on unamended tailings sand were stunted and as a rough estimate produced a standing biomass of only 100-400 Kg/ha. The tissues contained 0.89% N; 0.11% P; 0.88% K; and 0.32% S (see Table 16, page 43). Most of the grasses were Brome Grass, though some Creeping Red Fescue, Foxtail Barley, and Crested Wheatgrass also occurred.

Table 22 shows the results of trace element analysis. An approximate guide to deficient and toxic levels of each element is shown below:

Element	Deficient (ppm)	Sufficient (ppm)	Excessive or Toxic (ppm)
B	<15	20-160	200+
Cu	< 4	5-40	40+
Fe	<50	50-1300	Not Known
Mn	<20	20-500	500+
Zn	<15	25-150	150+

(Data adapted from references 8 and 9)

It must be realized that quite large variations may be encountered depending upon the element involved, the plant species, its stage of maturity and the particular part of the plant sampled.

The concentrations of boron varied between 24 ppm and 87 ppm and were all within the range considered normal.

Copper concentrations of 8 ppm to 26 ppm were also

TABLE 22

Trace Element Concentration in Plant Top Material Taken from Selected Experimental Treatments, September 1978

Treatment	Concentration (ppm)				
	Fe	Mn	Cu	Zn	B
Unamended Tailings Sand	1355	205	79	71	n.d.
Experiment I					
T_0	435	245	12	34	39
T_4	360	330	13	25	24
Experiment II					
1A	500	445	26	52	46
5A	485	380	13	54	53
1B	380	305	10	38	60
5B	320	445	8	44	75
1C	290	370	9	31	67
5C	270	385	12	41	87

n.d. Not Determined

Results are means of 3 replicates except for the material growing on unamended tailings sand which was a bulk sample of separate collections from the tailings dike.

within the normal range for plant tissues from the two revegetation experiments. However, a concentration of 79 ppm for the plants growing on unamended tailings sand was considered potentially toxic.

Iron concentrations in plant tissues varied quite widely. Grasses frequently contain several hundred ppm of iron in dry tissue while values around a thousand ppm are often found in legumes. The concentrations found here ranged from 270 ppm to 500 ppm from the experimental plots while a maximum of 1355 ppm was found in plant tissues from the unamended tailings sand. Within Experiment II, there seemed to be an inverse relationship between iron uptake and fertilizer added, though the effect may have been due to the lime addition in reducing the solubility of iron. Iron toxicity per se probably rarely occurs in plants though deficiencies of manganese may be associated with high iron concentrations.

Manganese concentrations in the dry tissues varied between 205 ppm and 405 ppm and indicated an adequate supply of manganese to the plant.

Similarly, zinc concentrations were all within the range considered sufficient for plant growth. Within the Experiment II treatments studied, zinc concentrations were lower where lime and high rates of fertilizers had been added.

In summary, for the trace elements studied, the concentrations in the above-ground tissues indicated that nutrition was normal with the only exception being a moderately high luxury uptake of copper by plants growing on unamended tailings sands.

3.8 Microbial Activity

3.8.1 *Introduction*

Comparisons of the biological activity in the surface 15 cm of selected treatments from Experiments I and II were continued in 1978. In the previous two years, it had been concluded that the older established area (Experiment I) contained a greater bacterial population and a higher rate of soil respiration than the area that had been treated and seeded in 1976 (Experiment II). Data from 1977[6] seemed to indicate that these differences were becoming smaller as the new plant cover became established and decomposition of plant residues occurred.

3.8.2 *Soil Respiration*

No significant differences in soil respiration rates were noted between treatments within Experiment II (see Table 23). The overall respiration rate has exhibited a gradual rise since the area was seeded in 1976. In 1976, a value of 0.076 mg CO_2-C/100 g/hr was recorded; this rose to 0.119 in 1977 and to 0.146 mg CO_2-C/100 g/hr in 1978. This is the direct result of increased input of plant residues into the soil system and increased activity of decomposer microorganisms.

Soil respiration was still generally higher at the older site. However, respiration from treatments that were

TABLE 23

Total Soil Respiration and Microbial Numbers in Selected Treatments from Experiment I and Experiment II, September 1978

Treatment	Soil Respiration Mg CO_2-C/100 g soil/hr at 20°C	Bacteria /g x 10^7	Actinomycetes /g x 10^6	Fungi /g x 10^4
Experiment I				
T_0	0.186	9.5	4.5	14.5
T_2	0.423	13.8	3.7	25.4
T_4	0.256	10.3	3.1	17.3
T_5	0.296	10.7	4.2	15.4
Experiment II				
1A	0.147	5.7	2.3	18.4
5A	0.120	4.4	5.5	18.1
6A	0.173	4.4	4.3	16.3
7A	0.149	5.4	4.5	18.0
1C	0.200	11.8	4.6	23.3
5C	0.091	9.8	3.7	17.9
6C	0.135	8.6	3.3	21.1
7C	0.155	9.9	4.1	20.3
Significance	***	N.S.	N.S.	N.S.
L.S.D.	0.126			

unfertilized in 1978 (T_0 and T_4), or received a low fertilizer addition (T_5), was significantly lower than Treatment T_2 which received the highest rate of fertilizer in 1978.

3.8.3 *Microbial Numbers*

Numbers of bacteria, actinomycetes and fungi were all lower than had been recorded in previous years for the treatments studied from Experiment I. This may have resulted from inhibition of the aerobic flora due to the very moist and cool conditions prevalent during the summer. Microbial numbers were not significantly different from those of the newer experimental area. No significant differences between different fertilizer or soil amendment treatments were found within the experimental units studied from Experiment II.

4.0 CONCLUSIONS AND DISCUSSION

4.1 Surface Cover and Soil Erosion

The soil loss equation of Wischmeir and Smith [10] states that soil loss in tons per acre is equal to RKLSCP where:

R = a rainfall factor

K = a soil erodibility factor

L = a slope length factor

S = a slope gradient factor

C = a cropping-management factor

P = an erosion control practice factor.

Despite the fact that this equation was developed for estimation of erosion of agricultural land, it does have some use in its basic approach to the stabilization of industrial areas that have been disturbed by man. Many of the factors are relevant to soil movement from tailings sand slopes and may be manipulated by management of such an area to reduce the potential for soil erosion to occur.

In practice, each factor is assigned a numerical value derived from tables and nomographs. However, for the purposes of this discussion, such refinements are not necessary since our interest lies in eliminating erosion rather than quantifying it .

Rainfall is one factor which is not within our direct control. In this context, it is the intensity of rainfall rather than absolute amounts that are important. Although our data has not been measured as intensity, it is noticeable from daily measurements and on-site observation that several periods of heavy continuous rainfall are likely each year in the Fort McMurray area. Thus, the potential motive force for erosion exists.

In order to obtain minimum erosion, the slope length should be large and the gradient approaching zero. However, mining operations are constrained within the usual commercial bounds of balancing costs against productivity and, in more recent times, by living within government regulations designed to maintain environmental well-being. Thus, in practice, slope lengths and gradients will be determined by an overall mining plan that takes into account materials handling and storage as well as regulatory guidelines and are therefore fixed at the inception of the land reclamation program.

The soil erodibility factor is intrinsic to each particular mine spoil under consideration. In the case of a uniformly fine grained sandy material, such as the G.C.O.S. and Syncrude tailings sands, the factor is large and of great importance in any discussion of erosion.

The erodibility of tailings sand may be ameliorated by the addition of other soil materials or by surface treatments such as mulches and adhesive stabilizers which modify the surface properties of the sand. In the case of peat additions, the erodibility factor is reduced substantially since both wind and water erosion will be reduced. Mine overburden in this area tends to contain more soil particulates of clay and silt size and may also have a greater structural stability due to the presence of carbonate concretions and thus tends to reduce the erodibility of the tailings surface, though to a lesser extent to the local muskeg peats.

In the soil loss equation, the cropping management factor is the ratio of soil lost from land cropped under specified conditions to the corresponding loss from fallowed and tilled land. On a tailings sand slope, we may consider this parameter to refer to the ability of the slope to support any vegetative cover capable of intercepting the Kinetic energy in the rainfall and lessening its impact on the underlying soil surface. Providing such cover has always been one of the main objectives of the experiments. The research has been largely directed to determining the effectiveness of fertilizer additions, soil amendments and different plant species in providing an adequate cover.

The erosion control practices concern various physical methods such as slope drainage, contour tillage, terracing etc. which are designed to reduce water runoff once microchannelling of the slope surface has occurred.

Our research indicates that under conditions of fixed slope length and gradients, the erosion of tailings sand slopes may be reduced to acceptable levels by manipulation of the inherent erodibility of the soil by the addition of peat or peat and overburden and by the rapid establishment of a complete surface cover of vegetation.

When local muskeg peat is mixed with the tailings sand surface, the effect of fertilizers on the production of a suitable plant cover is not as significant as the addition of peat itself. However, the addition of a complete fertilizer initially is advisable in view of our results concerning the uptake of nutrients from fertilizers and then release from decomposition of plant residues in subsequent years. The precise amount of fertilizer required will depend upon the characteristics and amount of the peat or other soil amendment and the type of plant cover required in later years, both in terms of quantity and quality. Questions concerning the maintenance of an erosion-free surface at minimum cost are not as yet fully answered. An important question concerns whether such a man-made soil can eventually support a self-sustaining system of vegetation. If so, how long does the process take to develop? Will a sward of agronomically developed grasses and legumes develop into such an ecological unit or are native grasses, legumes, shrubs and trees required to reach such a stable state?

It is evident that a surface cover that is capable of resisting erosion for at least three years may be obtained by mixing peat into the surface 15 cm of the tailings dike and fertilizing the area at a rate equivalent to 80 Kg-N, 35 Kg-P, 75 Kg-K and 20 Kg-S per hectare for two years. Indeed, from studies on the area established in 1971, it seems that, with a similar addition of peat, such an area maintains itself in an erosion-free state without further additions of fertilizer for at least four years after. In this latter example, shoot growth is quite low at between 0.5 to 2.4 tonnes/ha dry matter production as measured between 1975 and 1978. A concern might be justified as to the ability of such an area to remain intact during a poorly productive period under heavy rainfall. For a comparison, biomass production in the range of 1.6 to 4.0 tonnes/ha has been quoted over a four year period for native short grass prairie in Saskatchewan(11) with, of course, a substantially longer growing period.

The addition of higher amounts of fertilizer results in greater plant growth and generally increased nutrient uptake into the green tissues. This has a benefit since the elements taken up into the plant are slowly released into the soil system as the tissues decompose at a later date and are partially made available for new plant production. When high annual rates of application are employed or where two doses of fertilizer are given each year, the efficiency in the use of fertilizer nutrients is reduced. Soluble forms of nutrients, such as nitrate nitrogen, potassium and sulfate sulfur, may be leached below the rooting zone or, in the case of nitrate nitrogen, may be lost by denitrification reactions.

However, if the reduction in efficiency is not too great, a cost benefit may still be incurred when the application costs of smaller but more frequent fertilizer applications are taken into account.

Addition of complete fertilizer blends also may have repercussions upon the stability of the original species seeded. Even small amounts of added nitrogen tend to repress the growth of legumes, especially where the accompanying grasses are uncropped or ungrazed. Similarly, the potassium requirements of grasses and legumes differ. Grasses are generally more able to extract potassium from the soil so that at low potassium levels legumes are the first to suffer deficiencies of potassium. If excess potassium is present, luxury consumption may occur in grasses to the extent that over 4% potassium may be found in the tissues[12].

Since 1975, when experimental fertilizer treatments were imposed, the distribution of particular grass and legume species has changed drastically on an area of tailings sand revegetated in 1971. Originally the area was seeded to Brome Grass, Creeping Red Fescue, Crested Wheatgrass, Sweet Clover and Alsike Clover. After four seasons' growth and an average annual fertilizer application of 70 Kg-N; 35 Kg-P and 50 Kg-K per hectare, the area had a cover of 90% Creeping Red Fescue, 9% Brome Grass and 1% legumes. Cessation of fertilization has resulted in a shift to 72% Creeping Red Fescue, 5% Brome Grass and 23% legumes. Increasing the fertilizer application to 90 Kg-N;

23 Kg-P and 90 Kg-K per hectare since 1974 has resulted in a cover of 99% Brome Grass and 1% Creeping Red Fescue in 1978. A slight reduction in fertilizers has provided a cover of 58% Brome Grass, 33% Creeping Red Fescue and 9% legumes.

In the area that was seeded in 1976, it was possible to monitor the survival and growth of plants from a more complex seed mix under conditions where higher rates of fertilizer were added initially. The seed mix contained nine pasture grasses, four legumes and oats, as a companion crop, to provide most of the first year cover. After two years fertilization at 80 Kg-N; 35 Kg-P and 75 Kg-K per hectare, followed by one year with no fertilizers, a cover of 95% grass and 5% legumes was found. The grass cover was composed of 36% Brome Grass, 26% Wheat-grasses, 22% Blue grasses and 7% Fescue. Annual additions of 150 Kg-N; 40 Kg-P and 150 Kg-K per hectare during the first two years and 75 Kg-N and 75 Kg-K per hectare in the second further altered the species composition such that legumes comprised only about 1% of the cover while Brome Grass made up 81% of the cover. Increased amendments equivalent to two applications as above in the initial two years followed by one application containing 150 Kg-N and 150 Kg-K per hectare in the third year produced an almost pure stand of Brome Grass.

Neither the Lupine nor Altai Wild Rye showed any degree of winter hardiness and did not reappear in 1977. Cicer Milk Vetch and Sainfoin showed poor survival and did not compete successfully with the grasses and other legumes, even at the lowest rate of fertilizer addition. Red Top was not detected after the first year's growth and would probably have preferred more acidic conditions. Smooth Brome, of all the plants tested, seemed best adapted to the short growing season and generally cool summers of the Fort McMurray area and was particularly vigorous under a high nutrient regime.

4.2 Plant Root Development and Soil Stabilization

The success of plant growth in unstable and potentially erodible habitats is in large measure related to differences in extent, depth and mechanical strength of the root system. The factors that affect the development of plant roots are not as well understood as those concerned with growth of the above ground tissues[13]. In light textured sandy soils, the root system is often shallow due to the concentration of nutrients and available moisture at the soil surface. In heavy textured soils, roots may accumulate due to difficulties in penetrating below tough surface layers. Improvement in rooting may be noted by increasing the supply of nitrogen and phosphorus. Deficiencies of boron and calcium particularly restrict root development. Root growth is affected both by the moisture status of the soil and by the temperature of the soil. At low moisture tensions, root growth is slow while in excessively wet soils poor aeration restricts root growth.

The binding and anchoring effects of plant roots has always been considered important in stabilizing erodible slopes.

Observations of grass growth on tailings sands mixed with peat show that the roots are largely restricted to the peat + tailings sand layer and that root development into the pure tailings material below is comparatively slight[3]. Table 24 summarizes root distribution data for the two experimental areas studied on the G.C.O.S. tailings sand dike at Fort McMurray. The three years' data since 1976 on the older area seeded in 1971 shows that on average some 87% of the root mass occurs in the surface 15 cm containing the peat + tailings sand mix while only 10% is found in the 15-30 cm depth.

On the area seeded in 1976 after amendment of the surface 15 cm with peat or peat + overburden, the penetration of roots has increased steadily. In 1976, the surface 15 cm contained 91% of the total root mass while values of 87% and 81% were determined in 1977 and 1978, respectively.

In both experiments the addition of fertilizer has not significantly improved root mass production or deeper penetration.

A separate experiment designed to show the effect of deeper tillage of peat + overburden has conclusively demonstrated that tillage of amendments to 30 cm rather than 15 cm does stimulate deeper rooting. Results from 1978 show that, where tillage was carried out to a depth of 15 cm, some 86% of the root mass occurred in the 0-15 cm zone while 11% and 3% occurred at 15-30 cm and 30-60 cm, respectively. Comparative figures for tillage to 30 cm are 78% in the 0-15 cm zone and 18% and 4% in the 15-30

TABLE 24

The Distribution of Plant Roots to a Depth of 60 cm in Tailings Sand Amended with Peat or Peat and Overburden During a Three Year Period Between 1976 and 1978

Treatment	Percentage Distribution of Root Biomass								
	1976			1977			1978		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Experiment I									
(Peat tilled to a depth of 15 cm)									
T_0 (unfertilized)	91	7	2	87	9	4	83	14	3
T_2 (fertilized yearly)	95	5	0	87	10	3	84	14	2
T_4 (fertilized every 2 years)	85	12	3	84	12	4	88	10	2
T_5 (fertilized yearly)	88	10	2	88	9	3	86	10	4
Experiment II									
(Peat or peat + overburden tilled to 15 cm)									
Low Rate of Fertilization									
1A	94	6	0	93	5	2	82	13	5
5A	91	9	0	83	15	2	81	16	3
6A	87	13	0	85	15	2	74	18	8
High Rate of Fertilization									
1C	95	5	0	89	9	2	86	11	3
5C	92	8	0	87	11	2	78	16	6
6C	88	12	0	87	12	1	84	14	2

(... continued)

Treatment	Percentage Distribution of Root Biomass								
	1976			1977			1978		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Experiment III									
(Peat or peat + overburden tilled to 30 cm)									
1	76	23	1	76	22	2	79	16	5
2	87	12	1	79	18	2	78	17	5
3	81	18	1	79	19	2	77	20	3
(Peat tilled to 15 cm)									
4	90	10	0	82	15	3	86	11	3

cm and 30-60 cm depths. However, despite this obvious benefit, no differences in surface erosion have been noted and therefore the practise of deeper tillage cannot be justified in terms of surface stability.

4.3 Fertilizer Use

Table 25 summarizes some of the data obtained since 1975 concerning plant uptake of nitrogen, phosphorus and potassium into shoot tissue in relation to the amount of fertilizer added.

Precise measurements of the efficiency of fertilizer use are only possible by isotopically labelling the particular element in the fertilizer and following its passage into the plant. However, an approximation may be obtained by balancing additions of fertilizer nutrients against total uptake into the shoot tissues, taking into account the likely contribution from native sources from the soil. Unfortunately, none of our experimental treatments are true controls in that they do not represent totally unfertilized situations. Treatment T_0 from Experiment I comes close to this criterion in that it has had no fertilizer additions since 1974. Consequently, Treatment T_0 was used as the baseline in calculations. On the average, 15.3 Kg-N/ha; 26.3 Kg-K/ha and 3.8 Kg-P/ha were estimated to be taken up annually into the plant tops entirely from native soil nutrients. The calculations do not take into account uptake into root tissues or the reuse of added fertilizer nutrients once they have been recycled through the decomposition of dead plant

TABLE 25

Nutrient Uptake in Plant Tops Related to Fertilizer Additions During 1975-1978

Treatment	1975			1976			1977			1978			
	Input	Uptake	Efficiency*	Input	Uptake	Efficiency	Input	Uptake	Efficiency	Input	Uptake	Efficiency	Overall
	(Kg/ha)		(%)	(Kg/ha)		(%)	(Kg/ha)		(%)	Kg/ha)		(%)	Efficiency
							Nitrogen						
Experiment I													
T_0	0	9		0	22		0	7		0	23		
T_2	90	58	54	90	101	88	90	69	69	90	65	47	64%
T_4	180	84	42	0	44		180	72	36	0	44		51%
T_5	41	14	12	43	68	107	43	27	47	43	28	12	45%
Experiment II**													
A				80	61	49	80	49	53	0	19	0	48%
B				150	58	24	150	76	46	75	55	43	37%
C				300	77	18	300	100	31	150	122	66	33%
							Phosphorus						
Experiment I													
T_0	0			0	6		0	1.9		0	3.5		
T_2	23	no data		23	11	22	23	11.7	43	23	10.0	28	31%
T_4	0			0	7		46	6.2	9	0	5.1		15%
T_5	11			11	11	45	11	3.3	13	11	4.1	5	21%

(...continued)

Treatment	1975 Input (Kg/ha)	1975 Uptake (Kg/ha)	1975 Efficiency* (%)	1976 Input (Kg/ha)	1976 Uptake (Kg/ha)	1976 Efficiency (%)	1977 Input (Kg/ha)	1977 Uptake (Kg/ha)	1977 Efficiency (%)	1978 Input (Kg/ha)	1978 Uptake (Kg/ha)	1978 Efficiency (%)	Overall Efficiency
							Phosphorus						
Experiment II													
A				35	7.7	5	35	4.0	6	0	1.9		3%
B				40	7.0	3	40	5.3	9	0	6.3		9%
C				80	10.3	7	80	9.4	9	0	13.9		14%
							Potassium						
Experiment I													
T_0	0			0	36		0	11		0	32		
T_2	90	no data		90	85	54	90	81	78	90	92	67	66%
T_4	180			0	46		180	72	34	0	60		55%
T_5	22			22	77	195	22	33	100	22	40	36	108%
Experiment II													
A				75	62	35	75	58	63	0	21		41%
B				150	66	20	150	86	50	75	95	84	45%
C				300	93	19	300	101	30	150	184	101	40%

* The efficiency index is calculated by subtracting the amount of nutrient supplied from native soil sources (approximated by T_0 value) and expressing this as a percentage of fertilizer applied.

** Values for each fertilizer level represent the means of all soil treatments within each fertilizer treatment.

tissues.

Apparent recovery of nitrogen varied quite widely from year to year, especially where alternate years of differing fertilization rates were involved.

During the 1975-1978 period for the older revegetated area, nitrogen supplied in fertilizers was utilized at an efficiency between 45% and 64%. Yearly additions of 90 Kg-N/ha were more efficiently used than one addition of 180 Kg-N/ha supplied every two years. However, both practices were superior to an annual addition of only 41-43 Kg-N/ha. Apparently at this level, other plant nutrients are more important in limiting plant growth and uptake.

On the experimental area seeded in July of 1976, the initial use of fertilizer nitrogen was very poor (18-49% efficient) and was lowest at the higher rates of addition. Improvement occurred in the second growing season when efficiencies between 31% and 53% were recorded, although the same trend related to addition rates was evident. It was not until cycling of nutrients previously immobilized in the plant tissues occurred that the apparent efficiency improved at high fertilizer addition rates. This also coincided with a general reduction in fertilizer applications. Over the three year period, the overall efficiency ranged from 33% at a rate equivalent to a total addition of 750 Kg-N/ha to 48% where 160 Kg-N/ha had been added.

As may have been anticipated due to the chemical and physical fixation reactions that tend to occur in soils, the use of added phosphorus was noticeably inferior to that of nitrogen or potassium. Overall use of added phosphorus on the revegetated area established in 1971 was 15-31% during a three year period from 1976-1978. Broadcast addition of 46 Kg-P/ha every two years was the least efficient method of application while 11 Kg-P/ha every year gave an intermediate efficiency and addition of 23 Kg-P/ha gave the best results.

The apparent recovery of added phosphorus was far less in the more recently seeded part of the dike. The efficiency was greatest at the highest rate of phosphorus application and showed an increased apparent efficiency with time as the earlier additions of phosphorus were gradually made available to the plants.

Potassium use was similar or slightly superior to that of added fertilizer nitrogen. In the old revegetated area, the effectiveness of potassium use increased as the rate of fertilizer potassium was reduced. The overall efficiency when equivalent to 22 Kg-K/ha were added annually was double that obtained by adding potassium at a rate of 180 Kg-K/ha every second year.

As was found with nitrogen use on the more recently seeded area, the uptake of potassium from the fertilizers during the first growing season was very poor (19-35% apparent efficiency). A significant improvement to 30-63% occurred in the second season but the lowest efficiency was still found at the highest rate of addition. This suggests that, if high rates of potassium are initially supplied, available potassium will accumulate in the soil and may be partially lost by leaching. This seems to be in agreement with the soil data obtained in 1976 and 1977. During the third year, when potassium additions were reduced (B and C) or eliminated (A), greater uptake of applied potassium apparently occurred due to recycling of potassium previously immobilized in plant tissues. Efficiencies tended to stabilize over the 1976-1978 period and varied between 40-45% overall at the end of the third growth period.

The data indicates that the most efficient use of fertilizers occurred on established areas on the dike when additions were about 90 Kg-N; 25 Kg-P and 40 Kg-K per hectare. Larger additions every second year were less efficient and can not be recommended.

Fertilizer use was quite inefficient during the first year of growth on tailings sand slopes amended with peat or peat + overburden. A fertilizer blend containing 60-80 Kg-N; 40 Kg-P and 60-80 Kg-K per hectare should be adequate to produce a sufficient plant cover and will be efficiently utilized by the plants. Even though higher rates of addition are still not particularly efficiently used during the second year, the nutrients taken up into plant tissues will be beneficially released in subsequent years as the tissue dies and decays in the soil. Depending upon the nature of the cover required (i.e. grass/legume or primarily grass), the rate could be increased during the next two years in terms of nitrogen and potassium content.

4.4 Nutrient Cycling and Plant Residue Decomposition

Figure 10 shows a general scheme for the cycling of nitrogen on the tailings sand dike and the likely yearly limits on each component. It can be used as a framework to discuss what we know of nutrient cycling on the tailings dike.

Nutrient losses from water runoff and leaching are most serious during the initial growing season while the surface is partially bare and overall uptake of nutrients from the soil is still quite low. For nitrogen, a total maximum loss of 10% from runoff and leaching may occur at high fertilization rates though this amount should be substantially reduced in future years.

Under conditions of high soil temperature and high moisture, loss of nitrogen by denitrification could be very large. However, a loss of 30% of the nitrate nitrogen in the mineral pool would seem the maximum likely under the normally well-drained and cool conditions on the dike. Such losses would be greatest where excess nitrogen fertilizer was added and allowed a large buildup of nitrate in the soil.

Very small additions of nitrogen into the system are likely from free-living microbial fixation and rainfall. The fixation of atmospheric nitrogen by legumes could be significant where little or no fertilizer nitrogen is added but the effect has not been quantified under these conditions.

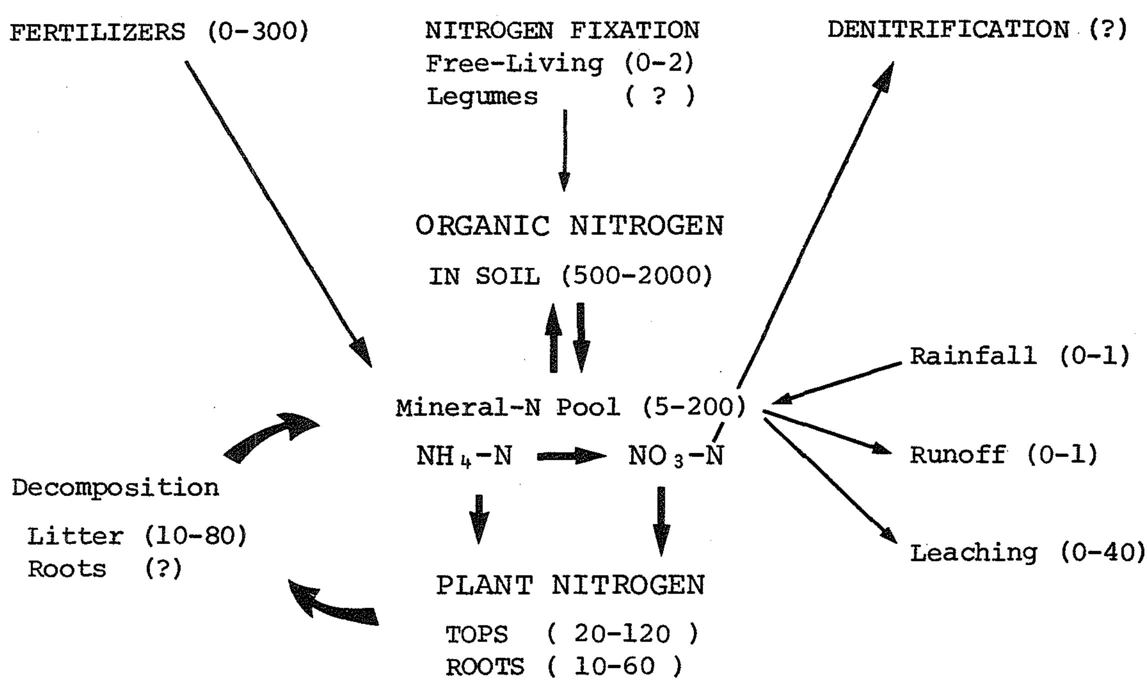


FIGURE 10. Cycling of Nitrogen on a Tailings Sand Dike Amended with Peat, Overburden and Fertilizers and Seeded in 1976.

Depending upon the nature and amount of the peat addition, some 500-2000 Kg of organic-N may be added. The slow mineralization of this organic reserve could release in the order of 50-200 Kg of N/ha into the mineral pool. Part of this would be available to plant growth.

Our data indicates that yearly uptake of nitrogen in shoot material varies between 20 and 120 Kg-N/ha depending upon fertilizer practice. Of this, potentially half could be released through litter decomposition during the next year. Root tissues may contain between 50 and 150 Kg-N/ha though part may be already in dead and decaying tissues. Yearly uptake in the order of 10-60 Kg-N/ha may be more realistic.

Few studies have been conducted that provide an accurate assessment of nutrient cycling from roots. Longevity of grass roots varies considerably from possibly only a few weeks for primary roots to over two or three years for suberized perennial tissues(13). We might expect 5-30 Kg-N/ha/yr to be mineralized from plant roots on the dike.

In general, our studies have indicated that litter decomposition and microbial activity as determined by cellulose decomposition rates, numbers of aerobic bacteria and total soil respiration are slightly higher on well established revegetated areas of the dike in comparison to recently seeded regions.

Less data is available concerning the cycling of phosphorus, potassium and sulfur on the dike.

Losses of phosphorus are very small since phosphate is largely immobile in the soil and becomes readily fixed, probably as calcium phosphates when added as ammonium phosphate in fertilizers. For native short grass prairie in Saskatchewan, Stewart *et al.*[14] have measured an annual release of 17.6 Kg-P/ha and an uptake of 12.2 Kg-P/ha by plants. This compares with a range of 2-14 Kg-P/ha measured in plant tops growing on the dike in 1978.

Initially, losses of potassium by leaching and in runoff water may be as large or greater than for nitrogen. Leaching may account for a loss of 1-10 Kg-K/ha depending upon fertilizer additions while smaller losses occur from water run-off. In subsequent years, leaching losses will generally be smaller and be dependent upon large accumulations of soluble potassium in the soil and on rainfall characteristics.

Data concerning sulfate movement in tailings sand[4] show that considerable amounts of sulfate may pass below the rooting zone of the plants. This downward loss of soluble sulfur may be as high as 40 Kg-S/ha where sulfate containing overburdens are added to stabilize the tailings sand surface. In terms of plant nutrition, the effect is not serious since adequate amounts of available sulfur have always been found in revegetated areas where peat or overburden has been used.

For comparative purposes, Figures 11-18 show the current status of N, P, K and S in plant tissues and the soil under the main treatments under study on the tailings sand dike. Additional emphasis is needed in future years on the study of overall nutrient cycling under these conditions. It will then be possible to make more confident predictions as to the self-maintaining characteristics of the vegetation and, in particular, the influence that management practices such as the addition of fertilizers and other soil amendments may have in hastening the creation of a stable ecological unit.

NITROGEN (kg/ha)

Treatment

To ...... SOIL (31)
..... PLANT TOPS (23)
.... PLANT ROOTS (89)
ADDED AS FERTILIZER SINCE 1971 (0)

T_2 .... SOIL (50)
.... PLANT TOPS (65)
.... PLANT ROOTS (122)
....//......... FERTILIZER (639)

T_4 ...... SOIL (29)
.... PLANT TOPS (44)
.... PLANT ROOTS (148)
....//......... FERTILIZER (639)

T_5 .... SOIL (49)
...... PLANT TOPS (28)
.... PLANT ROOTS (119)
....//......... FERTILIZER (449)

....//......... TOTAL NITROGEN IN SOIL IN 1976 (1250)

FIGURE 11. Present Status of Nitrogen in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat and Revegetated in 1971.

PHOSPHORUS (kg/ha)

Treatment

To
...... SOIL (31)
. PLANT TOPS (4)
.. PLANT ROOTS (7)
FERTILIZER (0)

T_2
.... SOIL (41)
.. PLANT TOPS (10)
.. PLANT ROOTS (11)
.... FERTILIZER (230)

T_4
.... SOIL (47)
. PLANT TOPS (5)
.... PLANT ROOTS (18)
.... FERTILIZER (230)

T_5
.... SOIL (39)
. PLANT TOPS (4)
.. PLANT ROOTS (10)
.... FERTILIZER (183)

FIGURE 12. Present Status of Phosphorus in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat and Revegetated in 1971.

POTASSIUM (kg/ha)

Treatment

T_0

.... SOIL (142)
... PLANT TOPS (32)
. PLANT ROOTS (7)
FERTILIZER (0)

T_2

.... SOIL (336)
.... PLANT TOPS (92)
. PLANT ROOTS (11)
.... FERTILIZER (548)

T_4

.... SOIL (314)
...... PLANT TOPS (60)
.. PLANT ROOTS (18)
.... FERTILIZER (548)

T_5

.... SOIL (256)
.... PLANT TOPS (40)
. PLANT ROOTS (10)
.... FERTILIZERS (276)

FIGURE 13. Present Status of Potassium in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat and Revegetated in 1971.

SULFUR (kg/ha)

Treatment

T_0
.... SOIL (57)
.. PLANT TOPS (9)
..... PLANT ROOTS (25)
FERTILIZERS (0)

T_2
.... SOIL (83)
.... PLANT TOPS (20)
...... PLANT ROOTS (32)
.. FERTILIZER (9)

T_4
.... SOIL (99)
... PLANT TOPS (13)
.... PLANT ROOTS (42)
.... FERTILIZER (18)

T_5
.... SOIL (118)
.. PLANT TOPS (9)
.... PLANT ROOTS (43)
.... FERTILIZER (67)

FIGURE 14. Present Status of Sulfur in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat and Revegetated in 1971.

NITROGEN (kg/ha)

Treatment

A ... SOIL (31)
.. PLANT TOPS (19)
.... PLANT ROOTS (68)
.... TOTAL FERTILIZER ADDED (160)

B ... SOIL (32)
...... PLANT TOPS (55)
Roots not determined
.... FERTILIZER (375)

C .... SOIL (74)
.... PLANT TOPS (122)
.... PLANT ROOTS (100)
.... FERTILIZER (750)

.... TOTAL N IN SOIL IN 1976 (1720)

FIGURE 15. Present Status of Nitrogen in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat or Peat + Overburden and Revegetated in 1976.

PHOSPHORUS (kg/ha)

Treatment

A .... SOIL (22)
. PLANT TOPS (2)
... PLANT ROOTS (5)
.... FERTILIZER (70)

B ...... SOIL (11)
... PLANT TOPS (6)
Roots not determined
.... FERTILIZER (80)

C .... SOIL (42)
.... PLANT TOPS (14)
.... PLANT ROOTS (8)
.... FERTILIZER (160)

FIGURE 16. Present Status of Phosphorus in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat or Peat + Overburden and Revegetated in 1976.

POTASSIUM (kg/ha)

Treatment

```
A     .................. SOIL (179)
      .. PLANT TOPS (21)
      . PLANT ROOTS (11)
      ................ FERTILIZER (160)

B     ................................ SOIL (326)
      .......... PLANT TOPS (95)
       Roots not determined
      ...................................... FERTILIZER (375)

C     ....................................................... SOIL (530)
      .................. PLANT TOPS (184)
      . PLANT ROOTS (12)
      ............................................................................ FERTILIZER (750)
```

FIGURE 17. Present Status of Potassium in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat or Peat + Overburden and Revegetated in 1976.

SULFUR (kg/ha)

Treatment

A .... SOIL (132)
. PLANT TOPS (6)
.... PLANT ROOTS (23)
.... FERTILIZER (40)

B .... SOIL (152)
... PLANT TOPS (15)
Roots not determined
.... FERTILIZER (40)

C .... SOIL (187)
...... PLANT TOPS (28)
.... PLANT ROOTS (34)
.... FERTILIZER (80)

FIGURE 18. Present Status of Sulfur in Soil and Plant Tissues on an Area of Tailings Sand Amended with Peat or Peat + Overburden and Revegetated in 1976.

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APPENDIX

TABLE I

Assessment of Percentage Cover by Different Seeded Grasses and Legumes in Experiment I During May and October, 1978

Treatment	Percentage Cover					
	Brome Grass	Creeping Red Fescue	Crested Wheatgrass	Sweet Clover	Alfalfa	Alsike Clover
May 1978						
T_0	4	92	0	3	1	0
T_0A	54	45	0	1	0	0
T_1	87	13	0	0	0	0
T_1A	98	2	0	0	0	0
T_2	98	2	0	0	0	0
T_2A	99	1	0	0	0	0
T_3	91	9	0	0	0	0
T_3A	100	0	0	0	0	0
T_4	82	18	0	0	0	0
T_4A	93	6	1	0	0	0
T_5	24	75	0	1	0	0
T_5A	72	28	0	0	0	0
October 1978						
T_0	5	72	0	6	3	13
T_0A	45	47	0	2	2	4
T_1	98	2	0	0	0	0
T_1A	98	2	0	0	0	0
T_2	99	1	0	0	0	0
T_2A	99	1	0	0	0	0
T_3	96	3	0	1	0	0
T_3A	100	0	0	0	0	0
T_4	88	10	2	0	0	0
T_4A	97	1	2	0	0	0
T_5	33	58	0	0	0	9
T_5A	80	20	0	0	0	0

TABLE II

Assessment of Percentage Ground Cover by Seeded Grass and Legume Species in Experiment II, October 1978

	Percentage Cover								
Treatment	Bare Ground	Brome Grass	Wheat Grasses	Blue Grasses	Hard Fescue	Cicer Milk Vetch	Sainfoin	Alfalfa	Weed Species
1A	5	35	25	20	10	P	0	5	0
5A	3	39	26	20	4	P	0	8	0
6A	3	39	25	22	7	P	0	4	0
7A	4	34	28	24	7	0	0	3	0
8A	10	56	13	13	6	P	S	1	1
1B	1	87	6	4	2	0	0	P	0
5B	1	78	9	8	4	0	0	P	0
6B	1	79	10	6	4	S	0	P	0
7B	1	78	11	6	4	0	0	P	0
8B	5	74	10	6	4	S	0	P	1
1C	0	100	P	P	P	0	0	0	0
5C	0	99	1	P	P	0	0	0	0
6C	0	99	1	P	P	0	0	P	0
7C	0	98	2	P	P	0	0	P	0
8C	2	92	4	1	1	0	0	P	P

P Present but <1%.
S Generally present but <<1%.

Lupine and Oats have been absent since 1977.
Red Top and Altai Wild Rye were only rarely detected in 1978.

TABLE III

Concentration of Mineral Nitrogen (NH_4-N + NO_3-N) in the 0-30 cm Depth Between May and October, 1978, in Selected Treatments from Experiments I and II

	Total Mineral Nitrogen (NH_4-N + NO_3-N) in ppm				
Treatment	May	June	July	August	October
Experiment I					
T_0	5.9	5.7	1.2	6.2	9.3
T_2	7.3	6.8	3.0	11.8	16.2
T_4	5.1	5.4	0.8	9.8	13.0
T_5	6.3	3.1	4.4	15.5	11.7
Experiment II					
1A	2.1	2.4	1.3	9.2	10.0
5A	2.3	3.2	1.4	13.2	11.9
6A	1.7	3.5	1.5	14.2	10.2
7A	3.5	3.2	2.0	10.2	14.3
1B	1.6	4.1	5.2	13.1	17.4
5B	3.3	8.0	19.2	21.5	16.6
6B	2.0	6.8	20.5	7.2	16.1
7B	2.2	6.6	13.0	7.9	10.8
1C	16.3	58.1	52.7	20.9	22.2
5C	7.4	30.9	48.2	37.1	17.8
6C	7.7	43.5	49.2	40.5	23.8
7C	7.3	44.8	37.9	45.4	20.4

Results are means of 3 replicates.

TABLE IV

Concentration of Available Phosphorus in the 0-30 cm Depth Between May and October, 1978, in Selected Treatments from Experiments I and II

	Available Phosphorus in ppm				
Treatment	May	June	July	August	October
Experiment I					
T_0	12	11	10	17	10
T_2	21	22	25	21	17
T_4	21	23	23	26	18
T_5	18	15	16	26	15
Experiment II					
1A	11	10	9	12	7
5A	6	9	11	7	6
6A	6	8	9	12	8
7A	10	10	6	10	10
1B	13	10	11	8	13
5B	10	9	7	6	6
6B	7	7	8	7	7
7B	16	12	7	9	11
1C	27	31	21	18	31
5C	27	33	33	33	22
6C	19	29	21	15	18
7C	18	21	23	16	21

Results are means of 3 replicates.

TABLE V

Concentration of Available Potassium in the 0-30 cm Depth Between May and October, 1978, in Selected Treatments from Experiments I and II

	Available Potassium in ppm				
Treatment	May	June	July	August	October
Experiment I					
T_0	30	25	39	68	48
T_2	51	83	61	149	152
T_4	48	72	129	163	103
T_5	52	80	50	113	107
Experiment II					
1A	19	37	36	29	37
5A	56	107	51	93	80
6A	63	77	59	87	69
7A	44	67	37	51	58
1B	53	90	107	95	132
5B	79	125	111	143	191
6B	76	83	131	195	195
7B	53	87	91	87	88
1C	105	136	141	180	169
5C	126	113	148	163	138
6C	139	142	176	287	179
7C	77	144	153	268	218

Results are means of 3 replicates.

TABLE VI

Decomposition of Cellulose Strips Buried During October 1977

Treatment	October 1977 to May 1978	October 1977 to July 1978	October 1977 to November 1978
Experiment I			
T_0	46.9	73.7	89.8
T_2	36.5	74.4	98.4
T_4	26.0	67.4	83.1
T_5	45.9	79.2	90.6
Experiment II			
1A	35.0	70.6	93.0
6A	19.7	23.5	59.1
1B	37.3	74.5	92.6
6B	16.0	56.2	98.6
1C	17.3	74.9	98.2
6C	16.9	40.9	89.8
Tailing Sand (November only)			17.3
Significance	*	***	***
L.S.D.	22.6	28.5	18.3

Results are means of 3 replicates.

TABLE VII

Nutrient Contents of Roots, Shoots and Soil from Lysimeters Recovered During 1978 from Experiment II

	Nutrients in Plant Tissues								Available Nutrients in Soil to 30 cm			
	Shoots (Kg/ha)				Roots (Kg/ha)				(Kg/ha)			
Treatment	N	P	K	S	N	P	K	S	N	P	K	S
1A	43	4.1	39	10.6	65	5.8	5.8	20.3	18	26	128	267
3A	18	1.5	11	3.9	40	3.3	3.7	12.5	16	16	95	38
4A	22	1.9	17	5.0	49	3.7	4.9	29.0	29	24	158	43
5A	29	3.1	20	7.9	43	4.3	4.8	17.1	26	28	147	223
6A	29	2.5	21	6.6	54	4.6	6.3	20.1	17	23	136	390
7A	30	2.4	19	8.0	46	2.3	4.6	23.0	22	24	128	319
1B	83	7.2	128	19.1	108	8.0	10.0	43.0	28	13	187	74
3B	50	4.2	58	8.0	66	4.0	5.3	27.2	30	12	167	59
4B	70	5.8	73	15.6	75	6.2	7.6	21.4	38	26	175	162
5B	56	5.4	63	12.1	39	2.6	4.0	18.1	21	25	200	263
6B	48	4.4	48	7.9	61	5.4	8.1	27.7	30	24	155	269
7B	46	4.5	53	9.9	64	5.7	7.9	27.8	27	30	179	286
1C	123	12.6	166	26.2	67	4.1	4.6	20.4	26	15	196	189
3C	93	8.3	133	14.4	73	5.0	5.6	24.8	17	21	151	57
4C	96	8.1	119	14.9	65	4.9	5.6	27.6	19	20	185	43
5C	86	10.4	118	19.7	81	6.7	7.4	34.0	19	32	209	172
6C	92	9.8	99	23.9	61	3.8	5.9	23.6	16	25	228	418
7C	79	6.6	78	11.0	82	4.1	6.2	36.3	25	16	179	328

Bulk Density 0.8 g/cm^2 0-15 cm depth
1.3 g/cm^2 15-30 cm depth

TABLE VIII

Statistical Analyses

Parameters	DF_1	DF_2	F	$F_{5\%}$	Sig.	Error MSS	LSD
Bacteria, Expt. I	3	8	0.62	4.07	N.S.	17.54	
Expt. II, Tr. A	3	8	0.74	4.07	N.S.	1.84	
Expt. II, Tr. C	3	8	0.18	4.07	N.S.	26.59	
Expt. I & II	11	24	1.84	2.25	N.S.	15.33	
Actinomycetes, Expt. I & II	11	24	0.61	2.25	N.S.	3.38	
Fungi, Expt. I	3	8	1.53	4.07	N.S.	48.41	
Expt. II, Tr. A	3	8	0.05	4.07	N.S.	54.5	
Expt. II, Tr. C	3	8	0.41	4.07	N.S.	36.17	
Expt. I & II	11	24	0.66	2.25	N.S.	46.36	
Respiration, Expt. I	3	8	3.66	4.07	N.S.	.0081	
Expt. II, Tr. A	3	8	0.62	4.07	N.S.	.0022	
Expt. II, Tr. C	3	8	0.95	4.07	N.S.	.0065	
Expt. I & II	11	24	4.49	2.25	***	.0056	0.126
Litter % Loss, May	9	20	9.79	2.39	***	8.08	4.8
July	9	20	4.13	2.39	***	24.95	8.5
November	9	20	5.52	2.39	***	11.76	5.8
Top Yield, Expt. I	11	24	13.94	2.25	***	.00385	0.105
Expt. III	3	24	8.93	4.07	***	.00120	0.065
Legume Top Yield, Expt. II	11	24	5.96	2.25	***	.0000135	0.0062
Total Top Yield, Expt. II	23	48	15.09	1.75	***	.00184	0.071
Expt. II, Tr. A	7	16	0.53	3.22	N.S.	.00119	
Expt. II, Tr. B	7	16	2.64	3.22	N.S.	.00200	
Expt. II, Tr. C	7	16	0.84	3.22	N.S.	.00234	

(... continued)

Parameters		DF_1	DF_2	F	$F_{5\%}$	Sig.	Error MSS	LSD
Lysimeter,	Top Yield Total	17	36	5.54	1.84	***	.00641	0.373
	Root Yield Total	17	36	1.77	1.84	N.S.	.0294	
	Top Yield A	5	12	3.43	3.11	*	.00475	0.123
	Top Yield B	5	12	3.59	3.11	*	.00918	0.171
	Top Yield C	5	12	0.69	3.11	N.S.	.00530	
	Root Yield A	5	12	1.03	3.11	N.S.	.02998	
	Root Yield B	5	12	4.64	3.11	**	.02059	0.225
	Root Yield C	5	12	0.60	3.11	N.S.	.03774	
Total Root Yield,	Expt. I	3	8	0.79	4.07	N.S.	.03563	
	Expt. II	3	8	0.48	4.07	N.S.	.03059	
	Expt. III	3	8	0.88	4.07	N.S.	.01119	
Root,	Expt. I, II, & III	13	28	4.19	2.10	***	.02648	0.272
Experiment I,	Roots, N	3	8	3.69	4.07	N.S.	.02461	
	Roots, P	3	8	8.62	4.07	***	.00055	0.04
	Roots, K	3	8	1.51	4.07	N.S.	.000433	
	Roots, S	3	8	1.60	4.07	N.S.	.0057	
	Tops, N	3	8	8.04	4.07	***	.009658	0.19
	Tops, P	3	8	4.75	4.07	*	.001108	0.06
	Tops, K	3	8	1.49	4.07	N.S.	.1275	
	Tops, S	3	8	10.20	4.07	***	.0041	0.12
Experiment II,	Roots, N	5	12	8.21	3.11	***	.02636	0.29
	Roots, P	5	12	3.68	3.11	*	.000428	0.04
	Roots, K	5	12	0.56	3.11	N.S.	.005383	
	Roots, S	5	12	2.45	3.11	N.S.	.01057	
	Tops, N	11	24	26.4	2.25	***	.08271	0.48
	Tops, P	11	24	20.65	2.25	***	.001522	0.07
	Tops, K	11	24	22.52	2.25	***	.2939	0.91
	Tops, S	11	24	9.28	2.25	***	.009092	0.16
Experiment III,	Roots, N	3	8	0.097	4.07	N.S.	.02203	
	Roots, P	3	8	0.186	4.07	N.S.	.0002833	
	Roots, K	3	8	0.10	4.07	N.S.	.005592	
	Roots, S	3	8	2.78	4.07	N.S.	.001517	
	Tops, N	3	8	6.70	4.07	**	.02793	0.31
	Tops, P	3	8	15.66	4.07	***	.000625	0.05
	Tops, K	3	8	18.30	4.07	***	.1404	0.71
	Tops, S	3	8	3.31	4.07	N.S.	.008867	

(... continued)

Parameters		DF_1	DF_2	F	$F_{5\%}$	Sig.	Error MSS	LSD
Cellulose Strips,	May	9	20	2.47	2.39	*	176.35	22.6
	July	9	20	3.51	2.39	***	279.89	28.5
	November	9	20	3.49	2.39	***	116.98	18.4
				15.53	with T. sand	***	114.86	18.3

7.0 PHOTOGRAPHIC PLATES

Plate 1. View of part of Experiment I in July, 1978. Treatment T3A is to the left and treatment To is to the right. Note the increased growth of Clover and Alfalfa on the unfertilized To treatment in 1978 and the presence of Brome on the heavily fertilized T3A treatment related to Creeping Red Fescue on the unfertilized plot.

Plate 2. View of another portion of Experiment I in July 1978. Treatment T5 is in the foreground and treatment T5A in the background. Each has received quite a low rate of fertilization each June (about 40 kg-N/ha) while treatment T5A has been given an additional increment every other August. The extra fertilizer has resulted in a greater production of Brome relative to the Creeping Red Fescue.

Plate 3. Selected treatments were sampled every month to determine the amount of available plant nutrients in the soil. About 12 cores per plot were taken to a depth of 30 cm and the sample mixed and sub-sampled in the field. Samples were sent by air the same day to Edmonton for analysis.

Plate 4. General view of Experiment III and part of Experiment II. Note the greener growth of plots around the central plot which was unfertilized in 1978 (rate A).

Plate 5. Experiment II, treatment 1A. Note the greater diversity of plants here relative to the following two plates which were fertilized in 1978.

Plate 6. Experiment II, treatment 4B.

Plate 7. Experiment II, treatment 1C. Under the highest fertilizer treatment (rate C) an almost pure stand of Brome grass has been produced.

Plate 8. In areas where the "Bitumuls" soil stabilizer was used most of the stabilizer has been broken down by physical and microbial activity such that a thin crumbling crust now remains.

Plate 9. Experiment II, treatment 2B. Where contour trenching was studied, the trenches have become largely overgrown.

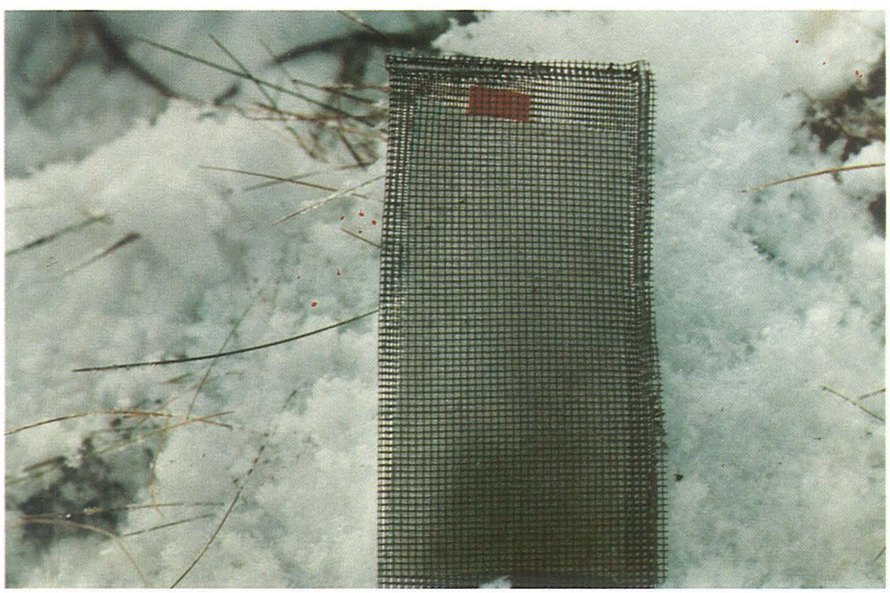

Plate 10. Cellulose strip enclosed in nylon mesh bag prior to burial in soil in October, 1977.

Plate 11. Cellulose strip in place in soil in Experiment I.

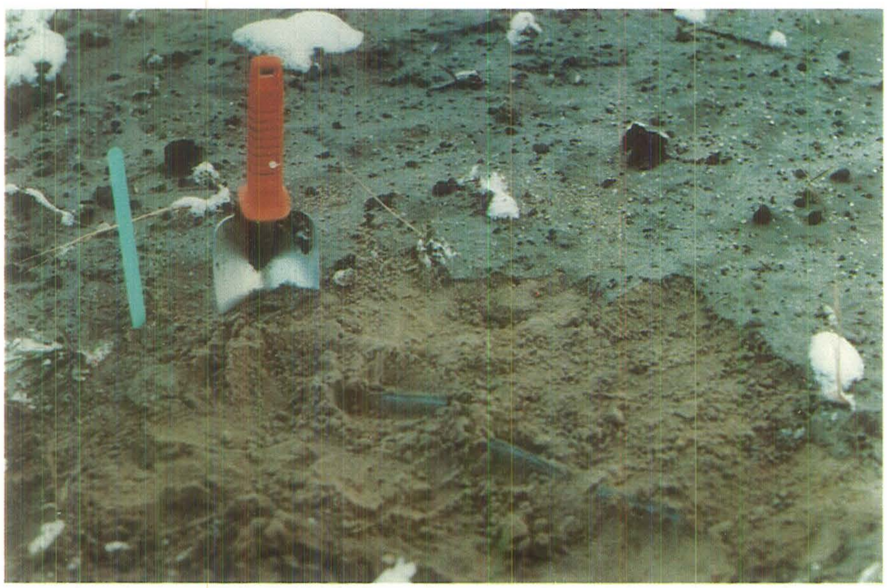

Plate 12. Strips of cellulose were also added to unvegetated tailings sand.

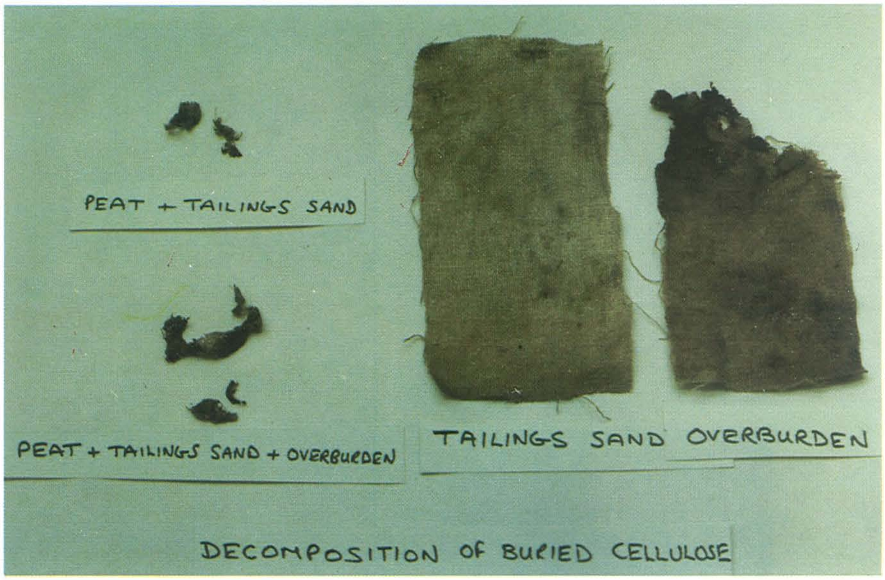

Plate 13. Condition of recovered cellulose strips after burial for 12 months. Peat + tailings sand, and peat + tailings, sand + overburden are almost completely decomposed while cellulose strips added to pure tailings sand or pure mine overburden are much less decomposed.

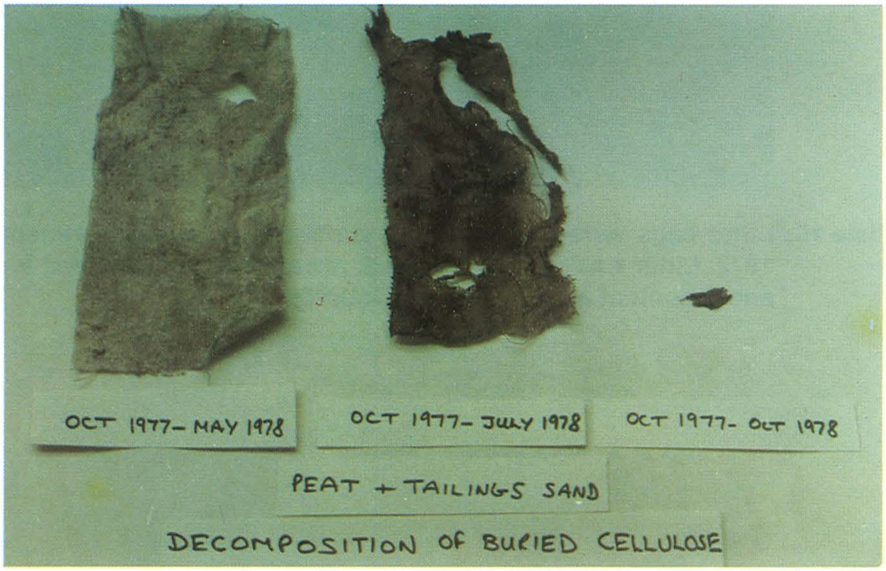

Plate 14. This photograph shows the relative extent of decomposition of the cellulose in May, July, and October, 1978 after burial in October, 1977.

Plate 15. Litter bags were placed on the surface of selected treatments in October, 1977. Litter was recovered, dried, reweighed and analysed for total N, P, K, and S content after 7, 9, and 12 months.

Conditions of Use

Rowell, M.J., 1979. Revegetation and management of tailings sand slopes from tar sands extraction: 1978 results. Syncrude Canada Ltd., Edmonton, Alberta. Environmental Research Monograph 1979-5. 131 pp.