REPORT #
RRTAC OF-6

Oil Sands Tailings Capping Study

by

HBT AGRA Limited

Prepared for

Oil Sands Reclamation Research Program

ALBERTA CONSERVATION AND RECLAMATION MANAGEMENT GROUP
(Reclamation Research Technical Advisory Committee)

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Alberta's Reclamation Research Program

Regulating surface disturbances in Alberta is the responsibility of the Conservation and Reclamation Management Group. The Chairman is from Alberta Environmental Protection. The Group oversaw a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program was provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program. Funding ended in March of 1994.

Additional information on the Reclamation Research Program may be obtained by contacting:

Chris Powter, Chairman

Reclamation Research Technical Advisory Committee

Alberta Environmental Protection

3rd Floor, Oxbridge Place

9820 - 106 Street

Edmonton, Alberta T5K 2J6

(403) 422-2612

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REVIEWS

This report was reviewed by RRTAC and the Oil Sands Reclamation Research Program committee.

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ABSTRACT

In the summer of 1990, research plots were designed and constructed on the Syncrude Canada Ltd., mine site at Mildred lake to test the effect of thickness and quality of replaced soil over tailings sand on the performance of trees and shrubs. Treatments included three cap thicknesses (70, 50 and 30 cm) of replaced soil salvaged from an area rated as "fair" soil suitability for reclamation, as well as one cap (70 cm) of replaced soil salvaged from an area of "poor" soil suitability. Following plot construction, seedlings of four species were planted including: jack pine, white spruce, aspen, and dogwood. Baseline soil data were collected and height was measured on a random selection of permanently marked seedlings. Survival and growth data were collected annually from 1991 to 1993.

Soil analysis after plot construction indicated good control of cap thickness during soil placement but minimal difference in the quality of replaced soil between plots constructed from the "fair" and "poor" rated source materials. Seedling survival after three growing seasons ranged from 68 to 96%. Almost all mortality occurred during the first overwinter period. Spruce had the highest survival and dogwood the lowest. In general, seedlings doubled in size during the three year period. Survival and growth were unrelated to soil thickness or quality. Naturally invading plants, primarily weedy species, varied according to the amount of peat present near the surface of the replaced soil.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 BACKGROUND

Open pit oil sands mines such as the Syncrude Canada Ltd. (Syncrude) and Suncor Inc. mines north of Fort McMurray, Alberta result in the disturbance and subsequent need for reclamation of thousands of hectares of land. An important step in reclaiming this land is the provision of a soil, suitable for reforestation, on the residual tailings sand after oil extraction.

RRTAC and the oil sands industry completed a literature-based study of soil requirements for oil sands reclamation in 1983 (Monenco Consultants Ltd. 1983). The Oil Sands Tailings Capping Study is the second large-scale field experiment addressing the requirements of a suitable soil on tailings sand. The first of these experiments involved testing the performance of 10 tree and shrub species on soil mixtures consisting of peat, mineral overburden and tailings sand. Results of this five year study are reported in HBT AGRA Limited (1992). The Tailings Capping Study reported herein, tests the performance of four tree and shrub species on soils placed as a cap after excavating from in-situ deposits on the Syncrude Lease. The change in study design from a mixture of sand plus amendments to a layer of suitable soil over the sand reflected a change in Syncrude's operational practices.

1.2 SCOPE

This report describes plot construction methods and monitoring results from the summer of 1990 to 1993. Included are monitoring results from three consecutive years of data collection on:

1. tree and shrub survival;
2. tree and shrub growth; and
3. herbaceous ground cover.

Emphasis is placed on differences in vegetation among treatments in the last year of monitoring. Other data collected intermittently and summarized in this report include:

1. soil physical and chemical properties;
2. incidence of damage to trees and shrubs due to insects and mammals; and
3. groundwater elevation.

1.3 OBJECTIVE

The overall objective of the study is to determine the effect of depth and quality of replaced soil over tailings sand on the survival and growth of: (1) jack pine (*Pinus banksiana*), (2) white spruce (*Picea glauca*), (3) aspen (*Populus tremuloides*), and (4) dogwood (*Cornus stolonifera*). These species were chosen because they are compatible with the natural vegetation in the region and have been successful in previous reclamation efforts at Syncrude.

2. STUDY AREA

The Syncrude oil sands mine is approximately 50 km north of Fort McMurray, Alberta (Figure 1). Prior to development, the lease supported a boreal mixed wood vegetation type (Rowe 1972) consisting of white spruce (*Picea glauca*), aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), balsam fir (*Abies balsamea*), and white birch (*Betula papyrifera*) as the major upland species. Jack pine (*Pinus banksiana*) occurred locally on dry sandy sites and often formed a mixture with black spruce (*Picea laricina*) on level hill tops. Black spruce and larch (*Larix occidentalis*) muskeg occurred in depressions and poorly drained flats.

The dominant soils included Luvisols, organics and Gleysols (Crown and Twardy 1970). The Luvisols occurred mainly on the well to moderately well drained upland sites with parent materials of glacial till, glacio-lacustrine or glacial outwash. Organic and Gleysolic soils occurred on the poorly drained sites and typically contained thick (50 to 300 cm or more) layers of sphagnum moss at the surface.

The area has a subarctic continental climate characterized by short, cool summers and long, cold winters. Long-term climate data are available from Fort McMurray (Environment Canada 1982a,b). Mean annual temperature is -0.2°C ranging from 16.4°C in July to -21.8°C in January. Annual precipitation averages 471.9 mm, most of which (252.4 mm) falls as rain during the growing season (May to August). The average frost-free period is 67 days (Boughner 1974).

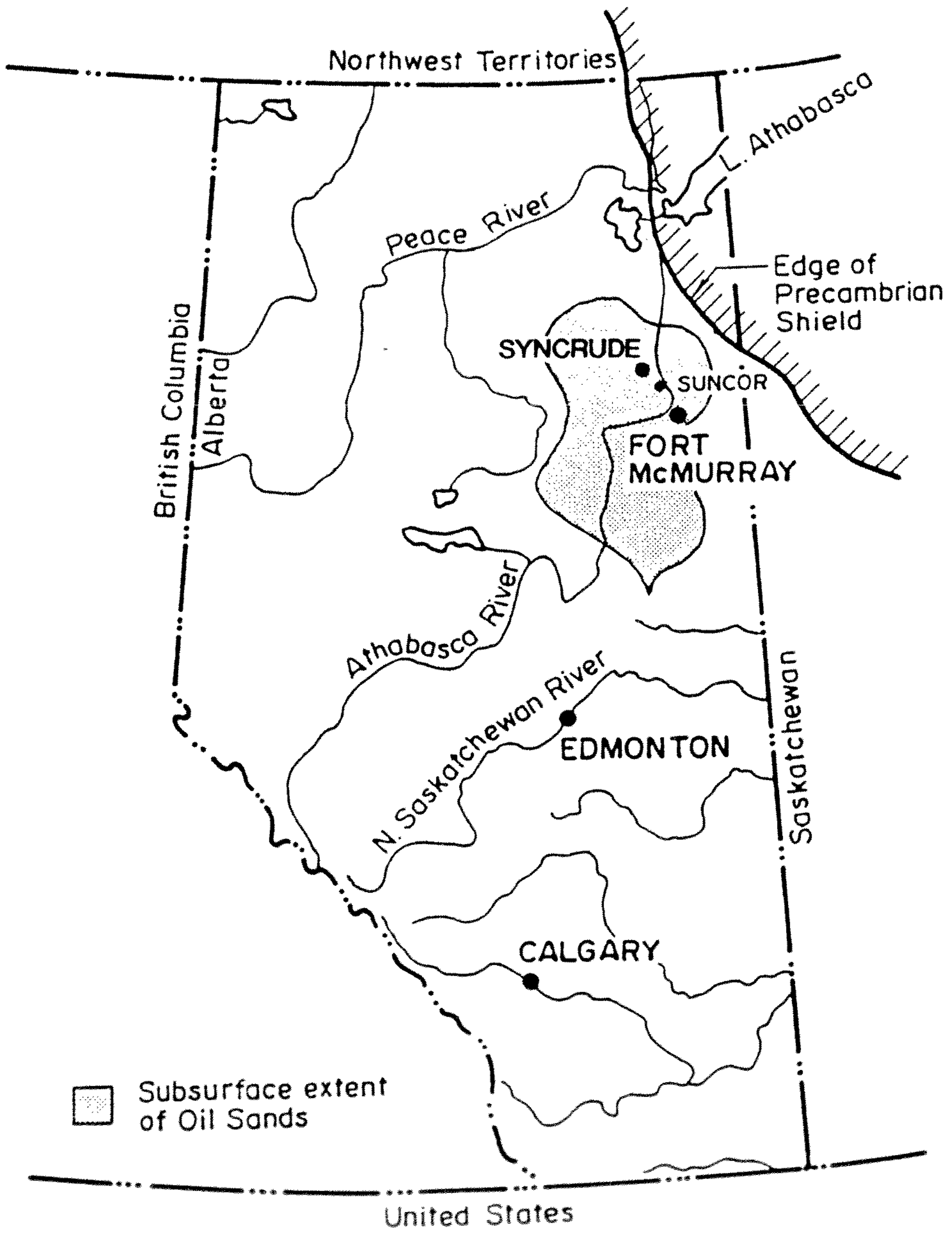


Figure 1. Location of the Study Area.

3. METHODS

3.1 PLOT ESTABLISHMENT

The tailings sand base was constructed in March, 1990 adjacent to Cell 5 of the Syncrude tailings pond. The area where the plots were located is referred to as the toe berm, constructed (using standard cell construction techniques) to provide added stability to the tailings pond dyke. The toe berm has a very gentle overall slope of approximately 25 to 1 from east to west. Apart from the overall slope, the surface was very uniform containing only minor ridges and depressions (up to 20 cm). Overall thickness of the toe berm is estimated at 3 to 5 m.

3.1.1 Experimental Design

Four soil cap treatments were tested.

1. 70 cm "fair quality or better" (70 cm Fair)
2. 50 cm "fair quality or better" (50 cm Fair)
3. 30 cm "fair quality or better" (30 cm Fair)
4. 70 cm "poor quality or better" (70 cm Poor)

The soil quality ratings were based on the criteria used for determining soil suitability for reclamation in Alberta (Soil Quality Criteria Working Group 1987) and were based on samples taken from a single borehole (to a depth of 2 m) in each of the two in-situ deposits on the Syncrude Lease which served as source material for the study. The deposit rated as "poor quality or better" had a heavier texture than the one rated as "fair quality or better", which was the reason for its lower rating.

Three plots of each treatment were arranged in replicated blocks as shown in Figure 2. The four tree and shrub species used in the study were arranged in species subplots placed at random within soil treatment plots, which in turn were placed at random within the replicate blocks.

3.1.2 Plot Configuration

Overall plot size measured 60 m squared, within which the four species subplots measured approximately 12.5 m by 50 m. This provided adequate buffer zones (approximately 5 m) around each plot to slope the capping material between adjacent plots or down to the tailings sand base at the sides of the block.

Within each species subplot, 125 individuals of each species were planted in 5 rows of 25 plants per row. Rows were spaced at 2.5 m intervals whereas plants within the rows were spaced every 2 m (Figure 3).

3.1.3 Plot Construction

Plots were constructed July 3 to 15, 1990 using a fleet of five Cat™789 haul trucks, a loader, and two Cat™ dozers (D9 for stripping, D6 for spreading).

The capping material was hauled from in-situ deposits being stripped for advancement of the west side of the Syncrude mine. The area rated as "fair or better" was immediately north of that rated as "poor

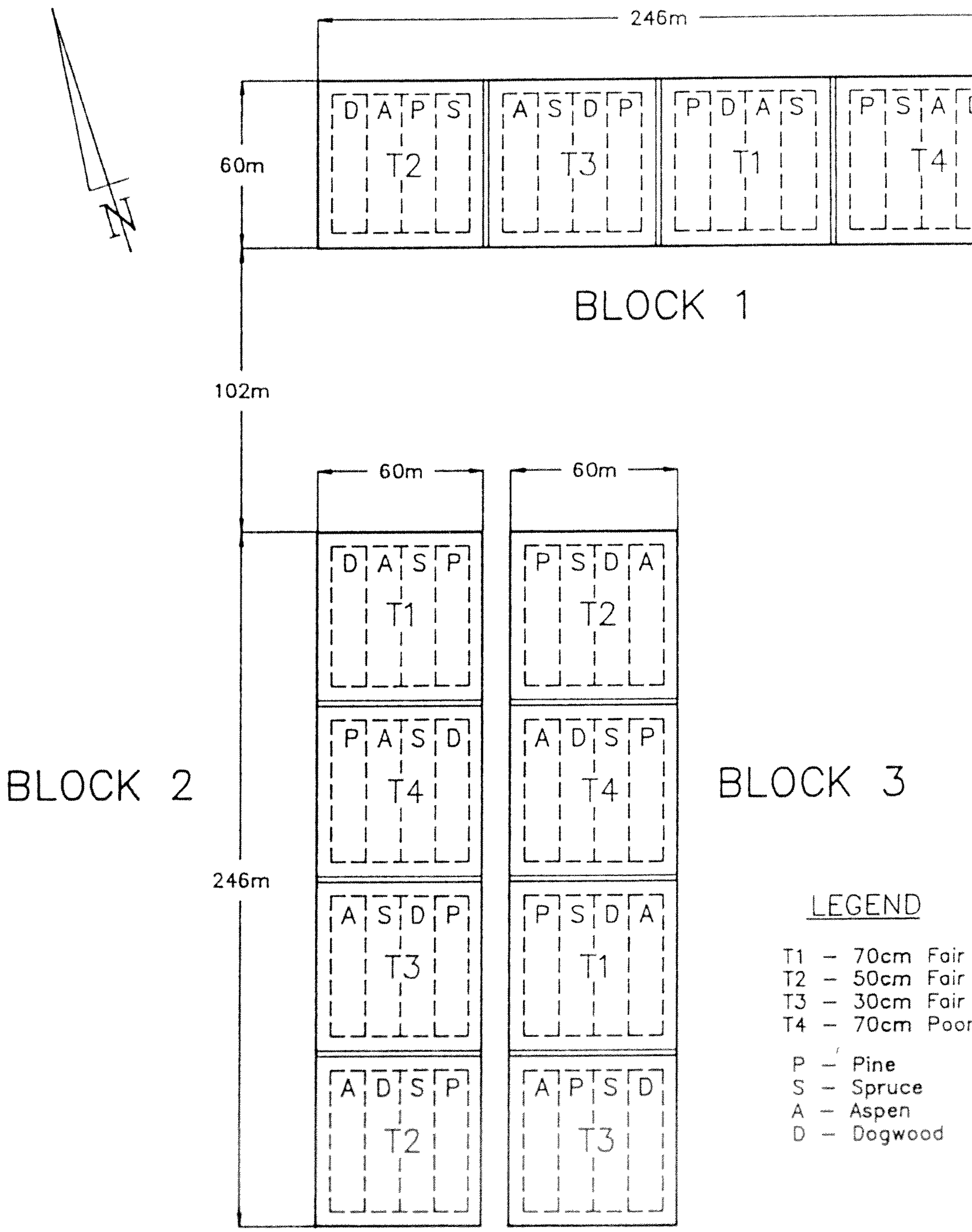


Figure 2. Plot Layout.

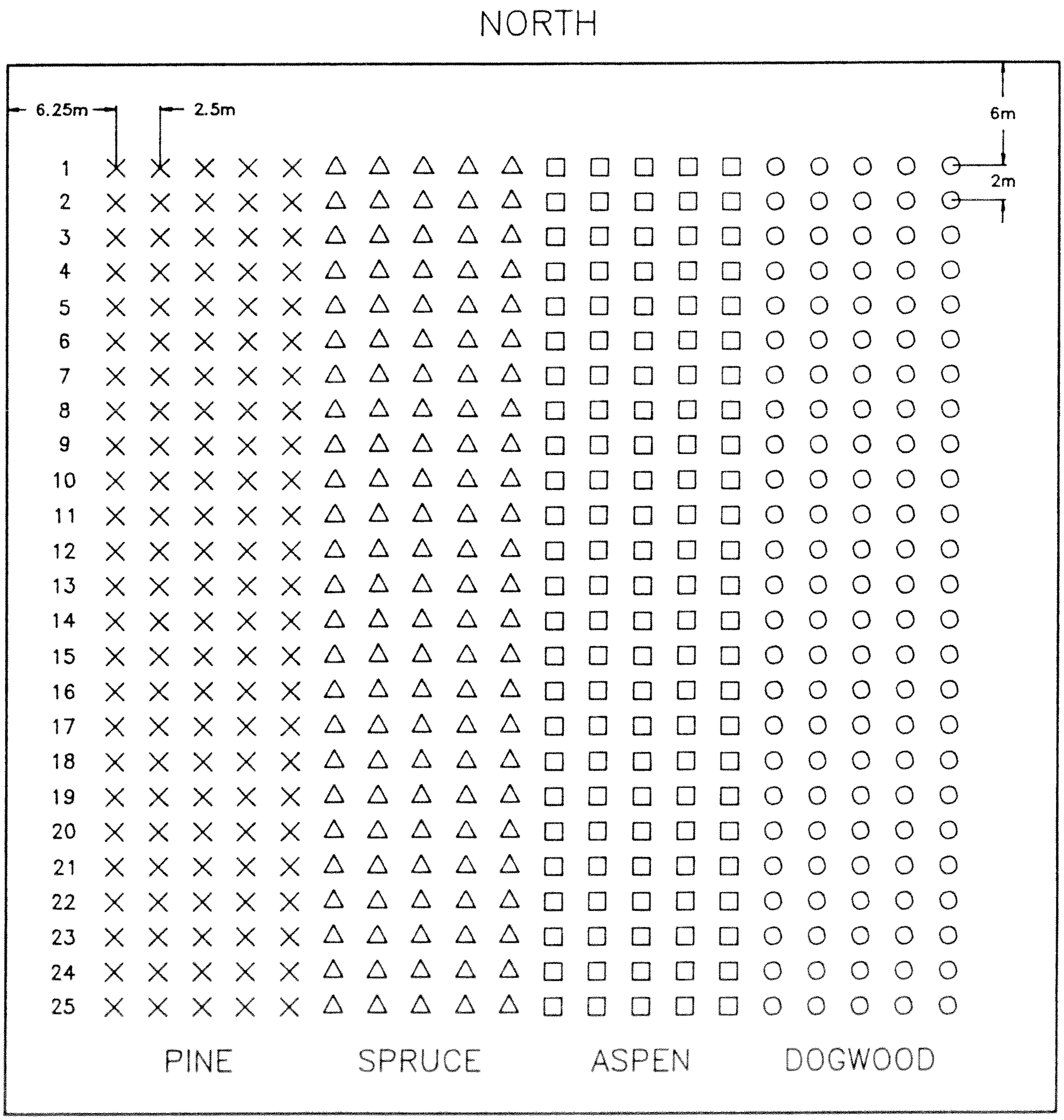


Figure 3. Planting Pattern Within a Typical Plot.

or better". In both cases, the material represented the upper 2 m of surface material including approximately 50 cm of surface peat. The mineral overburden portion was a clay till with very few stones. There was no obvious difference evident during construction between the "fair or better" compared to the "poor or better" material. In both instances, the mineral material ranged from pink to light-brown to greyish-brown with minor occurrences of dark grey to black shale. This latter material is associated with the Cretaceous Clearwater Formation of marine shale and interbedded silts and sands. This material is generally considered poor to unsuitable for reclamation because of its heavy clay texture and high sodicity.

Plots were constructed in such a manner that the haul trucks remained on the tailings sand base at all times to minimize compaction of the capping material. The trucks would end dump their load and the dozer would spread the material. A series of lath stakes were placed at 10 m intervals along three sides of the plots (one side left open for access) and marked with flagging tape at the appropriate height to control cap thickness. There were very few problems related to placement and spreading. One exception was the south end of Block 2. This was a relatively low-lying area where the sand was moist at the surface prior to hauling. During construction, the weight of the haul trucks coming down from the higher ground to the east forced the water to the surface resulting in a pool developing in the eastern third of the last plot (50 cm Fair). It was necessary to stockpile capping material around this pooled area for final capping the last day of construction, after the water had subsided and the surface of the capped portion of the plot had dried allowing better traction for the dozer.

The plots designated as "fair or better" were built first so that the hauling contractor would not have to repeatedly move his equipment at the source. Due to the method of stripping, the first 15 to 20 loads of the "fair or better", contained a high proportion of peat which was evenly distributed across the north end of the three plots in Block 1 which were to receive this source material. The peat portion of the "poor or better" material was received more sporadically and was simply placed in the plot being constructed as it was received.

3.1.4 Surface Preparation

Surface preparation for planting included fertilizer application and plowing. Fertilizer was applied to all plots August 18th, 1990 by helicopter broadcast. The formulation and rate applied was Syncrude's operational blend as follows:

37-0-0-14 (NPKS) @ 100 kg/ha
0-45-0-0 @ 300 kg/ha
0-0-60-0 @ 100 kg/ha

Immediately following fertilizing, plots were plowed using Syncrude's rome plow. This left a series of ridges on the plots oriented in a north to south direction. Ridges were approximately 1 m wide and ranged from 30 cm to 50 cm high. The material in the ridges, especially within 10 cm of the surface, resembled lumps of fractured clay ranging in size from 1 cm to 5 cm squared. This provided a much more favourable planting surface compared to the flat, compacted condition that existed following initial plot construction.

3.1.5 Fencing

A "6-foot" chainlink fence was installed in November, 1990 to exclude large mammals and prevent inadvertent vehicle access from the plots.

3.1.6 Installation and Monitoring of Groundwater Observation Wells

Twelve groundwater observation wells (one per plot) were installed in June, 1991 to a depth of approximately 2.25 m. Each well consisted of one slotted and one solid "5-foot" sections of "1½" inch PVC. The wells were installed by hand augering to the required depth, inserting the PVC tubing, and then backfilling the annulus with tailings sand except for the upper 15 cm which was backfilled with surrounding capping material. Depth to groundwater within each well was measured twice annually in conjunction with the tree and shrub survival assessment described below.

3.2 SEEDLING STOCK PROPAGATION AND PLANTING

A summary of planting stock characteristics is shown in Table 1. All four species were containerized seedlings grown from seed in Syncrude's greenhouse. The jack pine, white spruce, and aspen seeds were collected in the Fort McMurray region whereas the dogwood seed was supplied by the Alberta Environmental Centre in Vegreville. This seed was a composite of collections around Slave Lake, Athabasca, and Lac La Biche.

The white spruce were two-year-old stock which had been seeded in June, 1988 and stored outside in the Syncrude shadehouse since August, 1988. The remaining species were current year (1990) stock seeded either in March (jack pine) or June (aspen and dogwood).

The two conifers were grown in large, 750 mL containers approximately 20 cm deep while the deciduous species were reared in smaller 350 mL, 15 cm deep containers. Root plugs were firm for all species at the time of planting.

Seedlings were planted September 25 and 26, 1990 by Evergreen Forestry Services Ltd. of Grande Prairie, Alberta. The crew consisted of eight planters and one foreman. Seedlings were planted at the middle of the ridge slopes left by the rome plow (Figure 4). All planters used a planting shovel and were very consistent in methodology to ensure firmly planted seedlings.

3.3 SOIL SAMPLING AND ANALYSIS

Unless stated otherwise all soils work was conducted in September, 1990 immediately following planting.

Table 1. Summary of planting stock.

Species	Seed Source	Seeding Date	Plug Size (mL)	Root Collar Diameter[a] (mm)
Jack Pine	Fort McMurray	March, 1990	750	3.2 ± 1.0
White Spruce	Fort McMurray	June, 1988	750	3.6 ± 0.6
Aspen	Fort McMurray	June, 1990	350	2.5 ± 0.5
Dogwood	N. Alberta	June, 1990	350	3.5 ± 0.8

[a]Mean ± SE based on a random sampling of 15 individuals per species

3.3.1 Thickness of Soil Cap

Thickness of the capping material was assessed by hand augering down to the tailings sand base from the bottom of the valley between adjacent ridges left by the rome plow (Figure 4) and then adding a distance of approximately one-third of the height of the ridges. It was felt that this method of measurement would yield the most accurate assessment of original cap thickness. Measurements were taken within 1 m of every second permanently marked seedling (see Section 3.4.1) for a total of 50 measurements per plot.

3.3.2 Soil Sampling and Analysis of Physical and Chemical Properties

Soil samples were collected for laboratory analysis of the capping material as well as the tailings sand base material. Samples of the capping material were taken from the 0 to 15 cm and 15 to 30 cm depths in each plot. Each sample was a composite of five subsamples collected at regularly spaced intervals while diagonally traversing the plot. At each subsample location, a separate sample was taken for determination of bulk density by extracting a soil core (7 cm diameter by 9.5 cm deep) from the surface.

An additional six samples (two per Block) were collected from the surface of the tailings sand toe berm adjacent to the plots. The samples were bulked to give one composite per Block for laboratory analysis.

In August, 1992 the surface (0 to 15 cm) was sampled for a second determination of texture. Five subsamples were taken from random locations within each plot and each sample was analyzed separately. This comprehensive sampling program was undertaken to see if it was possible to statistically differentiate the "poor or better" treatment from those rated as "fair or better".

Parameters analyzed and analytical methods are summarized in Table 2.

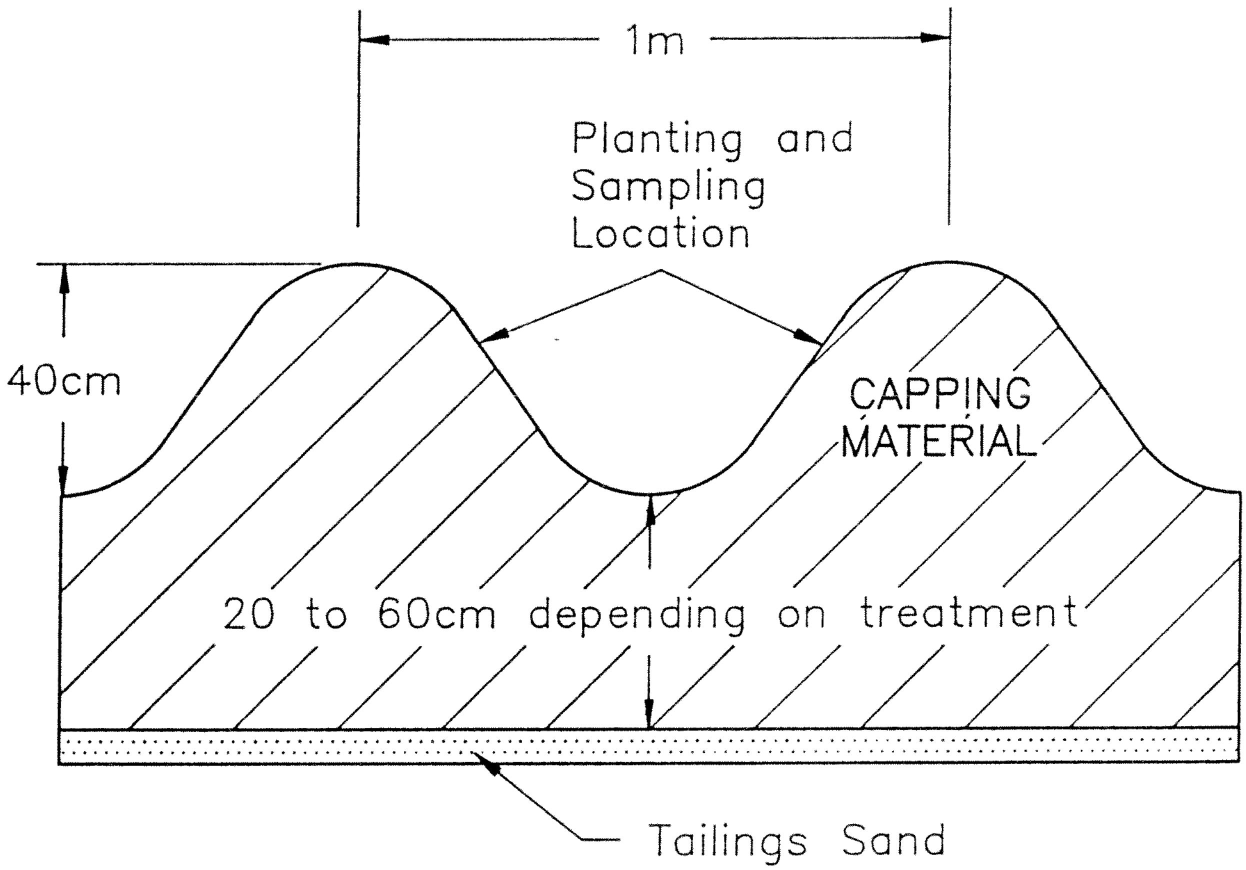


Figure 4. Cross-Section of a Plot Surface Showing Ridges Left by the Rome Plow.

Table 2. Soil analytical methods.

Analysis	Method	Reference[a]
Available Moisture	Pressure Plate	Method 2.43
Bulk Density	Core	Method 2.21
Particle Size	Pipet (1990) Hydrometer (1992)	Method 2.11 Method 2.12
pH and EC	Saturation Extract	Method 4.12
Soluble Salts, SAR	Saturation Extract	Methods 3.21, 3.26
Available N, S	$CaCl_2$ extraction/Colorimetric Determination	Method 4.48
Available P, K	$NaHCO_3$ extraction/Colorimetric-P, Flame Emission-K	Methods 4.41, 4.52
Organic Carbon	Dry Combustion/Titration	Methods 3.614, 3.45
Total N	Kjeldahl	Method 3.623
Total S	Alkaline Oxidation	Method 3.633
Total P and K	HNO_3/$HC10_4$/HF digestion, IPC atomic emission	Method 3.64

[a]All methods correspond to sections in McKeague (1978).

3.4 VEGETATION MONITORING DATA COLLECTION

3.4.1 Tree and Shrub Survival and Growth

Throughout the study, assessment of survival and growth of the planted seedlings was based on 25 permanently marked individuals per species subplot selected immediately after planting. The 25 individuals were randomly selected from the middle three rows (i.e., 75 seedlings) in each subplot and marked with a wire survey flag.

Survival of the permanently marked seedlings was assessed annually in June and again in either late August or early September (in conjunction with growth measurements) from 1991 to 1993. Seedlings were rated as dead only if there was nothing green (i.e., leaf, needle or stem) visible on the plant.

Baseline height of the permanently marked seedlings was measured in September, 1990 at the time of selection. For the conifers, height was based on the measurement from the ground to the base of the uppermost needles while the plant was held in an upright position. The deciduous height measurement was taken at the base of the uppermost leaf or bud. Subsequent height measurements were recorded annually, along with other growth parameters, in late August or early September from 1991 to 1993.

Crown diameter and root collar diameter were two other growth measurements assessed annually beginning in August, 1991. Crown diameter was determined by measuring the narrowest and widest points of the plant and converting these to a geometric mean of the two measurements. Root collar measurements were taken on the stem, approximately 1 cm above the ground.

3.4.2 Tree and Shrub Health

The permanently marked seedlings were inspected at the time of survival assessment (i.e., twice annually) for evidence of damage due to insects, disease or mammals. Stems were examined for mammal damage (e.g., girdling) while damage due to insects or disease was noted if a significant portion of the plant was affected (i.e., more than 10% of the leaves).

3.4.3 Herbaceous Ground Cover

Growth of vegetation on the plots other than the planted trees and shrubs was estimated annually in conjunction with tree and shrub growth monitoring beginning in 1991.

3.5 STATISTICAL ANALYSIS

Differences in survival, growth and soil properties among treatments were assessed statistically using an analysis of variance (ANOVA) test for a randomized block design. Data were reduced to a single mean value per plot prior to testing. Multiple comparisons among treatments were assessed using the Tukey HSD test whenever the overall ANOVA declared at least one of the treatments was different. In all cases, test results were based on a 95 percent confidence limit. Statistical procedures are described in Zar (1984).

4. RESULTS

4.1 GENERAL SITE CONDITIONS THROUGHOUT THE STUDY

The plots were constructed on the tailings pond toe berm which consisted of exposed tailings sand surrounding the plots for several metres. As a consequence, there was evidence of wind erosion on several of the plots during the first year of the study in the form of tailings sand deposited (up to 5 cm) in the valleys left by the rome plow. In the spring of 1991, the surrounding areas were capped with a material similar to that used for the plots and seeded with a mixture of grasses and legumes to serve as grazing land for bison introduced in the spring of 1993. This effectively curtailed any further wind erosion on the plots.

One small erosion gully developed on one of the plots at the south end of Block 3 in 1992. The gully extended for approximately 5 m, measuring a maximum 30 cm wide by 15 cm deep. No attempt was made to repair the gully as no seedlings were affected. The gully appeared to be stable in 1993.

Climatic conditions throughout the study are summarized in Table 3. Total precipitation during the growing season (May to August) ranged from 221.0 to 332.6 mm. This compares with the long term average of 252.4 mm. Conditions were especially dry at the time of planting (September, 1990) following two months of below normal precipitation coupled with above normal temperature. The following summer (1991) had the greatest amount of precipitation, approximately 30% more than the long term average.

4.2 SOIL PROPERTIES

4.2.1 Cap Thickness

Cap thickness of all 12 plots is illustrated in Figure 5. In general, thickness exceeded the target thickness by approximately 10 cm for all treatments. For the "fair quality" treatments thicknesses averaged 80, 58, and 39 cm whereas the "poor quality" treatment averaged 79 cm. Statistical testing of these data revealed that each of the "fair quality" treatments had a significantly different mean thickness from each of the others and the "poor quality" treatment (target of 70 cm) was not significantly different from the "fair quality" treatment targeted for 70 cm. Although results are not shown, these same statistical differences were obtained when comparing thickness within individual species subplots.

4.2.2 Physical Properties of the Capping Material

Soil physical properties for the 0 to 15 cm and 15 to 30 cm soil layers are summarized in Table 4. Bulk density, measured in the surface layer only, averaged 1.15 Mg/m^3. Texture of all treatments, based on the 1990 sampling, was on the borderline of the clay loam/sandy clay loam soil types with sand, silt, and clay contents averaging 45%, 25%, and 30%, respectively. The more detailed 1992 sampling program indicated a clay textured surface layer with sand, silt, and clay averaging 36%,

Table 3. Monthly precipitation and mean monthly temperature at Fort McMurray[a].

Month	Monthly Precipitation (mm)					Monthly Temperature (°C)				
	1951-80	1990	1991	1992	1993	1951-80	1990	1991	1992	1993
January	22.7	16.4	13.1	19.8	16.3	-21.8	-18.0	-19.8	-12.8	-17.7
February	18.8	12.4	16.2	13.2	4.4	-15.4	-19.0	-9.6	-10.7	-11.9
March	20.7	7.1	23.1	13.2	4.0	-9.2	-3.1	-3.1	-5.1	-1.1
April	20.5	52.5	1.2	33.1	34.0	2.1	1.9	5.9	3.4	4.4
May	36.3	29.5	35.4	20.8	54.8	9.7	11.2	12.0	9.5	10.6
June	64.1	125.4	163.5	108.2	72.8	14.0	15.6	15.0	14.1	13.4
July	75.4	18.6	111.3	39.6	78.6	16.4	17.7	17.2	15.7	15.3
August	76.6	18.6	22.4	52.4	50.1	14.8	16.0	18.8	14.0	14.5
September	58.5	32.0	51.2	69.0	34.4	9.0	11.0	5.6	6.7	8.6
October	28.1	35.3	36.5	9.3	17.2	3.3	-0.2	-1.5	2.5	1.8
November	25.2	42.1	33.9	22.8	16.7	-8.2	-12.8	-10.5	-3.7	-7.7
December	25.0	18.7	17.2	7.8	15.2	-17.0	-21.4	-14.2	-20.9	-11.4
TOTAL	471.9	446.4	525.0	409.2	398.5					
Growing Season										
May to August	252.4	229.9	332.6	221.0	256.3	13.7	15.1	15.8	13.3	13.5

[a]Data from Atmospheric Environment Station at the Fort McMurray Airport.

16%, and 48%, respectively. The difference is attributed to a change in laboratory methods (pipet method in 1990 versus hydrometer method in 1992). The 1990 data should be considered the most accurate. Plant available moisture averaged 11% based on the difference between the 1/3 bar saturation point (25%) and 15 bar wilting point (14%) limits. Statistical analysis of these physical properties revealed no significant differences among treatments. No attempt was made to statistically compare properties in the 0 to 15 cm versus the 15 to 30 cm sampling depths, but based on the limited variation in the data it is highly unlikely that differences occurred.

4.2.3 Chemical Properties of the Capping Material

Soil pH, electrical conductivity (EC), soluble ion concentrations and the sodium adsorption ratio (SAR) for the two soil depths analyzed are given in Table 5. As with soil physical properties, there was no obvious difference between the two soil depths. Soil pH was mildly alkaline averaging 7.5. Electrical

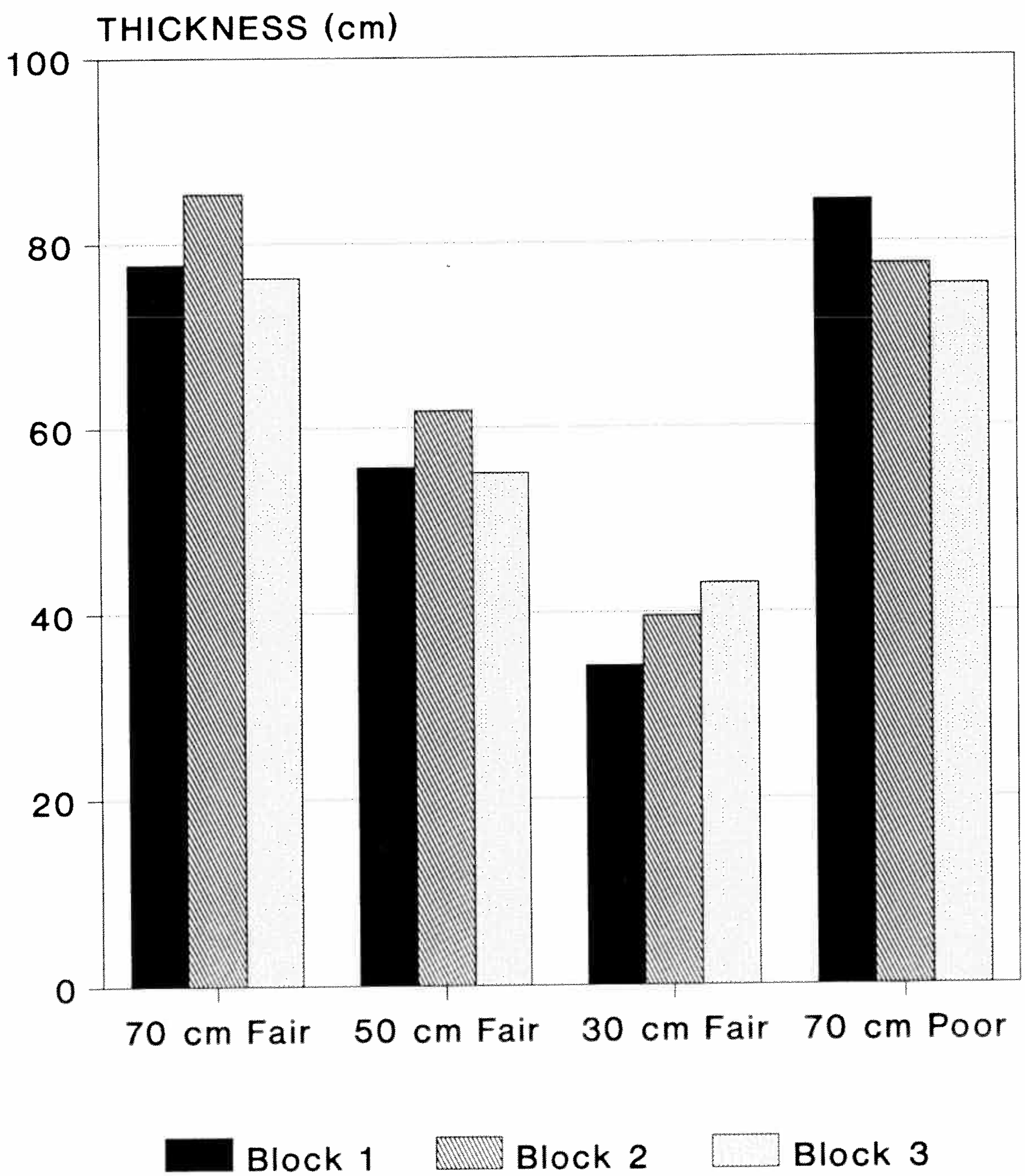


Figure 5. Mean Cap Thickness (n=50).

Table 4. Physical properties of the capping material.

Property	Capping Treatment: 70 cm Fair	50 cm Fair	30 cm Fair	70 cm Poor
0 to 15 cm Depth (1990)				
Sand (%)	44	46	48	44
Silt (%)	27	23	23	24
Clay (%)	29	31	29	32
Bulk Density (Mg/m^3)	1.10	1.19	1.15	1.11
Available Moisture (%)	11.5	10.8	11.2	11.0
15 to 30 Depth (1990)				
Sand (%)	47	46	49	44
Silt (%)	23	24	22	23
Clay (%)	30	30	29	33
Available Moisture (%)	10.9	10.4	10.0	11.0
0 to 15 cm Depth (1992)				
Sand (%)	38	35	37	33
Silt (%)	17	17	15	14
Clay (%)	45	48	48	52

Note: Values for 1990 are the mean of 3 samples.
Values for 1992 are the mean of 15 samples.

conductivity was low, ranging from 1.2 to 2.2 dS/m. Analysis of soluble ions revealed that calcium and sulphate were the dominant anions and cations, respectively, except for the 70 cm Poor treatment where sodium content was equal to that of calcium. Furthermore, sodium content of the 70 cm Poor treatment (220 $\mu g/mL$) was significantly higher than the Fair treatments (average = 90 $\mu g/mL$). Similarly, the SAR was significantly higher in the Poor (3.4) compared to the Fair (average = 1.5) treatments.

4.2.4 Nutrient Content of the Capping Material

Results of organic carbon (C) content, total nitrogen (N), and plant available macronutrient concentrations are given in Table 6. There were no significant differences among treatments for any of these nutrients and concentrations were similar in both soil layers. Organic C content ranged from 1.1% to 1.5% and total N from 0.04% to 0.05%. Plant available N varied widely from 2 to 12 ppm. Available phosphorous (P) and potassium (K) were in

Table 5. Selected chemical properties of the capping material.

Property	70 cm Fair	50 cm Fair	30 cm Fair	70 cm Poor
	Capping Treatment			
0 to 15 cm Depth				
pH	7.4	7.6	7.4	7.5
EC (dS/m)	1.9	1.2	1.9	2.2
Soluble Ions $\mu g/mL$				
Na	94[a]	87[a]	93[a]	224[b]
Ca	269	130	278	219
Mg	95	45	81	63
K	12	6	10	11
Cl	88	83	96	114
SO_4	673	311	780	578
SAR	1.5[a]	1.7[a]	1.4[a]	3.4[b]
15 to 30 cm Depth				
pH	7.4	7.5	7.6	7.5
EC (dS/m)	1.7	1.2	2.1	2.1
Soluble Ions ($\mu g/mL$)				
Na	85[a]	84[a]	89[a]	217[b]
Ca	250	137	320	202
Mg	77	41	90	64
K	12	6	14	11
Cl	98	80	95	65
SO_4	665	344	947	475
SAR	1.4[a]	1.7[a]	1.2[a]	3.4[b]

Note: For each property, values superscripted with the same letter (or no superscript) are not significantly different from each other at the 95% significance level. All values are the mean of 3 samples.

Table 6. Nutrient content of the capping material.

Property	Capping Treatment			
	70 cm Fair	50 cm Fair	30 cm Fair	70 cm Poor
0 to 15 cm Depth				
Organic C (%)	1.27	1.12	1.38	1.29
Total N (%)	0.04	0.04	0.05	0.04
Available N (ppm)	5.2	2.2	7.8	12.0
Available P (ppm)	29.3	31.2	21.5	32.2
Available K (ppm)	110	95	103	133
Available S (ppm)	>12	>12	>12	>12
15 to 30 cm Depth				
Organic C (%)	1.30	1.31	1.10	1.52
Total N (%)	0.04	0.05	0.05	0.05
Available N (ppm)	3.4	2.6	3.8	7.2
Available P (ppm)	40.3	27.8	22.7	40.5
Available K (ppm)	133	95	105	128
Available S (ppm)	>12	>12	>12	>12

Note: All values are the mean of 3 samples.

the 21 to 41 and 95 to 133 ppm range, respectively. All available sulphur (S) contents were over 12 ppm.

4.2.5 Characteristics of the Underlying Tailings Sand

Physical and chemical properties of the three tailings sand samples are shown in Table 7. The results indicate that the sand was typical of other tailings sand (HBT AGRA Limited 1992) including its coarse texture (95% sand), alkaline pH averaging 8.3, and low soluble salt content (EC of approximately 0.5 dS/m). Nutrient status of this material was also low with an average 0.25% organic C (residual bitumen), 0.03% total N and very low levels of the plant available nutrients N, P, and K.

4.3 DEPTH TO GROUNDWATER

Only 2 of the 12 groundwater observation wells (1 per plot) showed evidence of the water table within 2.25 m of the surface. At one of the wells (Block 2, 50 cm Fair) the water table gradually declined from 1.3 m below the surface in 1991 to 1.8 m in 1992 and to lower than 2.25 m (i.e., water was not detected) in 1993. This was the same plot described in Section 3.1.3 where there was a problem

Table 7. Physical and chemical properties of the underlying tailings sands.

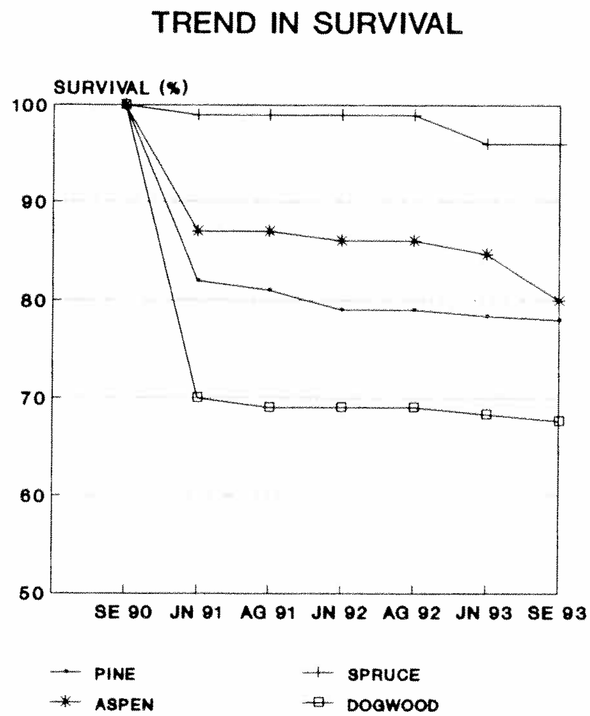
Property	Block 1	Block 2	Block 3
Sand (%)	95	95	93
Silt (%)	4	4	5
Clay (%)	1	1	2
pH	8.2	8.3	8.4
EC (dS/m)	0.6	0.4	0.4
Soluble Ions (μg/mL)			
Na	63	65	41
Ca	18	16	15
Mg	10	8	6
K	31	6	4
Cl	68	19	4
SO_4	84	96	85
SAR	3.3	3.3	2.2
Organic C (%)	0.20	0.23	0.31
Total N (%)	0.03	0.03	0.02
Available N (ppm)	<0.5	<0.5	<0.5
Available P (ppm)	3.5	4.5	2.5
Available K (ppm)	40	35	35
Available S (ppm)	6.6	7.3	6.5

Note: All values are based on a single analysis of a sample composed of two subsamples.

with water pooling at the time of construction. In August, 1991 the water table was also measured at a depth of 1.9 m in the well in the plot immediately to the north (Block 2, 30 cm Fair). However, this was the only time the water table was recorded in this well.

4.4 TREE AND SHRUB SURVIVAL

Survival of the trees and shrubs from September 1990 to September 1993 is illustrated in Figure 6. The data plotted represent survival of all of the permanently marked seedlings. After three full



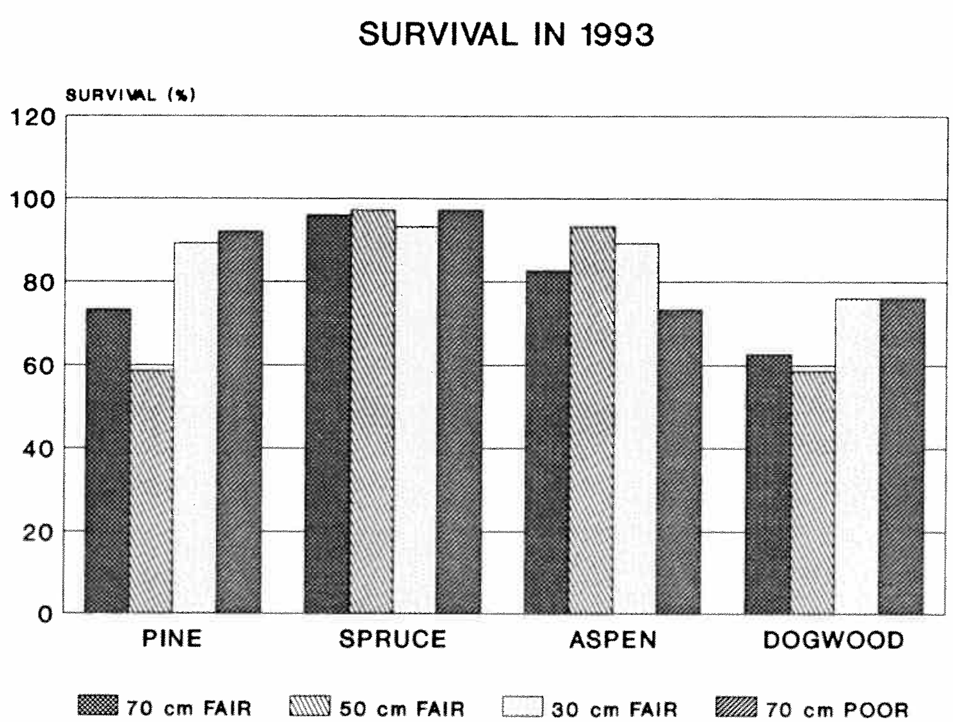


Figure 6. Mean Tree and Shrub Survival (n=3 in 1993).

growing seasons from the time of planting, overall survival averaged 96% for spruce, 80% for aspen, 78% for pine and 68% for dogwood. For the latter three species most of the mortality occurred during the first overwinter period, after which there was very little change in survival, especially for pine and dogwood. The aspen also experienced a relatively sharp decline during the summer of 1993 from 85% to 80% survival.

Survival among treatments in September, 1993 is also illustrated in Figure 6. Pine had the greatest variation in survival ranging from 59% in the 50 cm Fair treatment to 91% in the 70 cm Poor treatment. Statistical analysis of these data indicated that survival in the 50 cm Fair treatment was significantly lower than the two best treatments (30 cm Fair and 70 cm Poor). Intermediate to these was the 70 cm Fair treatment which, at an average 73% survival, was not significantly different from any of the other treatments.

Differences among treatments for the other species were less noteworthy and not statistically significant. Average survival among all treatments varied within a range of 20% for the aspen and dogwood, while the spruce were within 5%.

4.5 TREE AND SHRUB HEALTH

The most noteworthy factor affecting plant health was damage to the deciduous species as a result of bison which broke through the gate in Block 1 and remained on the plots for several days soon after they were introduced in the spring of 1993. The most extensive damage was a result of browsing. Only a few of the aspen (4 or 5 per plot) were not browsed to some extent and, more often than not, they were heavily browsed. The dogwood were also heavily browsed but typically more of the individuals (5 to 10 per plot) escaped damage. There was only limited damage to the coniferous seedlings. Typically fewer than 5 trees per plot were impacted, usually by browsing the terminal bud. In addition, 2 pine seedlings were completely pulled out of the ground.

Another factor affecting plant health was insect damage to the deciduous species, especially the aspen. In 1993, 94% of surviving aspen seedlings and 16% of the dogwood were affected. The damage appeared as brown to black blotches several millimetres in diameter and in extreme cases, the leaves were tightly curled. Although damage was extensive, in no case did it appear to cause mortality of the seedling. There was no visual evidence of insects on the leaves. Statistical analysis of the data for aspen indicated the incidence of insect damage in the 70 cm Poor treatment at 81% was significantly lower than the three Fair treatments which ranged from 97% to 100%.

Small mammal damage was noted on a few of the coniferous seedlings (4 pine, 1 spruce) for the first time in 1993. In all cases the seedlings were located in Block 1 where there was a dense invading vegetation cover in the area containing a high proportion of peat in the capping material.

4.6 TREE AND SHRUB GROWTH

Increase in height of the trees and shrubs from the time of planting in September, 1990 to September, 1993 is illustrated in Figure 7. Values plotted are the average of all plots except for the September, 1993 values for the deciduous species where, due to the bison browsing in Block 1, only data from Blocks 2 and 3 were used. Also shown in Figure 7 is the final height (September, 1993) of each species averaged for each of the capping treatments. Once again the averages for dogwood and aspen are based on data from Blocks 2 and 3 only.

All species displayed good growth from the start of the study and after three growing seasons had grown to approximately twice the height measured at the time of planting. Final height ranged from an average 35 cm for spruce to 75 cm for aspen. There were no significant differences in height among capping treatments for any of the species.

Changes in crown diameter throughout the study and the final crown diameter of each species in each capping treatment is illustrated in Figure 8. Note that crown diameter was not measured at the time of planting (September, 1990). Values were averaged from the same plots as the height measurements. All four species showed consistent increases in crown diameter from 1991 to 1993 and they generally doubled in size during this two year period. In 1993, crown diameter ranged from an average 22 cm for spruce to 40 cm for pine. Similar to the results of height, there were no statistically different crown diameters in 1993 among treatments.

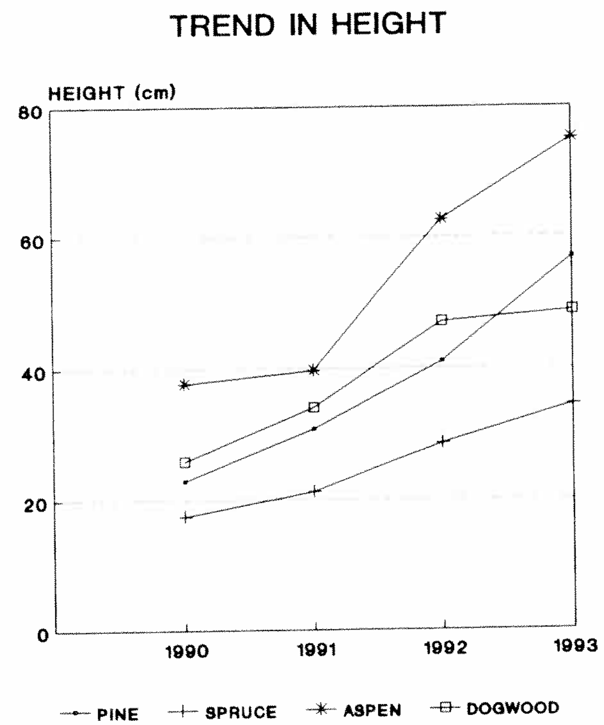
Changes in root collar diameter during the study are illustrated in Figure 9 along with differences among capping treatments for the final measurements taken in September, 1993. Values were averaged from the same plots as the height and crown diameter measurements. Increases in root collar diameter from 1991 to 1993 resemble those for crown diameter in that the rate of growth was nearly the same in both years for all species. In 1993 root collar diameters ranged from an average of 9 mm for spruce to 12 mm for pine. As with the other growth measurements, there were no statistically significant differences in root collar diameter among capping treatments.

4.7 HERBACEOUS GROUND COVER

The increases in herbaceous ground cover on the plots during the study and the average cover for each species subplot and capping treatment is illustrated in Figure 10.

Ground cover increased to an average of 40% cover during the first two growing seasons. As indicated in Figure 10 cover appeared to decline from an average 40% to 30% between 1992 and 1993. However, this apparent decline is likely a result of switching individuals assessing the cover.

Ground cover in 1993 averaged 10% to 15% higher in the 70 cm Poor capping treatment compared to the three Fair treatments. The difference, however, was not statistically significant.



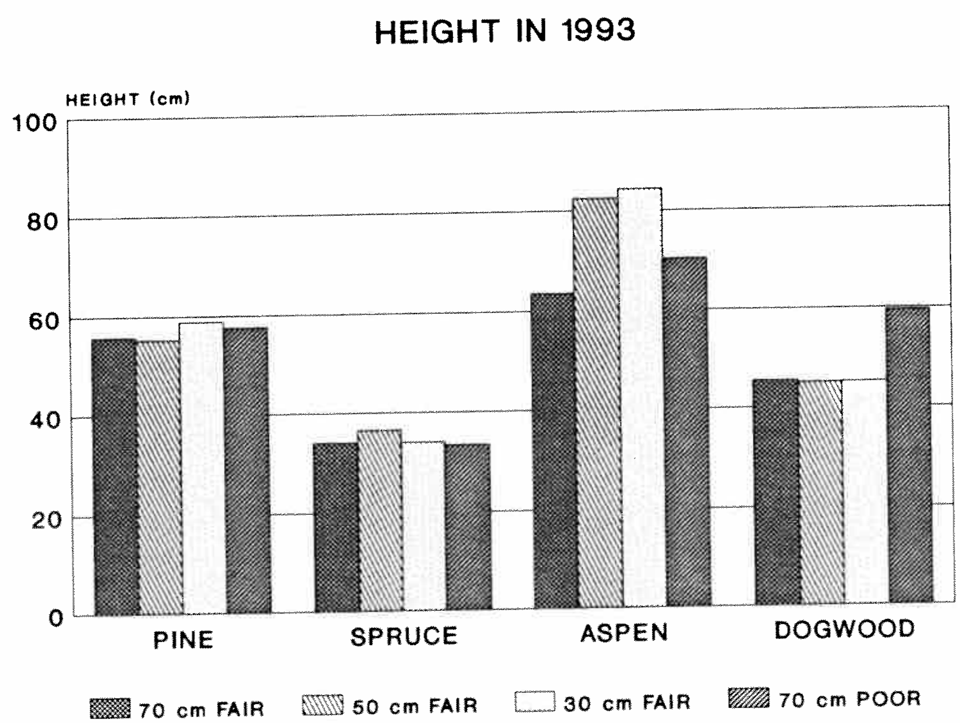
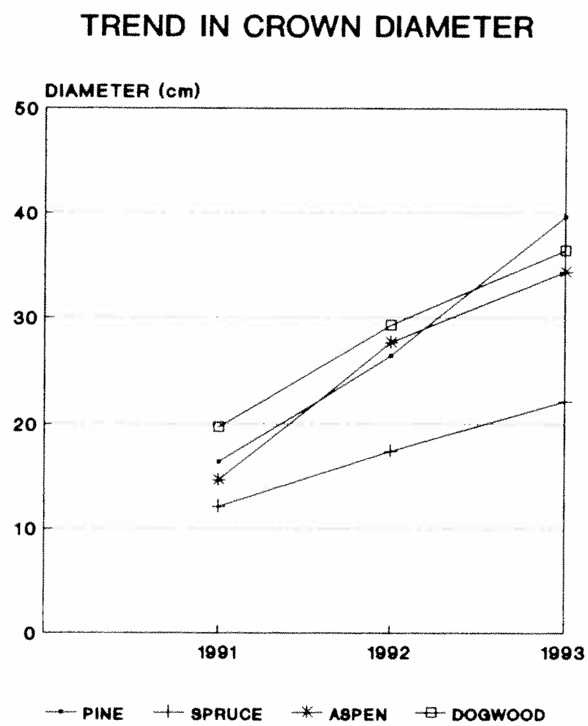


Figure 7. Mean Tree and Shrub Height.



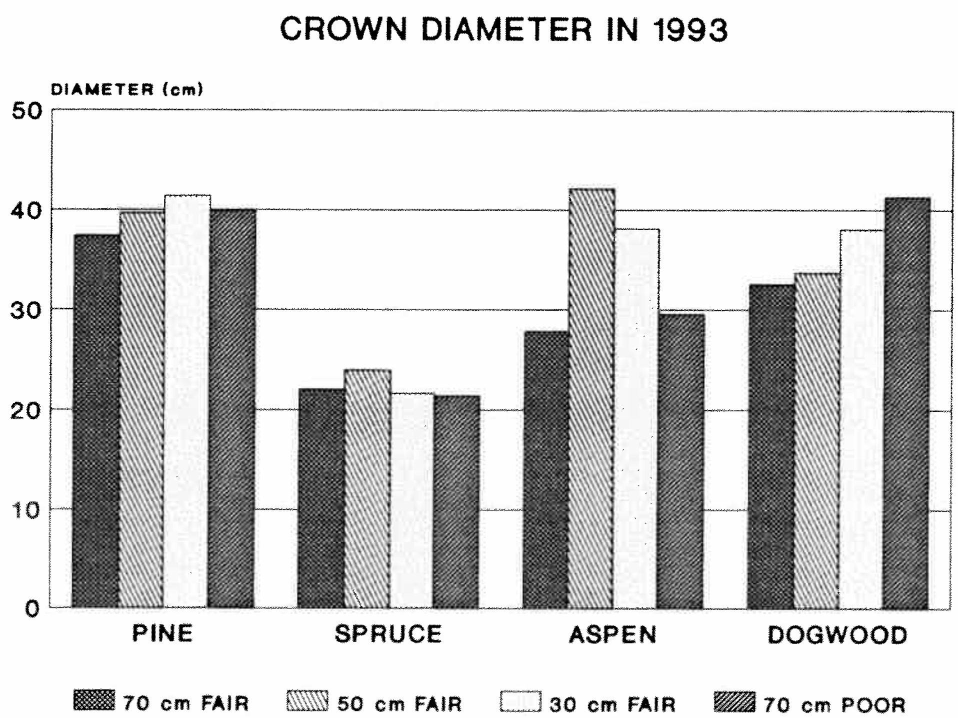
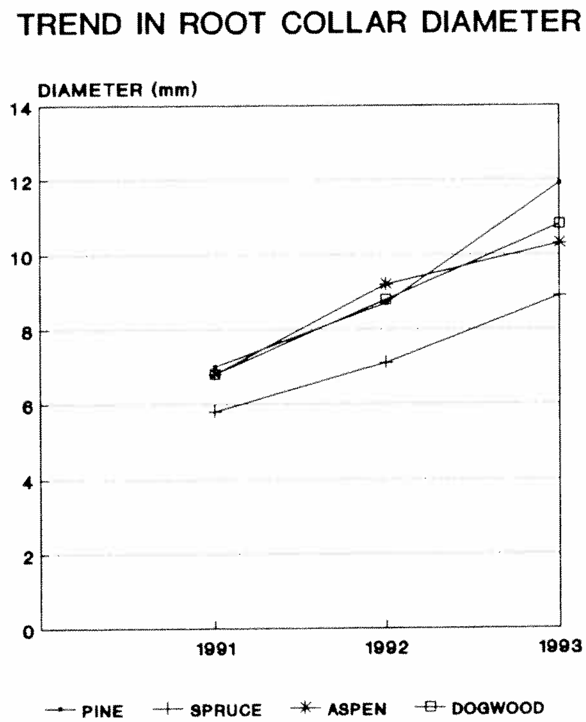


Figure 8. Mean Tree and Shrub Crown Diameter.



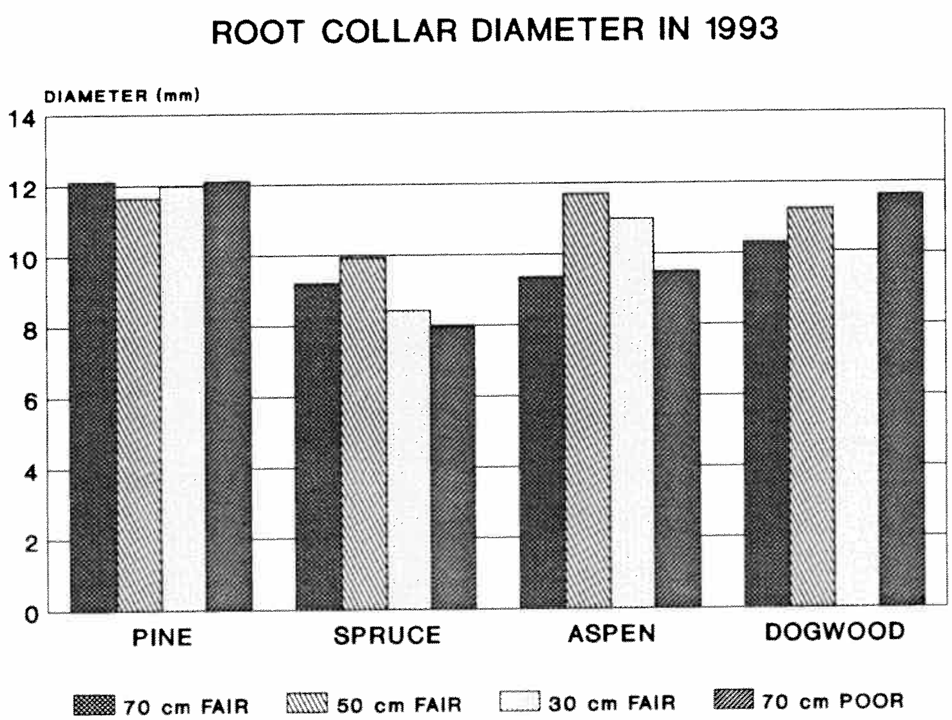
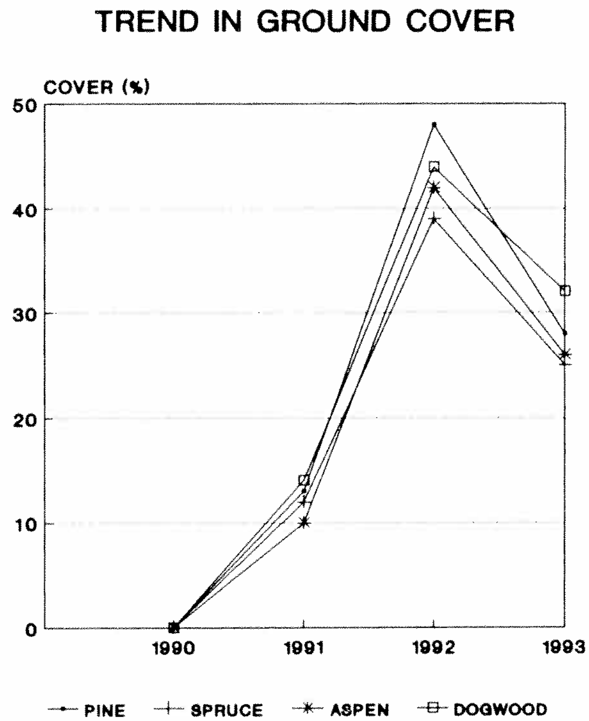


Figure 9. Mean Tree and Shrub Root Collar Diameter.



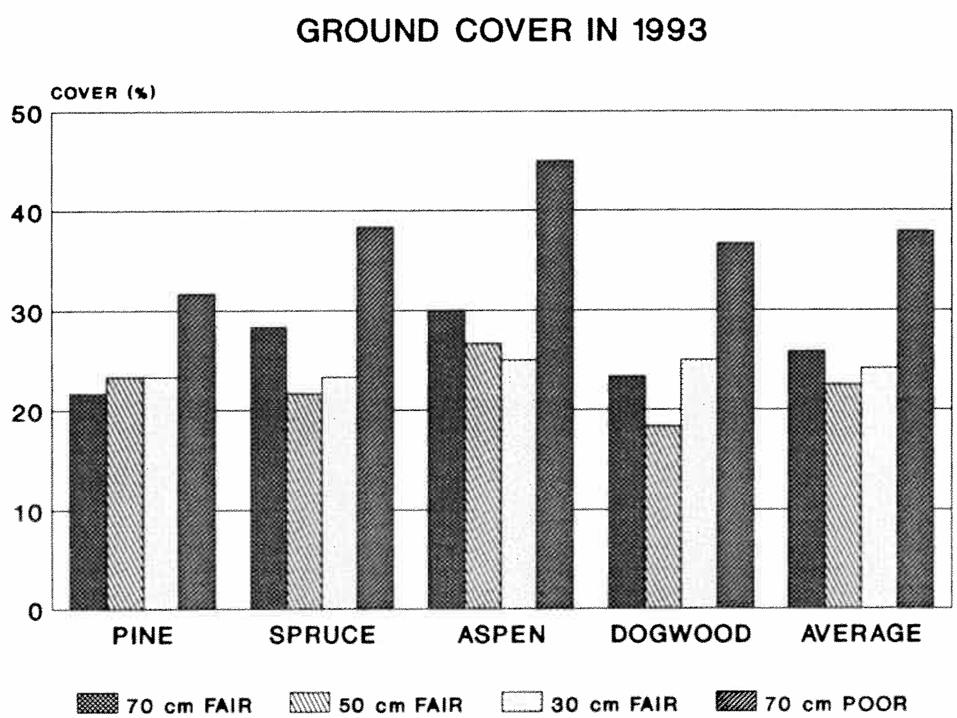


Figure 10. Mean Herbaceous Ground Cover (n=3 in 1993).

The most noteworthy feature regarding herbaceous ground cover on the plots was the extreme variability noted, not only among treatment plots but even within individual plots. Based on casual observations, it was not uncommon for cover to range from less than 5% to over 75% within a particular species subplot if the scale of measurement were reduced to approximately 10 m^2 instead of averaging the cover for the entire subplot. The reasons for this variability is attributed to the uneven distribution of peat over the plots. Cover was much higher in areas containing a relatively high proportion of peat near the surface. Incontrast, herbaceous species were virtually absent from several species subplots with almost no visible peat near the surface.

Three weedy forb species provided almost all of the herbaceous ground cover. In order of abundance these were: sow thistle (*Sonchus arvensis*); hawksbeard (*Crepis tectorum*); and fireweed (*Epilobium angustifolium*).

5. DISCUSSION

5.1 EFFECTIVENESS OF PLOT CONSTRUCTION METHODS IN ACHIEVING THE DESIRED SOIL CAP

The methods used to construct the plots were highly successful in achieving the desired differences in thickness among the soil caps (i.e., 70, 50, and 30 cm) even though the average thickness for all treatments was approximately 10 cm more than the target depth. Compaction of the tailings sand base by the trucks hauling the capping material to the plots likely accounts for most of this extra thickness. As well, the measurement of thickness was difficult, due to the pronounced ridges left by the rome plow, and may have led to a slight overestimate of thickness.

The methods were unsuccessful however, in achieving a uniform mixture of peat and underlying mineral material. The most apparent result of this lack of mixing was the wide variability in cover of herbaceous species depending on the amount of peat present near the surface. It will be necessary to alter the method used for salvaging the in situ soil to achieve a more uniform mixture. In order to mimic the operational method in use at Syncrude in 1990, capping material was stripped from the surface to a depth of 2 m with no attempt to blend the surface peat (approximately 50 cm) with the underlying mineral material. Logistics dictated a single loading area at one end of the source material deposit and consequently stripping entailed pushing the material to this point. Since there was a considerable volume of material required for the plots, especially the Fair treatments, there was likely a tendency to dig deeper into the source material to avoid a long push. As a result, large areas of the plots had little or no peat.

An unfortunate consequence of the heterogeneous nature of the capping material among the treatment plots is that it will likely be difficult to detect the influence of the cap thickness and quality on the seedlings with so much inherent variability in the material itself. To ensure that a good representative sample is obtained for future monitoring, the number of trees monitored should be increased from the current 25 per plot to perhaps 50 to 75 per plot. This should increase the likelihood that seedlings actually monitored on a particular treatment plot represent the average plot condition rather than isolated unique (e.g., no peat) areas.

5.2 DIFFERENCES IN QUALITY BETWEEN THE POOR AND FAIR TREATMENT PLOTS

Laboratory analysis of the capping material indicated no serious limitations to plant growth and a high degree of consistency among treatments and between the two depths sampled. Physical properties and total nutrient (C and N) concentrations were within the range of A and B horizons of natural soils (Ruth Lake and Mildred Series) in the region reported in Turchenek and Lindsay (1982). Plant available macronutrient concentrations were relatively high for oil sands reclamation areas likely due to fertilizer application prior to sampling, as well as the lack of vegetative growth on the plots at the time of sampling. Texture of the material is rated as "fair" (based on the 1990 sampling) for all treatments (Soil Quality Criteria Working Group 1987). Soil reaction, salinity, and sodicity properties contribute to an overall rating of "fair" to "poor" due to the mildly alkaline pH. (Note the rating for pH assumes a forest production end use, especially conifers.) Salinity ratings based on EC are either "good" (Fair treatments) or "fair" (Poor treatment). However, statistical analysis of EC did not reveal a significant difference among treatments. Sodicity, with SAR averaging less than 4 for all treatments, is rated as "good". It is important to note that this is the only property (along with soluble sodium content) that statistically differentiates the Poor from the Fair treatments even though the rating is "good" for all plots based on the reclamation criteria guidelines.

Overall, the capping material from both the Fair and Poor treatments would be rated as "fair", limited mainly by texture. (This assumes that the mildly alkaline pH of a few plots which would be rated as "poor" reclamation suitability is ignored.) There are several possible explanations why the Poor treatment was upgraded after stripping and placement on the plots. Information received from Syncrude Canada Ltd. after plot construction indicated that the material used for the Poor treatments was rated based on a single borehole in which a sample from a depth of 45 cm had a clay texture. In contrast, borehole samples from the Fair source material had sandy clay loam or sandy loam textures. The better than expected texture of the Poor treatment plots can be attributed to one or more of the following factors:

1. Dilution of the clay textured material with coarser material within the stripped area during stripping and spreading on the plots.
2. Unrepresentative sampling of the source material as a result of relying on data from a single borehole.
3. Unrepresentative sampling of the plots after construction.

Even though the Poor treatment was not significantly different than the other treatments in texture, it was the only treatment in which significant differences were noted based on the soil analyses. Specifically, sodium content and SAR were higher in this treatment compared to those built from the Fair source material, although the SAR was still sufficiently low so as not to affect its reclamation suitability. The results still suggest however, that there is some difference in the origin of the materials.

5.3 DIFFERENCES IN SUBSOIL CONDITIONS AMONG TREATMENT PLOTS

Analysis of the tailings sand below the soil cap indicates that the sand has uniform physical and chemical properties in the area where the plots are located. The water table, which was within 1.3 m of the surface at one of the plots at the time of construction, gradually declined such that it was lower than 2.25 m at all plots within three years. Varying subsoil conditions therefore, are not expected to influence growth on the plots.

5.4 TREE AND SHRUB SURVIVAL AND HEALTH

The relatively high rate of survival, after three growing seasons from the time of planting suggests that all four species tested are suitable for reclamation in the oil sands area. Furthermore, the survival trend with time indicates that the first overwintering period appears to be the most critical. Seedlings that survive this period are likely to survive for several years. This trend was also evident for most of the species tested in the Soil Reconstruction Project (HBT AGRA Limited 1992) and suggests that good stock condition and careful planting techniques are important factors for ensuring good survival. The relatively dry conditions at the time of planting may have also contributed to lower survival rates during this period.

The only species in which survival varied among treatments in a statistically significant manner was jack pine. Survival of this species was lower on the 50 cm Fair treatment than all other treatments. This result is considered an anomaly as this treatment does not appear to be any different from either the 30 cm or 70 cm Fair treatments based on soil properties (other than cap thickness) or vegetation cover. Since almost all of the mortality occurred during the first overwinter period, the difference was most likely a result of poorer stock and/or planting technique on these plots rather than soil quality or cap thickness differences.

The most noteworthy observation regarding plant health was that survival of the deciduous species was unaffected by factors such as heavy browse and insect damage. Even when individuals were completely defoliated by these factors they were able to quickly produce new shoots.

The only statistically significant difference in plant health among treatments was a slightly lower occurrence of insect damage to the aspen seedlings on the 70 cm Poor treatment (81%) as opposed to the three Fair treatments (97% to 100%). The reason for this difference is unknown, but the magnitude of the difference and the lack of an impact of this damage on survival suggests that even if soil quality did have an effect, the practical significance would be negligible.

5.5 TREE AND SHRUB GROWTH

Maximum annual height increments observed during the three growing seasons averaged less than 10 cm for spruce, approximately 15 cm for pine and dogwood, and nearly 25 cm for aspen. The maximum occurred in either the second or third growing season depending on species. Annual rates for the two conifers were comparable to those observed during the first three years of the Soil Reconstruction Project (HBT AGRA Limited 1992) whereas the rate for aspen was similar to that for northwest poplar (*Populus* spp.).

There were no significant differences among treatments for any of the species tested irrespective of which measurement was used to assess growth (i.e., height, crown diameter or root collar diameter). Clearly, there has been insufficient time to detect the influence of the varying cap thicknesses on seedling growth. It is unlikely that the root systems had penetrated the lower soil layers of the thicker (50 and 70 cm) caps and, based on the results of root measurements made during the Soil Reconstruction Project, it will likely be several more years before significant deeper penetration occurs. During the previous study, maximum rooting depth of the conifers averaged 22 cm after five growing seasons whereas northwest poplar, the deepest rooting of the 10 species tested, averaged 27 cm (HBT AGRA Limited 1992).

Since there were no significant differences detected in growth between the Fair and Poor quality capping materials it is apparent that the minor differences in soil properties have had little, if any, effect on seedling performance. This is not surprising considering how similar the soil characteristics were between the two materials after excavation and placement on the plots. It is unlikely that any difference in performance will ever be detected between the two soil quality treatments, in particular between those with the 70 cm target thicknesses, considering the amount of inherent variability in soil quality within the plots due to the uneven distribution of peat within the capping material.

5.6 HERBACEOUS GROUND COVER

The rate of natural plant invasion on the plots was not related to the treatments as designed. Instead, based on casual observations, ground cover varied according to the amount of peat present near the surface. This observation is consistent with results obtained from the Soil Reconstruction Project, as well as a study on the rate of natural invasion into reclaimed oil sands sites (Hardy BBT Limited 1990). The influence of peat on herbaceous cover is attributed to its ability to improve surface moisture for seed germination. The peat may also serve as an important source of propagules but, considering the high dispersal rates of the dominant species invading the plots, this factor is likely of lesser importance.

Possibly one of the most important observations in the current study is that there was less than 5% herbaceous cover, even after three growing seasons, in large areas with little or no peat on the surface. It was in one of these areas where an erosion gully had formed. Although the gully was relatively minor and probably will not result in significant damage, it must be recognized that the area was near level (less than 5% slope). On a more steeply sloping area, such as the outer slopes of the tailings pond dyke, serious erosional damage could have occurred.

It can be concluded therefore, that peat is an important component of the reclaimed soil materials due to its influence on the development of an erosion controlling vegetation cover. Methods used to salvage and place reclaimed soils should be adjusted to avoid creating large areas with little or no surface peat. One approach would be to reduce the ratio of underlying mineral material to peat of the excavated in situ soils. In this study, the ratio averaged 3:1 (i.e., 50 cm peat over 150 cm mineral material). A better ratio for salvage would be approximately 1:1

and certainly no more than 2:1. Another modification to the salvage procedure that should assist in achieving a more uniform mixture would be to excavate the entire depth of the salvaged layer at the same time rather than skimming successive layersover a wide area. Using this approach each haul truck would have a substantial component of both peat and underlying mineral material.

6. CONCLUSIONS

1. The methods used for construction of the plots were effective in controlling the thickness of the replaced soil cap but were ineffective in achieving a homogeneous mixture of peat with the underlying mineral material of the in situ deposit.

2. After salvage and placement on the plots, all soils were rated as "fair" suitability for reclamation irrespective of whether the source in situ deposit was rated as "fair" or "poor" suitability. The in situ "poor" rating was based on texture (clay).

3. Soluble sodium content and the closely related sodium adsorption ratio are the only soil properties significantly different (higher) in the Poor treatment plots compared to the Fair plots. The difference however, does not affect the overall rating of the soil's suitability for reclamation.

4. Subsoil conditions beneath the cap are relatively uniform among plots and should have minimal influence on performance of vegetation on the plots.

5. All four tree and shrub species are capable of good survival. The first overwinter period is the most critical.

6. Survival during the first three years was unrelated to cap thickness or soil quality differences.

7. Heavy browsing and insect damage to the deciduous species (aspen and dogwood) had minimal effect on survival.

8. Growth of the trees and shrubs during the first three years was unrelated to cap thickness or soil quality differences.

9. Growth of herbaceous species colonizing the plots varied according to the amount of peat near the surface. Due to the method used for salvage and placement of the soil, individual plots had areas with a dense cover of these species where peat was abundant, as well as relatively bare areas where peat was absent.

7. RECOMMENDATIONS

1. The plots should be monitored intermittently for several more years (e.g., at least 5 to 10) to determine the influence of cap thickness on seedling performance.

2. The number of trees monitored should be increased to account for variability in soil properties within the plots due to the uneven mixing of peat and underlying mineral materials.

3. Methods used for salvage and placement of the in situ soils should be changed to ensure that the replaced soil cap has a substantial peat component near the surface.

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