RECLAMATION RESEARCH FOR VARIOUS LANDUSES IN THE OIL SANDS REGION OF ALBERTA, CANADA[1]

by

T.M. Macyk,[2] M.Y.P. Fung[3] and R.W. Pauls[3]

Abstract. Syncrude Canada Ltd. produces 200,000 barrels of synthetic crude oil per day from its oil sands surface mining operations located 50 km north of Fort McMurray, Alberta. The three major types of materials generated by the oil sands mining and extraction process include overburden, coarse tailings sand, and fine tailings. The overburden and coarse tailings are reclaimed to a dry landscape. Since the mining operations are located in the Boreal Forest Region the major end land use is forestry. In addition to the establishment of trees and shrubs a multi-species ground cover is required to control soil erosion. In June 1993 the Alberta Research Council implemented a plot experiment consisting of 27 plots to evaluate the suitability of six native grass species for erosion control and co-establishment with white spruce *(Picea glauca)*, aspen poplar *(Populus tremuloides)*, jack pine *(Pinus banksiana)*, and dogwood *(Cornus stolonifera)*. Results to date indicate that white spruce and jack pine have a survival rate two-fold higher than aspen and dogwood and that survival rates are highest in the tall fescue treatments and lowest in the hard fescue and sheep fescue treatments. Syncrude Canada Ltd. is also assessing the feasibility of raising bison on a portion of their reclaimed lands. In 1992 the Alberta Research Council initiated a study to assess the impact of bison grazing on soil quality. Soils in the adjacent undisturbed forest and four reclaimed areas where the soils were reconstructed using different replacement techniques are being monitored. Monitoring at the reconstructed areas involves measurements at grazed and ungrazed locations. Field sampling and laboratory analyses are conducted annually. Volumetric water content, bulk density, and penetration resistance are measured four to five times and water infiltration once during the growing season. To date, grazing has had no significant effect on the physical properties of the reconstructed soils.

Additional Key Words: equivalent capability, reforestation, bison, soil quality, grazing treatments.

Introduction

The Athabasca deposit which has an average thickness of 38 m is the largest of four oil sands deposits located in Alberta, Canada and is the only deposit in the province that can be recovered through surface mining. Syncrude Canada Ltd. operates the largest oil sands crude oil production facility in the world and produces 200,000 barrels of synthetic crude oil per day from its operations located 50 km north of Fort McMurray.

Syncrude uses a combination of draglines/bucket wheels and truck-and-shovel methods to mine the ore which is then delivered to the extraction plant via conveyor belts (Fung and Macyk 1997). Bitumen is extracted from the ore using a hot water process pioneered by Dr. Karl Clark (McRory 1982). Approximately 96% of the bitumen is recovered in the process and upgraded to produce a light, sweet synthetic crude oil. The three major types of materials generated by the oil sands mining and extraction process include overburden, coarse tailings sand, and fine tailings. The overburden and coarse tailings are reclaimed to a dry landscape while the fine tailings are considered for both dry and wet landscape reclamation (Fung and Macyk 1997). Dry landscapes include those which are trafficable by heavy machinery and where tree and shrub species can be successfully established. Wet landscapes are areas that are waterlogged or underwater for at least part of the year and where aquatic plants predominate.

The overburden is comprised of all materials lying above the economically minable oil sands.

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[2]Terry M. Macyk, Senior Research Officer, Alberta Research Council, Edmonton, AB, T6N 1E4

[3]M.Y.P. Fung and Dr. R.W. Pauls, Environmental Research Associates, Syncrude Canada Ltd, Fort McMurray, AB, T9H 3L1.

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Revegetation of these materials are limited by low available water storage capacity, low nutrient status, high salinity or alkalinity, low or no organic matter, and minimal microbial activity (Fung and Macyk 1997). Bitumen may also be present in amounts that can be toxic to plant growth.

Tailings sand consists primarily of sand particles with small amounts of unrecovered bitumen entrained in the sand (Fung and Macyk 1997). The chemical characteristics of weathered tailings sand are similar to native sandy soils within the Athabasca oil sands region (Macyk and Turchenek 1995).

The general sequence of dryland reclamation begins with pre-disturbance soil assessments to identify suitable reclamation materials which is followed by the salvage, placement, and preparation of the replaced soil materials. Seeding of grass/legume mixtures or establishment of "mulch crops" is followed by reforestation, site maintenance and monitoring, and ultimately the certification of the land as sufficiently reclaimed (Fung and Macyk 1997).

The reclamation materials are salvaged and transported directly to the reclamation areas eliminating the need for stockpiling. Salvage and placement operations are conducted during the winter months. Following soil preparation agronomic grass and legume seed mixtures are broadcast seeded aerially on large areas or steeply sloping terrain. Other areas are ground broadcast, drill-seeded, or hydroseeded. The use of barley as a "mulch crop" is being evaluated.

A variety of trees and shrubs have been planted with varying degrees of success. Tree planting is done either in the year following the establishment of the initial ground cover or the next year depending on site conditions and availability of seedlings (Fung and Macyk 1997).

As is the case with surface coal mining, oil sands mining results in extensive surface disturbance with some topographic alterations. Reclamation research in the oil sands region has been ongoing since the early 1970's. In general, the research work addressed issues associated with soil reconstruction including the type and thickness of soil materials required, and the potential for the use of muskeg (peat) and tailings sand. Revegetation research has centered on evaluating the suitability of a variety of introduced and native species including grasses, legumes, trees, and shrubs.

Since the mining operations are located in the Boreal Forest Region the major end land use is forestry. In addition to the establishment of trees and shrubs a ground cover is required to control soil erosion. In 1993 the Alberta Research Council implemented a plot experiment to evaluate the suitability of six native grass species for erosion control and co-establishment with trees and shrubs.

In keeping with its goal to develop a diverse landscape that includes forestry, wildlife, agriculture (grazing), and recreation end land uses, Syncrude Canada Ltd. is reclaiming a portion of its lease areas as grassland to provide habitat for wood bison (Pauls et al. 1995). The wood bison project being conducted by Syncrude Canada Ltd. and the Fort MacKay First Nation is assessing the productivity of forage crops and the health and productivity of wood bison, and providing an opportunity for the Fort MacKay First Nation to determine whether this is a desirable post-reclamation land use. The results of this project will provide the basis for determining whether "equivalent productive capability" as required by the Alberta Environmental Protection and Enhancement Act has been restored (Pauls et al. 1995).

This paper describes the research undertaken by the Alberta Research Council on behalf of and funded by Syncrude Canada Ltd. to assess the impact of bison grazing on reconstructed soil characteristics and to evaluate the suitability of selected native grass species for erosion control and co-establishment with trees and shrubs.

Setting

Climate

The Athabasca oil sands area has a cool temperate climate with relatively long, cold winters and short, cool summers. January has a mean daily temperature of -21°C and July a mean daily temperature of 16°C. An extended period of over 17 hours of daylight occurs during June and July, and the average growing season from May through August is about 95 days.

Average annual precipitation is 305 mm of rainfall and 140 cm of snowfall with average potential evapotranspiration of 450 to 500 mm.

Geology

Most of the area is underlain by Cretaceous shales and sandstones. Glacial till is the most common surficial deposit and is comprised of an unsorted admixture of local bedrock and rock material from the Precambrian Shield (Turchenek and Lindsay 1982). Glacio-lacustrine deposits occur in the area and the material of more recent origin includes eolian, colluvial, fluvial, and organic deposits.

Soils

The typical mineral soils in the area are Luvisolic (Boralf) soils developed under mixed deciduous and coniferous vegetation (Turchenek and Lindsay 1982). Brunisolic (Cryochrepts and Dystrochrepts), Gleysolic (Aquents, Aquepts, Argiaquolls), and Regosolic (Entisols) soils also occur. Organic (Histosol) soils have developed predominantly from organic deposits and Cryosolic (Pergelic) soils have permafrost within 1 m of the surface.

Vegetation

The vegetation is characteristic of the Boreal Forest Region (Fung and Macyk 1997). The principal tree species of the area are white spruce *(Picea glauca* (Moench) Voss*)*, black spruce *(Picea mariana* (Mill.) B.S.P.*)*, trembling aspen *(Populus tremuloides* Michx.*)*, balsam poplar *(Populus balsamifera* L.*)*, and white birch *(Betula papyrifera* Marsh.*)*. Jack pine *(Pinus banksiana* Lamb.*)* is dominant on well-drained sandy areas, but also occurs with other tree species on drier glacial till soils and in mixes with black spruce in the uplands. Low-lying poorly drained areas have black spruce and tamarack *(Larix laricina* (Du Roi) K. Koch*)* cover (Turchenek and Lindsay 1982).

The understory vegetation includes bearberry *(Arctostaphylos uva-ursi* (L.) Spreng*)*, bog cranberry *(Vaccinium vitis-idaea* L.), twinflower *(Linnaea borealis* L.*)*, bunchberry *(Cornus canadensis* L.*)*, low-bush cranberry *(Viburnum edule* (Michx.) Raf.*)*, wild sarsaparilla *(Aralia nudicaulis* L.*)*, Labrador tea *(Ledum groenlandicum* Oeder*)*, horsetail *(Equisetum sylvaticum* L. and *Equisetum arvense* L.*)*, bluejoint reed grass *(Calamagrostis canadensis* (Michx.) Nutt.*)*, sedge *(Carex* spp.*)*, feathermosses *(Hylocomium splendens* (Hedw.) BSG. and *Pleurozium schreberi* (BSG.) Mitt.*)*, and lichens *(Cladonia* spp. and *Cladina* spp.).

Generally, regional vegetation has a low productivity due to adverse climatic conditions, poor soil conditions, and prolonged wetness due to high water tables (Techman Ltd. and Rheinbraun-Consulting GmbH 1979).

Materials and Methods

Co-establishment of Trees and Shrubs

The plot experiment was established on June 8, 1993 on the south-east corner of the Syncrude Canada Ltd. tailings dike (Macyk 1993). A total of 27 plots each 6 m x 10 m in size were staked out in a randomized block design. Soil sampling was completed prior to plot seeding. Composite samples of the coversoil (peaty or organic material) and the underlying tailings sand were collected and analyzed. Six individual grass species including Adanac slender wheatgrass *(Agropyron trachycaulum* var. Adanac*)*, Highlander slender wheatgrass *(Agropyron trachycaulum* var. Highlander*)*, streambank wheatgrass *(Agropyron riparium* Scribn. and Smith*)*, tall fescue *(Festuca arundinacea* (Screb.), and hard fescue *(Festuca ovina* var. *duriuscula* (L) Koch*)* were used. Two mixtures comprised of streambank wheatgrass with Adanac slender wheatgrass, and hard fescue with Adanac slender wheatgrass were also used.

The seed was applied at rates ranging from 15 kg/ha to 60 kg/ha depending upon the individual species. Each of the plots, with the exception of the control, received 1000 g (167 kg/ha) of 35-15-0 fertilizer by hand broadcast. The plots were then hand raked to incorporate the seed and fertilizer.

Initial tree and shrub planting was completed on September 20, 1994. Jack pine *(Pinus banksiana* Lamb.*)*, white spruce *(Picea glauca* (Moench) Voss*)*, trembling aspen *(Populus tremuloides* Michx.*)*, and red osier dogwood *(Cornus stolonifera* Michx.*)* grown in Spencer Lemaire (Tinus) rootrainers were planted. A total of six seedlings of each species were planted in each plot. In 1996 replanting was done to replace the mortalities that had occurred.

Harvesting of the grass in the plots to determine yield was conducted annually in the first or second week of July. The plots were harvested with a lawnmower equipped with a grass catcher to cut the grass to a uniform 5 cm height over the entire area of each plot. The grass was weighed immediately at the site and subsamples were returned to the laboratory, where they were dried at 30°C for 48 hours to determine dry weight.

Bison Grazing Study

Monitoring sites were established in 1992, 1994, and 1995, at locations where different soil reconstruction techniques were utilized (Thacker and Macyk 1993,

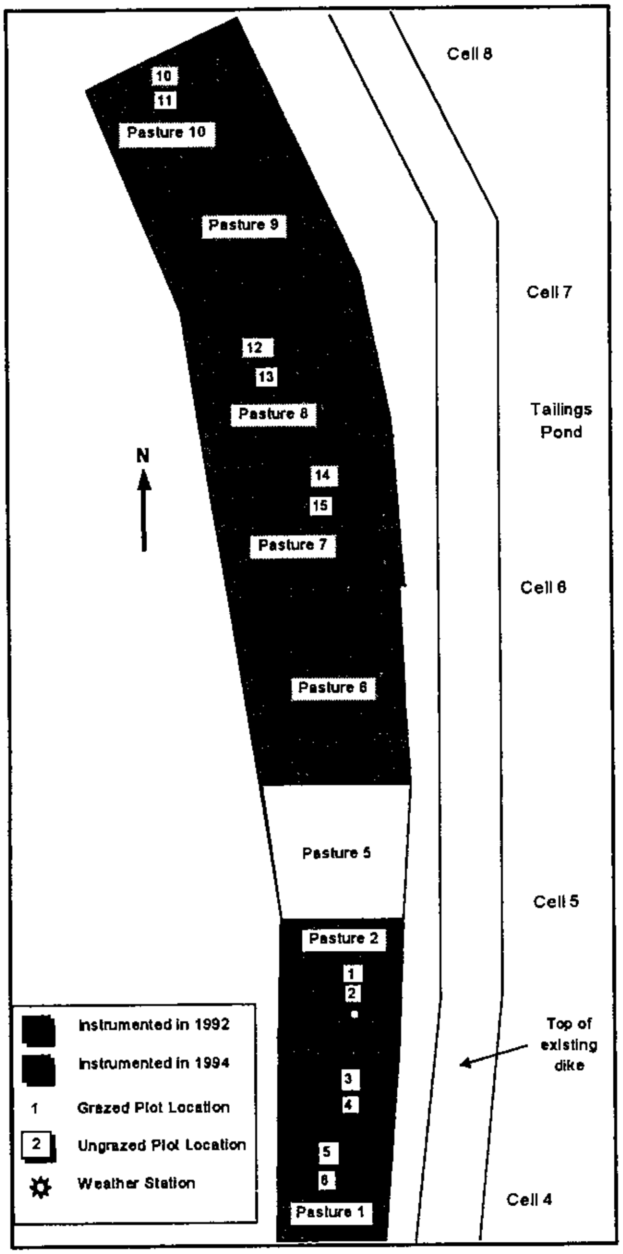

Figure 1. Plot locations in the north reclaimed areas at the Syncrude site

Macyk and Pojasok 1995, Macyk and Pojasok 1996). In 1992, three grazed and ungrazed sites were located in a 25 hectare section of reclaimed tailings pond toe berm and are referred to as Sites 1 to 6 in the north pasture (Figure 1). Soil reconstruction in this area involved the placement of a 50 cm thick "topsoil" layer comprised of glacial till over 10 m of tailings sand. In 1994, six additional sites referred to as sites 10 to 15, were established immediately north of the above described area (Figure 1). In this area the replaced soil profile was comprised of 20 cm of peaty material over 50 cm of glacial till underlain by 10 m of tailings sand. In 1995, six sites (16 to 21) were established in an 80 ha area at the south end of the lease characterized by complex, gently to steeply sloping topography interspersed with small ponds and sloughs. The replaced profile consisted of a 1.6 m to 2.2 m thick peaty surface layer overlaying glacial till overburden.

Each of the grazed and ungrazed plots are 5 m x 5 m in size and the ungrazed plots are set in exclosures to prevent bison grazing. The grazed plots are located 15 m north of each ungrazed plot to avoid any unrepresentative trampling that may occur where animals congregate adjacent to the exclosure fences.

For control purposes three undisturbed forest sites were established about 10 km south of the bison pasture. Two fine textured soils similar to the soil used for reconstruction of the grazing area and one sandy soil typical of soils in the Syncrude lease area were selected.

Neutron probe access tubes were installed in the center of each of the 5 m x 5 m sites to a depth of approximately 3 meters which allows measurement of soil bulk density (Mg/m^3) and soil moisture (% volume) to a depth of 2.7 m. Volumetric moisture and bulk density were measured in 15 cm depth increments to 120 cm and 30 cm increments to 270 cm at each site five times during each growing season.

Penetration resistance (MPa) was determined using a Centre Cone Penetrometer equipped with a cone having a basal diameter of 0.65 cm^2. Fifteen random measurements were made in the 0 to 10 cm and 10 to 20 cm depths for each of the sites at five different times during each growing season.

Water infiltration rates (mm/hr) were measured annually using a double-ring infiltrometer at three random locations at each of the plots. A modified USDA (1956) approach was used with the modifications consisting of a constant head of water rather than a falling head, maintaining the water in the outer cylinder at the same depth as the inner cylinder, and applying weight to the cylinders when driving them into the ground in order to reduce vibration and soil disturbance.

An Omnidata Easylogger data logging system was installed at site 4 to measure total rainfall and

Species	Plot Label	Grass Yield (Kg)	
		1995	1996
Hard Fescue (Aurora)	HF	4.12	7.57
Streambank Wheatgrass (Sodar)	SWG	5.05	6.56
Sheep Fescue (Nakiska)	SF	7.56	10.87
Tall Fescue	TF	3.88	5.72
Slender Wheatgrass (Adanac)	SW(A)	8.28	7.70
Slender Wheatgrass (Highlander)	SW(H)	4.86	4.60
Streambank Wheatgrass + Slender Wheatgrass (Adanac)	SWG+SW(A)	8.87	11.45
Hard Fescue + Slender Wheatgrass (Adanac)	HF+SW(A)	5.82	6.95

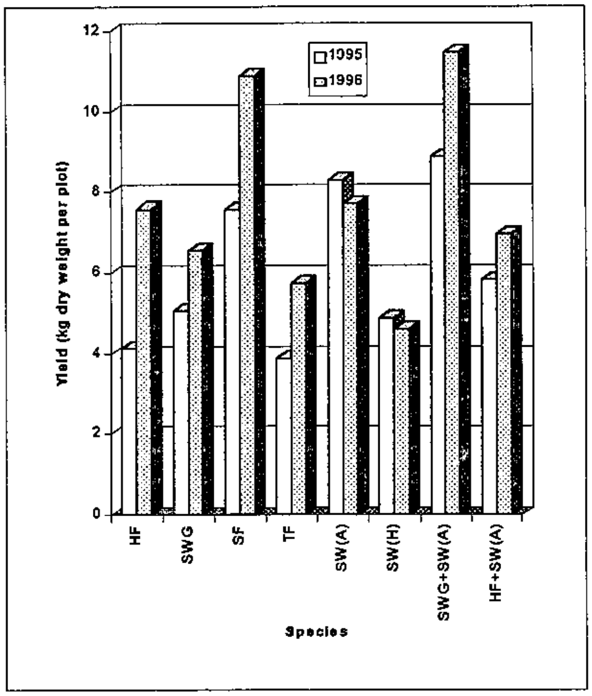

Figure 2. Mean grass yields in July, 1995 and 1996.

rainfall intensity, air temperature, solar radiation, wind speed and direction, and relative humidity in the study area on a continuous basis.

Baseline soil samples were collected in 15 cm depth increments to the 120 cm depth at each of the reconstructed and undisturbed sites. Sampling has been completed annually and analyses include pH, saturated paste extract properties, calcium carbonate equivalent, oil and grease content, and particle size distribution.

Results and Discussion

Co-establishment Study

Grass growth. Despite the drought conditions that prevailed in the early part of the 1993 growing season, good growth and initial establishment was achieved. One month after seeding, the grass was approximately 15 cm in height and in two months the wheatgrasses had achieved heights of 50 to 65 cm. Figure 2 provides mean yield values for the different treatments in 1995 and 1996. The streambank wheatgrass and slender wheatgrass mixture produced the largest mean yield of 11.5 kg/plot compared to the lowest yield of 4.6 kg/plot for the Highlander slender wheatgrass (Macyk 1997).

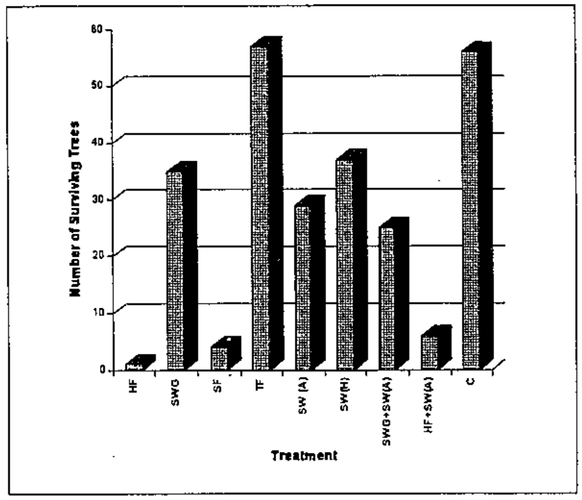

Figure 3. Tree survival in the different grass treatments from initial planting to September, 1996.

Tree survival and growth. The initial height of the trees and shrubs was determined following planting in the fall of 1994. Height measurements, and survival and mortality data were obtained in the fall of 1995 and 1996. Replanting occurred in 1996 to replace the trees and shrubs that had died. Figure 3 illustrates the combined number of surviving trees from initial planting to September 1996 for the nine different grass treatments. The data indicated that overall survival was 56% for the white spruce, 53% for the jack pine, 22% for the aspen, and 35% for the dogwood. Overall survival for the trees and shrubs was highest in the tall fescue and control treatments with the lowest survival in the hard fescue, sheep fescue, and the hard fescue and slender wheatgrass mixture (Macyk 1997).

Species evaluation. Visual observations and measurements provided the basis for selection of grasses most suitable for establishment of an erosion controlling cover and those most suitable for co-establishment of trees and shrubs. The sheep fescue and hard fescue produced the most dense cover which is useful for erosion control but negatively impacted co-establishment of trees and shrubs. On the other hand, tall fescue which is less competitive than the sheep and hard fescue produced good ground cover, a relatively low yield, and tree survival and growth that was relatively good compared to the other treatments.

The streambank wheatgrass provided excellent ground cover which was not as dense as the cover associated with the fescues. As a result, overall tree survival in the streambank wheatgrass plots was next highest to the control and tall fescue treatments. Overall establishment and cover development was similar for both slender wheatgrass varieties.

Bison Grazing Study

A significant amount of data regarding the chemical and physical properties of the reconstructed and undisturbed soils has been generated in the first five years of the study. As a result it is not possible to include data in this paper for all of the parameters measured. Emphasis is placed on physical properties including soil moisture and soil bulk density regimes, as well as, infiltration and penetration resistance data for the sites where data has been collected for a minimum of two years. The two major comparisons or interpretations of the data include assessing the grazed versus the ungrazed treatments for the different soil reconstruction techniques and a comparison of the different soil reconstruction techniques to the controls. Statistical analysis of the data was performed with a microcomputer Statistical Analysis System (SAS) package and analysis of variance conducted using the Tukey Studentized Range Test (SAS 1985).

Soil Moisture Regime. The differences in soil moisture content between the grazed and ungrazed treatments were minor for the different soil reconstruction techniques for the respective measurement periods. Figure 4 illustrates the mean soil moisture values for the three grazed sites compared to the ungrazed sites over a five year period where the fine textured topsoil material was used. No clear trends have developed with some of the grazed sites having higher mean moisture contents than the ungrazed sites. Figure 5 illustrates the mean moisture contents of the three grazed, three ungrazed and the coarse textured and fine textured control sites for the five year period. The moisture content in the fine textured topsoil layer was about mid-way between the values for the coarse textured and fine textured control sites and the values were also slightly higher for the ungrazed than the grazed sites. Below the topsoil layer the moisture regime in the tailings sand at the reconstructed sites was similar to the coarse textured undisturbed site.

Figure 6 provides the mean soil moisture content data for grazed and ungrazed sites with a shallow peat surface (20 cm) compared to the control sites from 1994 to 1996. The values for the surface layer were again mid-way between the values for the two controls. The values for the 15 to 60 cm interval or the fine textured layer above the tailings sand were similar to the values reported for the fine textured control. The values for the tailings sand at these sites were higher than those reported in Figure 5 due to the fact that less time has been available for the dewatering of the tailings. There

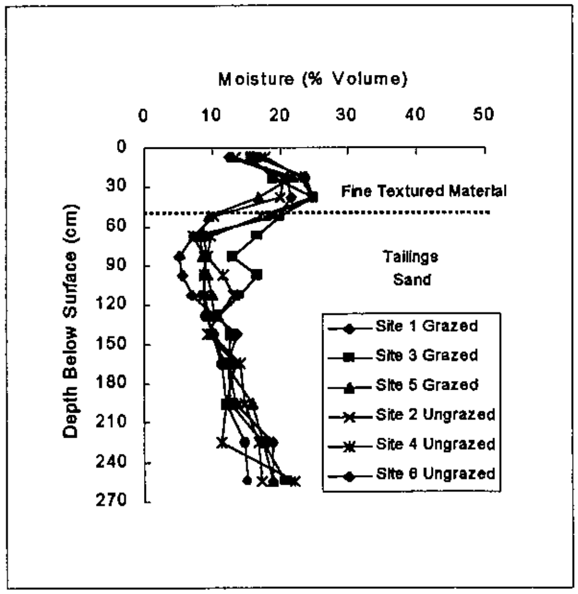

Figure 4. Mean soil moisture content at the grazed and ungrazed sites with the fine textured topsoil from 1992 to 1996.

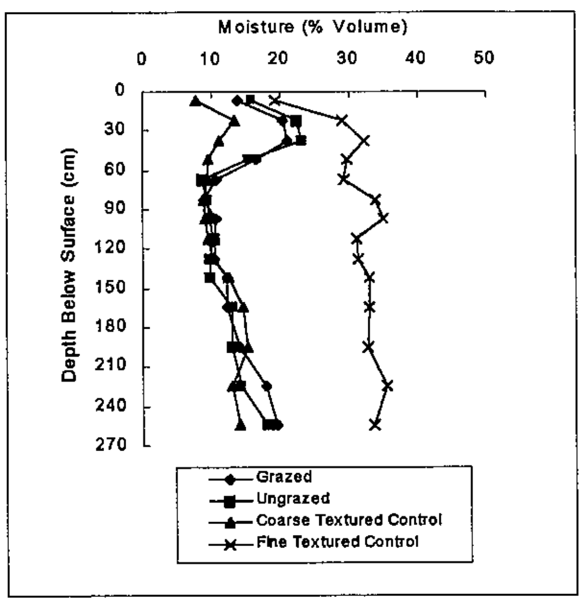

Figure 5. Mean soil moisture content at the grazed and ungrazed sites with fine textured topsoil and the control sites from 1992 to 1996.

were only small differences in moisture content between the grazed and ungrazed sites with slightly higher mean values occurring at the grazed sites.

Figure 7 illustrates the considerably lower mean moisture contents for the grazed and ungrazed sites with a thick peat surface of about 180cm compared to the two controls. Minor differences occurred between the grazed and ungrazed locations. Below the 180 cm depth the values for the reconstructed soils (till material) were similar to the values for the fine-textured undisturbed site.

Overall the reconstructed soils had favorable moisture regimes compared to the controls and there were no differences between the grazed and ungrazed sites indicating that grazing has not had a negative effect on reconstructed soil moisture content.

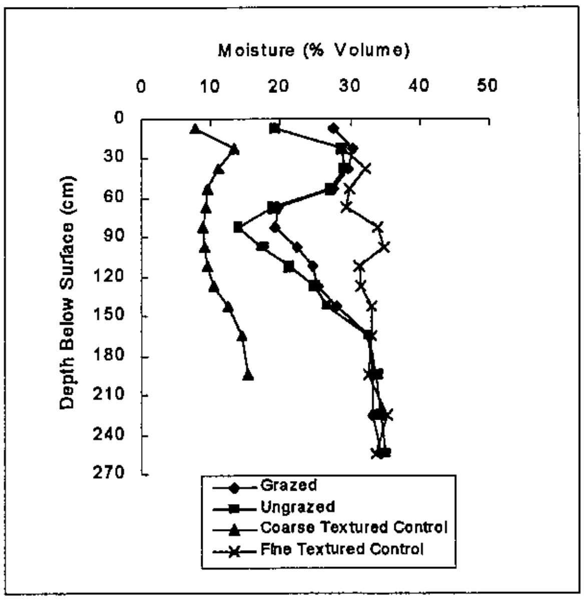

Figure 6. Mean soil moisture content of the grazed and ungrazed sites with a shallow peat surface compared to the control sites from 1994 to 1996.

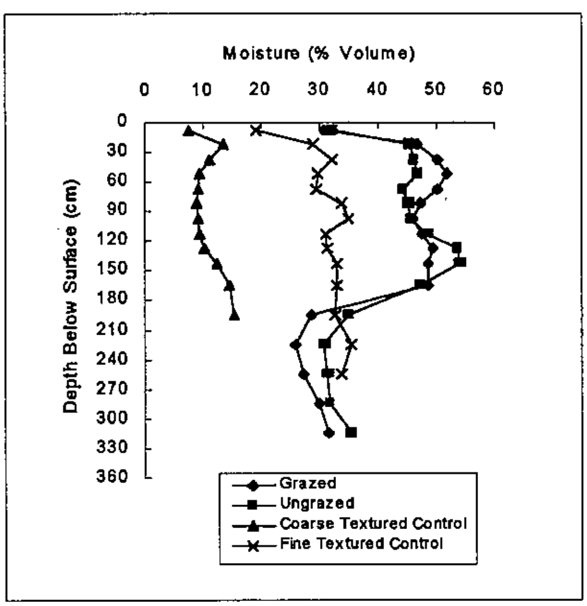

Figure 7. Mean soil moisture content of the grazed and ungrazed sites with a thick peat surface compared to the control sites for 1995 and 1996.

Soil bulk density. The differences in soil bulk density for the grazed and ungrazed treatments were also minimal for the different soil reconstruction techniques for the respective measurement periods. Figure 8 provides the mean bulk density values for the three grazed and three ungrazed sites over a five year period for the area where the fine textured topsoil material was used. With the exception of a few wide swings in the density profiles at sites 3 and 5, there were no clear trends established. For the 0 to 15 cm depth sites 2 and 4 (ungrazed) had the highest mean values for the five year period. Figure 9 illustrates the mean bulk density values for the three grazed, three ungrazed, and the coarse textured and fine-textured control sites for the five

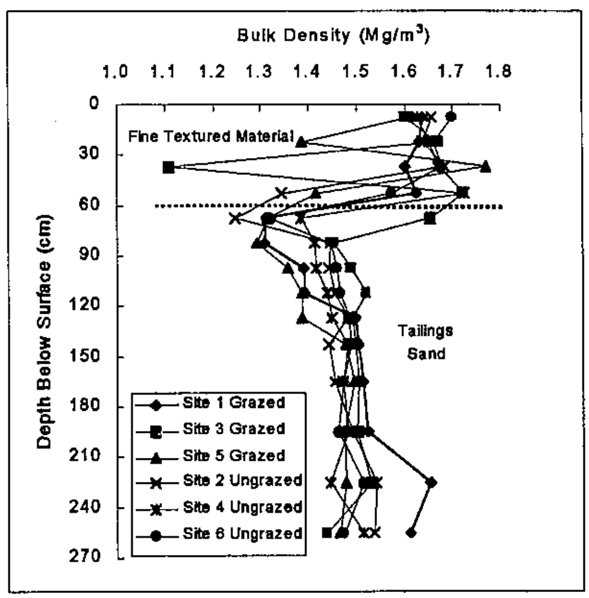

Figure 8. Mean soil bulk density at the grazed and ungrazed sites with the fine textured topsoil material from 1992 to 1996.

year period. The bulk density in the upper 45 cm of the reconstructed soil profile was higher than the density of both the fine textured and coarse textured controls. The values were actually higher for the ungrazed than the grazed treatments.

Figure 10 provides the mean bulk density values for the grazed and ungrazed sites with a shallow peat surface layer for 1994 to 1996. Again there was no clear trend of either the grazed or ungrazed locations having higher bulk densities. For example, in the peat layer the paired sites 12 and 13 had similar mean values whereas the value for site 10 (grazed) was lower than the value for site 11 (grazed). Figure 11 provides a comparison of the mean bulk density values for the grazed and ungrazed

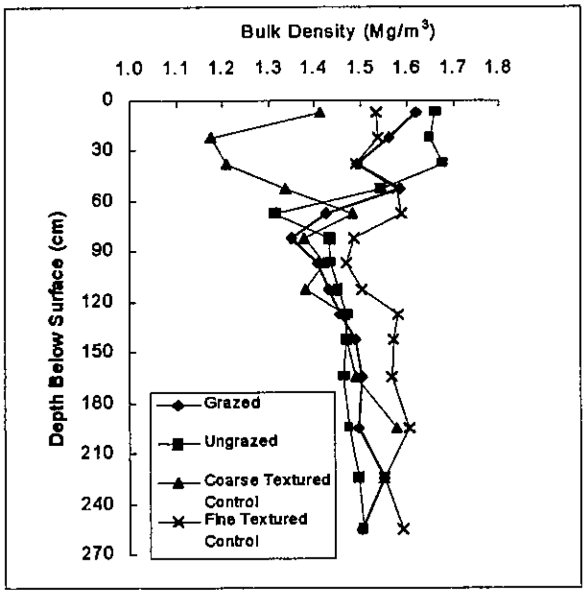

Figure 9. Mean soil bulk density values for grazed and ungrazed sites with the fine textured topsoil and the control sites from 1992 to 1996.

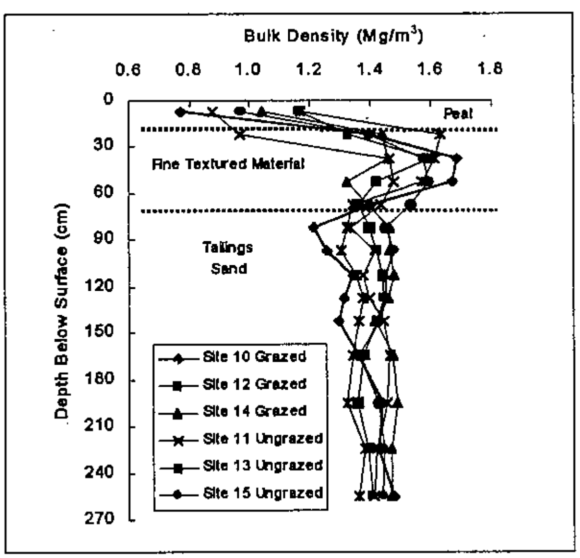

Figure 10. Mean soil bulk density values for the grazed and ungrazed sites with a shallow peat surface for 1994 to 1996.

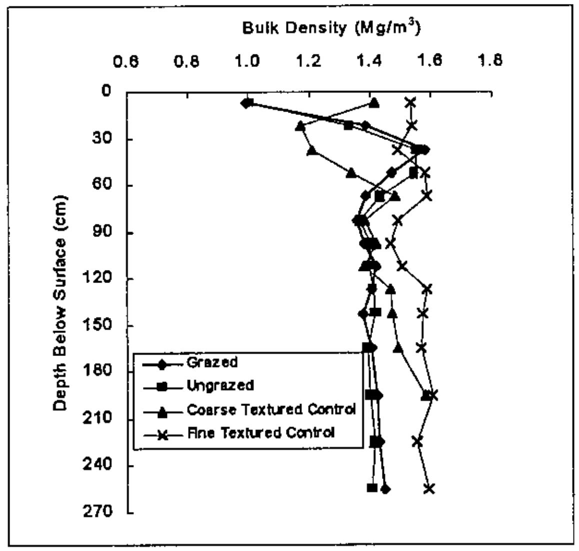

Figure 11. Mean soil bulk density values for grazed and ungrazed sites with a shallow peat surface compared to controls from 1994 to 1996.

sites with a shallow peat surface with the coarse and fine textured control sites. The values for the grazed and ungrazed sites varied from being lower than either of the controls in the surface (0 to 20 cm interval) to higher than both controls in the 30 to 45 cm interval. Below this depth the values for the grazed and ungrazed sites or the tailings sand were similar to the values for the coarse textured control.

Figure 12 provides the mean bulk density values for the grazed and ungrazed sites with a thick peat

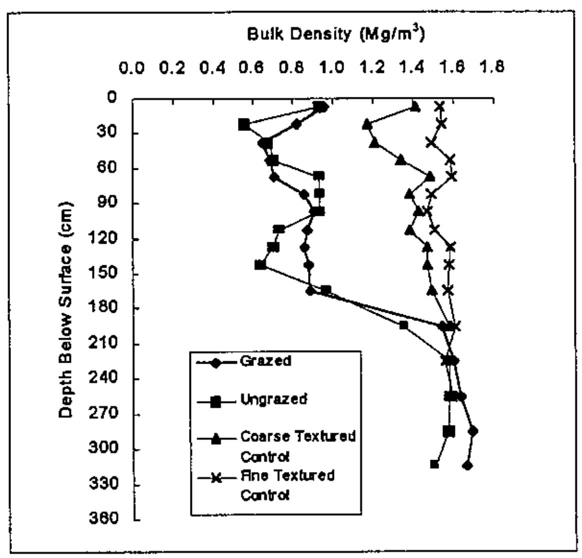

Figure 12. Mean soil bulk density values for the grazed and ungrazed with a thick peat surface and the control sites for 1995 to 1996.

surface layer and the control sites for 1995 and 1996. The difference in mean values between the grazed and ungrazed sites varied with depth. The mean values were about 0.70 Mg/m^3 in the peat layer compared to about 1.40 Mg/m^3 for the coarse textured control and about 1.50 Mg/m^3 for the fine textured control. Below the peat layer the values were similar. Overall the soil bulk density data indicates that to date grazing has not had a negative impact on soil bulk density status of the reconstructed soils. The soil reconstruction technique involving the placement of fine textured soil material on the surface resulted in bulk density values higher than either of the coarse textured or fine textured control sites.

Soil penetration resistance. Mean penetration resistance values (megapascals) for the grazed and ungrazed sites were compared to the values for the undisturbed sites. Table 1 compares the mean values recorded in 1996 for the undisturbed sites and sites 1 to 6 where the topsoil is comprised of fine textured material. For most of the measurement events there was a significant difference between the reconstructed soils (grazed and ungrazed) and the undisturbed soils. For the May measurement there was a significant difference between the grazed and ungrazed sites as well.

Table 1. Comparison of mean soil penetration resistance by treatment for the undisturbed sites and sites 1 to 6 (fine textured topsoil).

Date/Depth	Penetration Resistance (MPa)		
	Undisturbed	Ungrazed	Grazed
May 13, 1996			
0 to 10 cm	1.6c*	4.4b	6.7a
10 to 20 cm	3.6c	9.3b	16.3a
July 9, 1996			
0 to 10 cm	1.7b	4.0a	5.8a
10 to 20 cm	3.1b	9.7a	13.3a
August 12, 1996			
0 to 10 cm	2.3a	3.7a	4.6a
10 to 20 cm	4.5b	7.9b	12.1a
September 23, 1996			
0 to 10 cm	0.3b	7.2a	9.1a
10 to 20 cm	2.3b	15.4a	19.0a

*Treatment means not followed by a common letter are significantly different at 0.05 probability by Tukey's Studentized Range (HSD) Test.

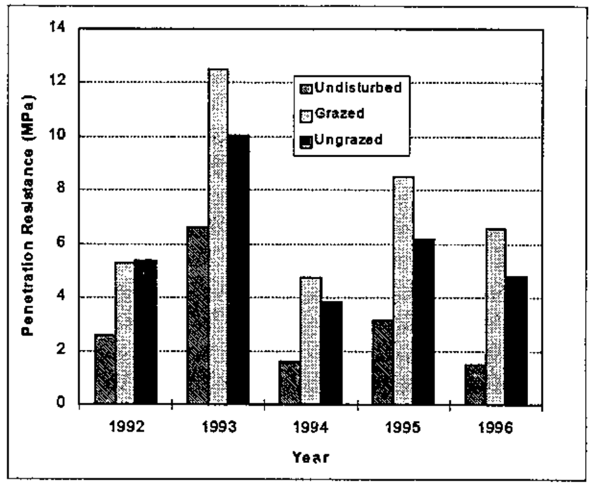

Figure 13. Mean soil penetration resistance for the 10 cm depth at the undisturbed sites and sites 1 to 6 (fine textured topsoil) from 1992 to 1996.

Table 2. Comparison of steady-state infiltration rates at reconstructed sites 1 to 6 (fine textured topsoil) and undisturbed sites 7 to 9 from 1992 to 1996.

Treatment	Year	Mean Infiltration Rate (mm/hr)
Undisturbed	1992	800 a*
	1993	500 a
	1994	269 a
	1995	233 a
	1996	816 a
Ungrazed	1992	60 a
	1993	37 a
	1994	85 a
	1995	97 a
	1996	172 a
Grazed	1992	32 a
	1993	19 a
	1994	32 a
	1995	47 a
	1996	51 a

* Means within each treatment not followed by a common letter are significantly different at 0.05 probability by Tukey's Studentized Range (HSD) Test.

Figure 13 provides a comparison of the mean penetration resistance values for the 0 to 10 cm depth at the same sites from 1992 to 1996. The mean values were highest for all treatments in 1993 and declined subsequently. The mean values reported for 1996 were similar to those reported in 1992.

Water infiltration rate. Infiltration measurements were replicated three times at each of the sites. The mean values for five years of measurement indicate that there were no significant differences between years for all treatments (Table 2). There were apparent differences in the mean values between the ungrazed and grazed sites, however these differences were not statistically significant (Macyk and Pojasok 1997). These infiltration rates were sufficient to accommodate the most intense rainstorm event since the inception of the project which resulted in 15 mm of rainfall per hour.

CONCLUSIONS

The research work conducted to date and described in this paper indicates that practical land use options for the Athabasca oil sands mining area include reforestation and establishment of grasslands to provide wood bison habitat. Conclusions based on the results of the first four years of the co-establishment study indicate the following:

1. The six grass cultivars used in the experiment are suitable for revegetation on the Syncrude tailings dike, especially for the purpose of erosion control.

2. Tall fescue is one of the most suitable species for co-establishment of trees and shrubs whereas hard fescue and sheep fescue are less suitable.

The measurements completed to date relative to the bison grazing study indicate that the reconstructed soils demonstrate quality characteristics that are comparable to the different types of undisturbed soil evaluated. The soil properties for the grazed and ungrazed locations remained relatively similar and it appears that grazing has not had any significant effect on the reconstructed soil properties.

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