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Edited by:
P.F. Ziemkiewicz
S.K. Takyi
H. Regier

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Reclamation Research Technical
Advisory Committee
of the
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FOREWARD

Over the past ten years, soil reconstruction in the reclamation of agricultural lands has received increasing attention, particularly in the Plains Coal Region of Canada and the United States. Despite this considerable level of research activity, some time remains before we will know how to reclaim agricultural land with maximum efficiency.

In comparison, reclamation of Western Canadian forest lands and restoration of commercial forestry potential are in the earliest stages of study. While some research results have been published many studies have yielded only tentative results thus far. Also, knowledge derived from operational-scale soil reconstruction programs is often of an intuitive nature and not available in the literature. Finally, we felt that the fields of forestry and soil science could contribute to our understanding of the problem. The workshop format was chosen as a means of focussing the attentions of individuals with a wide range of expertise on the specific problem of reconstructing forest soils in reclamation.

We wish to thank those who contributed to the discussions and particularly those who presented papers. These proceedings are made public in the belief that the participants have created a body of information which will be of interest to others involved in reclamation.

DISCLAIMER

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INTRODUCTION

Alberta's Land Reclamation guidelines require operators to reclaim land to a level of productivity equal to or greater than that which existed prior to disturbance. In the forested regions of Alberta, mining often impinges upon forests with immediate or future commercial prospects. Coal is mined in the eastern slopes of the Rocky Mountains and oil sands are mined in northeastern Alberta.

Establishment of productive forests on these disturbances will require considerable effort and time. One of the major areas of concern to both government and industry is the segregation, stockpiling and application of soil-building materials. Specifically, we need to know:

1. What kind of soil-building materials are available?
2. How will they behave when re-applied?
3. What are the optimal mixtures of materials?
4. To what depth should these mixtures be applied?

Or, in short:

> How much of what is necessary to grow decent trees in western and northern Alberta?

These questions will not be easy to answer. Since results of experimental or operational tests pertinent to Alberta are scarce, a research program may be required to clarify the above questions.

Alberta's Reclamation Research Technical Advisory Committee is responsible for developing such research programs for the provincial government. The Committee membership represents eight provincial government agencies and acts as an advisory body to the Land Conservation and Reclamation Council.

Before embarking on a research program the Committee first seeks guidance in the following areas:

1. "Topsoil" depth guidelines (given the constraints in our data base, what depth of "rooting zone" is required for commercial forest tree production in Alberta?).

2. Is further research required? If so, what direction should the research program take?

The goal of this workshop is to bring together those individuals who can focus either practical experience or the principles of Soils/Forest Science on the problem of Forest Soil Reconstruction.

Considering the lack of applicable hard data on the subject of reconstructed forest soils, we feel that the workshop approach will most effectively establish the state of the art and identify directions for further research.

P.F. Ziemkiewicz, chmn.
Reclamation Research Technical
Advisory Committee

Tree Rooting Characteristics

by
K.A. Armson, R.P.F.*

INTRODUCTION

There is an old expression - "what the eye doesn't see, the heart doesn't grieve" - which I think is particularly appropriate to a consideration of tree roots. In the establishment of vegetation on a bare area we tend to focus on the surface or superficial features of both the soil materials and the vegetation. Such a focus is not misplaced, but it should not divert us from an equal concern for the development of root systems and the soil as a rooting medium.

While there is a voluminous literature on soil as a rooting medium, many of the studies, whether observational or experimental, deal with the soil over short time spans and, therefore, over limited periods in-so-far-as the lifetime of a tree is concerned.

This meeting is an attempt to provide answers to questions about how to successfully grow trees on reclaimed land in Alberta. In the attempt to provide such answers, the nature and amount of soil-building materials required are of particular concern. However, I would suggest that in formulating those answers, the overall objective of revegetation management be viewed in light of the vegetation's development with time. While this may be of minimal concern with non-woody or shrub vegetation, it is of considerable importance where long-term forest conditions are to be maintained.

I am going to emphasize the space and time dimensions of soils as a tree rooting medium, but first I wish to speak to the subject of genetic control and variation in tree rooting characteristics.

DISCUSSION

Genetic Variation and Forest Tree Roots

Although much is known of the variation in root stock for fruit trees, there is a dearth of similar information for forest trees. For example, one of the more comprehensive reviews of the form and development of conifer root systems (Sutton, 1969) does not discuss genetic variation at all. Research in genetic variation in form and development of forest tree root systems is grossly neglected, yet it is a particularly important area as we intensify silvicultural practices, of which revegetation on reclaimed lands is a specific example. In Ontario, in our hybrid poplar silviculture there is observational evidence, both from practice and preliminary studies (Faulkner and Fayle, 1979) that clonal differences in root systems exist in Euramerican poplars. The major impetus to further studies will come, I believe, with the use of clonal populations of native conifers such as spruce (*Picea* spp.) and pine (*Pinus* spp.).

* Ontario Minsitry of Natural Resources, Forest Management Branch, Parliament Buildings, Ottawa, Ontario

In future studies on genetic variation within a species there are three attributes of special concern in silviculture:

1. The form of root development. Whether it is predominantly vertical, horizontal or some combination.
2. What is the rate of extension of the root system and its degree of intensification with time?
3. The interrelationships of 1. and 2. with above-ground tree growth and the soil.

The value of such information, when planning the establishment and management of vegetation, especially on man-made or conditioned soil, is obvious.

The Soil in Space and Time

The soil as a rooting medium can be considered in many ways, but essentially it is the space from which a plant draws water and nutrients. This simplified view of supply has as a counterpart: demand - the requirement of the tree itself. Supply and demand are not normally static, but increase or decrease. These changes are not necessarily concomitant and even when concurrent may do so at different rates. Two basic principles relating tree growth, root development and soil volume were enunciated by Day (1955):

First, " In order to remain healthy a tree must by its nature develop continually in size and to do this it must continually increase its demand on the soil".

Second, "The continued satisfaction of the demand on soil supply by the developing tree depends, therefore, on the condition of minimum supply being greater than that of maximum demand".

Both these principles involve the factor of time, growth of the tree with time and changes in rates of demand and supply. Demands for both water and nutrients can be primarily related to the amount and rate of development of the foliage of a tree; while supply from the soil is a function of the flux of water and nutrients to the roots.

This flux is a function of the rate at which one of the supply components for example, water, can move to a root surface, and also the rate at which a root system can expand into a soil. Periodicity of root growth is pertinent and has been neatly summarized by Zimmermann and Brown (1971) into three categories:

(1) Not all the roots grow at the same time; while some are growing, others are quiescent.

(2) In many plants in the temperate zone there is a peak period of active growth in the spring which may begin before, during or after shoot growth. There is sometimes a second peak of root activity in the fall.

(3) Individual roots show cyclic periods of growth. This may be modified by changes in the external environment. Seedlings are more responsive to environmental change than older trees.

Keeping the importance of periodicity in mind, I would now like to turn to the principles set forth by Day in relationship to root development at three stages of revegetation - initial establishment, immature development to polewood and from polewood to maturity.

Initial Establishment: The initial root habit and the rate at which roots may penetrate the soil are most important. Even if the form of roots may be appropriate to the site, their rate of growth, particularly elongation may be too slow to offset the progressive reduction in water supply which can often occur. Uniformly fine-textured soils such as silts are where this is more likely, rather than in coarser textured or loamy soils. It is also more likely to occur in early spring, when the soil is cold, yet in daytime, air temperatures may be great enough to induce high rates of both photosynthesis and transpiration.

In a hypothetical example, consider large vigorous transplant conifers outplanted in early spring into a silt with very low amounts of coarse organic fibre, but high moisture content and low temperatures. For the week following outplanting, there is very warm, bright weather. On inspection, two to three weeks after planting, more than half of the trees are found to be dead - from drought. This is an illustration of Day's second principle - the minimum supply not being equal to the maximum demand. The demand has been conditioned by both the above-ground temperature and light conditions on the relatively large foliage surface area. The supply depends not only on the amount of water in the soil, but also the rate at which it can move through the coarse pores to the root surface. In a cold silt this is minimal. Further, the cold soils will inhibit the rate of root initiation and elongation. The result is injury and mortality from drought in a cold wet soil. Those trees which survive will most likely reflect symptoms of nitrogen deficiency as the soil gradully warms up, because of the reduction in root development as above-ground growth proceeds.

In the above example, the cause is that the soil has too uniform and fine a system of pores. This physical system operates adversely on the tree by virtue of moisture supply and soil temperature. The degree to which it operates may be modified by such factors as species, size and physiological state of the planting stock, time of planting, surface features affecting soil temperature and moisture as for example, other vegetation or soil surface colour and weather conditions from time of planting.

Although the problem may be ameliorated by changing species, type of planting stock, or indeed may vary from year to year with weather conditions, the basic cause should be recognized as one related to the soil's physical properties.

Immature Development to Polewood: In forestry, we often use the term 'established' when we consider that the regeneration has come through its initial period of growth. Like many terms, it is used subjectively and sometimes quite differently. In Ontario, we have recently attempted to quantify the time of establishment by using measures of height for a species over a broad range of growing areas. The time at which a stand is established is based on quantitative criteria and we term the stand then as "Free-to-Grow". With our boreal species of conifer it may range from five to ten or more years after initial regeneration treatment. The period in a stand's development from "Free-to-Grow" to polewood is one characterized by rapid above-ground and below-ground tree growth. The ability of a soil to provide water and nutrients will vary both from season to season and between soils, but over time will remain relatively constant. The tree's demand during this period of time is not only changing within each year, but is increasing rapidly as it grows older. Sooner or later, a period is reached when minimum supply is inadequate to meet the tree's maximum demand. It is at this stage that tree mortality will occur. Pathogens and insects will also contribute, but I would suggest that often these, particularly the pathogens, are secondary rather than primary causes of debility and mortality.

An example of how root development may relate to above-ground growth is given by Fayle, 1978 for red pine (*Pinus resinosa* Ait). He found that initial stem and root growth of trees that became suppressed within 30 years were poorer than those that became codominants. Although the ultimate extent of the horizontal root system of suppressed trees was somewhat less than that of the codominants, the number and distribution were similar. In contrast, the vertical roots of codominants had reached deeper (2.8 m) moisture-holding layers six years after planting, whereas the vertical penetration of the suppressed was much less and slower; the very suppressed trees had vertical roots limited to a depth of 1.5 m or less. The initial rapid exploitation of the soil is, therefore, very important for a number of conifer species and should take place within the first ten to fifteen years of growth. It can be hypothesized that the greater the uniformity of exploitation, the more likelihood there will be of stand integrity, whereas the less the uniformity the greater the variation in above-ground development. Another feature that may be considered is that the greater the initial vertical exploitation of a tree's root system, the greater the likelihood the rooting volume will be increased for succeeding generations of forest stands. This not only is beneficial for growth of future stands, but has hydrologic implications since these old root channels, particularly when colonized by live roots, can be important conduits for rapid infiltration at depth.

There are situations in the establishment of trees on man-made soils, where a sharp discontinuity exists between the upper man-made soil which facilitates root growth, and the lower non-soil; the opportunity for continued vertical root development across the discontinuity will be minimal. This may be an advantage for herbaceous or other non-tree vegetation, but can pose major problems if the objective is to maximize root development. It can also be the source of later problems in tree development if natural root extension is inhibited in a rapidly developing stand.

Thus, as a stand proceeds towards the polewood stage of development, any significant interruption in water and nutrient supply will ultimately be reflected in above-ground growth. This illustrates the application of Day's first principle, that to remain healthy a tree must continually increase its demand on the soil. Interestingly, a comparison of rates of growth is important, thus in revegetation a rapid cover is usually required, but trees with initial rapid growth may well be the most unsuitable for the longer run when slower-growing species would be more appropriate. The opportunity, thus, exists for species combinations, which best achieve the objecties of management. Fast-growing soil improvers such as certain nitrogen-fixers could well be mixed with slower-growing but longer-lived tree species.

Polewood to Maturity: This is the period when the greatest opportunity exists for stand management. Often, much less attention is paid to root development during this period than any other, and the initial objectives for which the trees were established may change. If the original objective was to minimize erosion and establish a permanent vegetation cover, by the polewood stage, the forest may be increasingly viewed in terms of value for wood production, wildlife, recreation or other uses either singly or in combination. Root mortality will occur during this period, but intervention in the stand may affect or reflect certain features of the root system. For example, thinning may increase the frequency of root grafting (Armson and van den Driessche, 1959). Where root grafts occur, the residual stem has an increased root system if it maintains grafted roots cut from a tree. This provides for an immediate relative if not absolute increase in supply of water and nutrients to the residual tree. It also may provide for entry of pathogens such as *Fomes annosus* (Fr.) CKe.

Although trees in this third stage of development are in a relatively stable state because their rates of growth are usually much less than in the previous two stages, they will usually have somewhat greater absolute total demands. Ultimately, these demands cannot be met because the root system cannot increase further and the rate of new root regeneration decreases. Mortality is the consequence, but very often the onset of debility, which precedes mortality, is reflected in the above-ground part of the tree by crown deterioration, especially dieback from the top. When this is visible, you may be sure there is a decrease in the net effective root system. You are now ready for your second crop, but it will now have a different soil environment than the first.

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Questions

T. Ballard: I have a question for Ken, what differences are there in function among tree roots? Looking at root distribution, how important are the roots near the surface vs. the few which reach to depth? How important are large vs. small roots?

K. Armson: I wish I could answer that. It is a perennial question, but I do not have any answers and I don't know of anyone who has. We've casually looked at this for 15 years to try to get a handle on this question, and we still don't know. No one has really looked at it seriously.

We feel we have a much better feel for the kind of soil a given species requires. For example, with Aspen and Black Spruce, if you have a rooting depth in natural forest soil of 20-30 cm with 10 cm of LFH and the rest Ae-upper B, you're in business. With Jackpine, roots of some varieties will go 3 to 5 m. Generally, most roots are in 1 to 2 m range in sandy loams. The thing that is really critical is the shift in texture and more importantly in bulk density when going from one material to the other. We did some studies on Red Pine, which were published. If you have a bulk density greater than 1.3 g cm^{-3}, you are looking at soil that most of our tree roots just do not penetrate. If you are dealing with something between 1-1.2 g cm^{-3} (the smaller it is, the more you will have rapid egress) mechanical impedence becomes less of a factor. Black Spruce fine roots will go into a soil with higher bulk density more readily than Jackpine. Where you have the fine pores, a Black Spruce root, which is a fine one, will grow into that pore, whereas, in the same system, the Jackpine root tends to be larger and cannot fit in because you have a Physically rigid system. There are other factors, aeration, moisture, nutrients all tend to come into it, but if you are looking at bulk densities you have to look at something less than 1.3 g cm^{-3}. Now we come to the discontinuities and something I wonder about, if you lay down a prepared soil on top of mine spoil or tailings then in my view you are asking for trouble as you are putting in a very abrupt discontinuity. It would seem safer to disrupt the spoil/prepared soil boundary so that you are producing a soil with less restrictions to root penetration.

TREE NUTRITION

by
T.M. Ballard*

ABSTRACT

Physical and biological, as well as chemical properties of soil are important for tree nutrition. Weathering of minerals can provide many of the nutrients required by trees, but nitrogen must be accumulated almost entirely from precipitation and/or biological nitrogen fixation. The retention of nutrients in soil is enhanced by accumulated organic matter. Infection of tree root systems by mycorrhiza-forming fungi may be essential for good phosphorus nutrition and may also improve uptake of other elements. The trees' gross and net annual requirements for several macronutrients can be estimated approximately. Approximate ranges of desirable soil characteristics for tree nutrition can be estimated. However, in order to specify the soil conditions which will yield maximum tree growth or those which will yield optimum return on a reclamation investment, well designed field trails are necessary.

INTRODUCTION

The objective of this paper is to identify and discuss briefly some aspects of tree nutrition which may be important in reclamation after mining. The intent is not to provide an exhaustive review, but to indicate some major considerations which may be involved. Many of the references to be cited here review the original literature and provide a more comprehensive overview of certain sub-topics.

DISCUSSION

Essential Nutrient Elements

Of the essential mineral elements which the tree derives from the soil, the most important are N, P, K, Ca, Mg, S, Mn, Fe, Zn, B, Cu and Mo (Table 1). Although a few others may be proven essential in trace amounts, they are so unlikely to be deficient that they need no special consideration here. Some elements of no known nutritional value may also be taken up by trees. Both these and the essential elements may be toxic if taken up in greatly excessive amounts. The tree's tolerance to nutrients taken up in excess of need ranges from very slight (e.g. in the case of boron) to very great (e.g. in the case of manganese). Heavy metal toxicity may occur in association with some mine wastes. This problem is common with various metal sulfide ore wastes.

Most of the nutrient elements must be in ionic form in order to be directly available to trees (Table 1). Boron may be the only common exception: undissociated boric acid is quite available and may account for most of the boron taken up by plants growing in acid soils (Bingham et al. 1970). For mycorrhizal trees, certain organic forms of nutrients, e.g. organic phosphates, may also be available.

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* Department of Soils and Faculty of Forestry, University of British Columbia, Vancouver, B.C.

Table 1. Elements essential for tree nutrition and their available forms. Elements listed above the dash line, needed in relatively large amounts, are called "macronutrients". Those below the dash line, needed in small amounts, are called "micronutrients".

N	nitrogen	NH_4^+, NO_3^-
P	phosphorus	$H_2PO_4^-$, HPO_4^{2-}
K	potassium	K^+
Ca	calcium	Ca^{2+}
Mg	magnesium	Mg^{2+}
S	sulphur	SO_4^{2-}
Mn	manganese	Mn^{2+}
Fe	iron	Fe^{2+}
Zn	zinc	Zn^{2+}
B	boron	$H_2BO_3^-$, H_3BO_3
Cu	copper	Cu^{2+}
Mo	molybdenum	MoO_4^{2-}, $HMoO_4^-$

Factors Influencing Nutrient Availability

Most of the nutrient elements become available by weathering of minerals, releasing the elements in soluble form. Nitrogen is a significant exception. Nitrogen in soil parent materials is almost invariably present in extremely small amounts. It accumulates in soil mostly as a result of precipitation inputs (which are normally very small) and/or biological nitrogen fixation. The latter is a process which converts N_2 gas from the atmosphere into ammonium, a form usable by plants (Sprent 1979). Non-symbiotic nitrogen fixation is unlikely to be very significant quantitatively. This is commonly true in reclamation, where soils are usually low in organic matter content. Symbiotic fixation is more important. It occurs is certain lichens, in the root nodules of most legumes, in root nodules of certain non-legumes, in or on the leaves of some plants and in the root zone of a few plants (Sprent 1979). In the temperate zone, nitrogen-fixing bacterial symbionts in root nodules are particularly important, and sometimes account for fixation rates as high as 50 to 300 kg of N per hectare-year (Allison 1975; Cole et al. 1978; Zavitkovski and Newton 1968). In reclamation, legumes such as lupines (Lupinus spp.) and clovers (Trifolium spp.) are well known. Of increasing interest also are several non-legume trees and shrubs, e.g. alder (Alnus spp.), buffaloberry (Shepherdia spp.), ceanothus (Ceanothus spp.), myrica (Myrica gale; Myrica asplenifolia, also known as Comptonia peregrina), and bitter-brush (Purshia tridentata) (Sprent 1979), which are significant in various parts of western Canada. Strongly acid soils limit growth and nitrogen fixation in legumes, but some non-legumes, e.g. alders, are more acid tolerant.

The supply of other nutrient elements in soils is affected by a number of factors, including mineralogy, texture, moisture, acidity and aeration.

The rate of weathering release of nutrients from minerals depends not only on mineral composition, but also on such factors as soil water content, soil temperature and the composition of the soil solution. Acidity and the concentrations of weathering products are particularly important solution characteristics. The texture of the soil can also be significant, because fine textured soils possess a very large surface area, at which the release of elements by weathering occurs. Soil aeration tends to promote biological oxidation of some nutrient forms, e.g. Fe^{2+} to Fe^{3+}, Mn^{2+} to Mn^{4+}, NH_4^+ to NO_3^-, and S^{2-} or S to SO_4^{2-} (Alexander 1977). The oxidation of Fe^{2+} and Mn^{2+} lowers the availability of these elements because Fe^{3+} and Mn^{4+} are very insoluble, tending to form precipitates, e.g. Fe_2O_3 and MnO_2. The conversion of N_4^+ (ammonium) to NO_3^- (nitrate), termed nitrification, is unlikely to occur under extremely acid conditions. Ammonium may be used by all plants and nitrate by most, but for each species, there may be an optimum mixture of the two. Moreover, because NH_3 (ammonia) is toxic and its concentration is proportional to NH_4^+ concentration and increases ten-fold with each unit increase in soil pH, trees growing in near-neutral or alkaline soils may be unable to grow well if all of their N requirement must be supplied as NH_4^+. In nitrification, the nitrate accumulates as nitric acid. The resulting soil acidification is not likely to be very substantial in reclaimed soils because mine waste materials are likely to be too N-deficient for much ammonium to be available for nitrification. The biological oxidation of S^{2-} (sulfide) to SO_4^{2-} (sulfate) may be extremely significant in reclamation of mine waste containing some sulfide ores (e.g. chalcopyrite, sphalerite, pyrrhotite, galena). As oxidation lowers the dissolved sulfide concentration, more of the sulfide mineral dissolves, and the result is an extremely large accumulation of sulfate. The sulfate accumulates as sulfuric acid. In extreme cases, the soil pH may fall to about 1 or 2: far too low for the growth of the most acid-tolerant trees.

Soil acidity influences nutrient availability. Under conditions of low soil pH, such elements as Fe, Mn, Zn, B and Cu tend to be more available than at high pH (Mortvedt et al. 1972). The maximum solubility of soil mineral phosphates is likely to be at about pH 5 to 6. This is mostly because of precipitation as calcium phosphates at higher pH and as various iron, aluminum and manganese phosphates at lower pH (Brady 1974).

Reactions involving soil organic matter may influence availability of many nutrients. Nutrients may be immobilized, i.e. incorporated in organic molecules (principally by soil microbes) or mineralized, i.e. released in mineral form by the decomposition of organic forms. An important example involves nitrogen. The microbes decomposing the wood, which has a low N concentration, not only re-immobilize the N which they release through mineralization; they also compete with crop plants for other available N. (The competition may be low if the wood waste is not mixed into the mineral soil. The severity of the problem will be great if the wood waste is finely divided, offering a large surface area for microbial attack.) If the wood residues are composted before application, decomposition results in loss of C as CO_2, and consequent lowering of the C/N ratio. When well composted organic residues are applied to the soil, their N concentration has become high enough that the decomposers obtain more than enough N from them, enabling net mineralization, which provides plants with available N. Similar considerations may apply to several other nutrients. However, the N relationships are often of the most practical importance so far as mineralization and immobilization are concerned.

Nutrient Transport to Tree Roots

Mass flow and diffusion are the most important physical processes responsible for transporting nutrients in the soil to the tree roots (Ballard and Cole 1974; Nye and Tinker 1977). Mass flow is the passive transport of dissolved (or suspended) substances in flowing water. It is simply the product of water flow and the substance concentration in the water. The flow of water toward the roots is controlled almost entirely by factors implicated in transpiration: atmospheric demand factors (e.g. air dryness) and evaporative energy factors (e.g. net radiation), resistance to water flow through the soil and the plant, and soil water potential. Low soil resistance and high soil water potential promote transpiration. These conditions occur when the soil is wet. Resistance is also reduced by high temperature because of viscosity effects.

Diffusion is the movement of substances along their chemical potential gradients; in an isothermal system, this amounts to movement from a zone of high concentration toward a zone of low concentration. The diffusivity of dissolved nutrients is highest when the soil is wet and warm.

Although high soil temperature tends to enhance both mass flow and diffusion, the optimum temperature for tree root metabolism and growth in probably no higher than about 35°C for most species. Although high soil water content tends to reduce water flow resistance and increase diffusivity of dissolved nutrients, the maximum nutrient uptake for most tree species occurs in unsaturated soils. This is because oxygen diffusion in a saturated soil is too slow to supply oxygen needed for root respiration, and the latter is needed to release energy for "active" uptake of nutrients across the root cell membranes.

Mycorrhizae (symbiotic associations between plant roots and fungi) commonly enhance a tree's uptake of nutrients: especially P, but also others, e.g. N and K. (In some soils, trees lacking mycorrhizae suffer acute P deficiency.) The increase in nutrient uptake occurs partly because the fungus may be able to use nutrient forms (e.g. some organic phosphates) not otherwise available to the plant. However, the fungal hyphae also may reduce some physical limitations in nutrient transport, e.g. by reducing the tortuosity of the transport pathway and by helping to bridge between unsaturated soil and root. This bridging may be particularly significant because of air gaps which develop during dry periods in organic soils, coarse textured soils, and soils containing large amounts of expanding clays. Where trees are planted for reforestation after timber harvesting, natural inoculation by endemic fungi in the soil may be sufficient to provide this kind of nutritional enhancement. On severely disturbed sites, e.g. on lands being reclaimed after mining, the soil parent materials are unlikely to contain or receive sufficient inoculum to enable prompt natural infection. It is, therefore, desirable to ensure that tree seedlings planted in such situations are well infected with mycorrhiza-forming fungi which will be suitable for the tree species, climate and soil conditions of the area being reclaimed.

Nutrient Cycling in Forest Stands

Some aspects of the uptake and cycling of nutrients by forest stands have been estimated for several tree species. Data of Foster and Morrison (1976), for a 30-year-old jack pine stand in Canada, indicate gross net uptake of nutrients by the trees as summarized in Table 2. The amounts would be expected to vary with site productivity. The mean annual net accumulation of organic matter in this pine stand was about 3 t ha^{-1} yr^{-1}. The nutrient uptake data of Table 2 are similar to data of Cole et al. (1967) for a 35-year-old Douglas fir stand on a medium site, except that the latter stand had substantially higher gross and net uptake of potassium. (Neither study involved estimates of nutrient returns from roots to soil.)

A large proportion of the K return from stand to soil occurs as crown wash. A comparison of data from Cole et al. (1967) and Tiedemann, Helvey and Anderson (J.D. Helvey, personal communication), who studied high- and low-rainfall sites, respectively, illustrates that higher K loss from the forest canopy is likely to be characteristic of more humid climates. Annual gross uptake of K must be higher in such climates, if the annual net uptake is to be maintained. Some tree species tend to concentrate certain elements more than others; hence, net annual uptake may differ with species. Nutrient requirements and uptake also vary with stand age. Obviously, an old-growth stand at steady-state has, by definition, zero current annual net uptake of nutrients. Remezov and Pogrebnyak (1967) present data for Scots pine and Norway spruce in the Soviet Union, which closely resemble some of the data from which Table 1 was derived. Their data for hardwood species indicate higher uptake of potassium and/or calcium, in many cases. This is consistent with the high base concentration commonly found in hardwood leaf litter.

Table 2 Gross and net annual nutrient uptake by a jack pine stand. Based on data of Foster and Morrison (1976).

	N	P	K	Ca	Mg
	$kg \cdot ha^{-1} \cdot a^{-1}$				
Gross uptake, all vegetation	32	2.2	18	21	3.2
Gross uptake, trees	26	1.7	15	19	2.7
Net uptake, trees	5.5	0.47	1.1	3.7	0.6

The consistency of such data from various sources suggests that, if adjustments are made for differences in species, site productivity and stand age, one should be able to predict the annual net nutrient uptake of a stand. By adding reasonable estimates of annual nutrient losses from the stand by litterfall, crownwash and stemflow, one can also predict the annual total uptake of nutrients, i.e. the total amount which the soil must supply. (This annual total nutrient uptake prediction is an underestimate, because nutrient returns from roots to soil are neglected. Too few data are available yet to obtain confident estimates of these returns.)

Data from the nitrogen-deficient Douglas-fir stand studied by Cole et al. (1967) may be used to estimate nutrient uptake from the surficial organic layers and underlying mineral soil. The mineral soil root zone is about 60 cm thick; the overlying organic layers total about 1.75 cm in thickness. The former contains about 2800 kg N/ha; the latter, about 175 kg N per hectare. Yet, about 50 percent of the stand's nitrogen uptake is accounted for by uptake from the thin organic layers. This calculation illustrates the considerable nutritional significance which the organic layers may possess where mineral soil is deficient in available nutrients. It suggests the desirability of saving soil organic matter in a thin "first lift" when strip-mining, in order to take nutritional advantage of this material for reclamation purposes. (Whether such a practice is economically optimal will, of course, depend on the nature of alternative available materials, as well as on the cost of handling them.)

In the study in western Washington by Cole et al. (1967), precipitation inputs of N, P, K and Ca in precipitation, in kg $ha^{-1}yr^{-1}$, were 1.1, trace, 0.8 and 2.8 respectively. In the study by Foster and Morrison (1976) at latitude 46°21'N in Ontario, the precipitation inputs of N, P, K, Ca and Mg in kg $ha^{-1}yr^{-1}$, were 7.9, 0.1, 4.6, 5.6 and 0.8. The figures of Cole et al. are presumably much more representative of precipitation inputs from relatively unpolluted air masses. Hence, the accumulation of nutrients from precipitation in mined areas of western Canada is likely to be quite low, unless there are significant inputs of pollutants from various sources upwind. Examples of such inputs are nitrogen from urban sources, sulfur from industrial sources and calcium from calcareous agricultural soil dust.

Of the many soil properties influencing nutrient retention and cycling, soil texture and soil organic matter deserve special mention here. The available nutrient cations (e.g. Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}, Fe^{2+}, etc.) tend to be retained by cation exchange sites associated with clay and organic matter. Where mine waste materials are low in clay content, accumulation of organic matter may be particularly beneficial in this respect. However, regardless of cation exchange properties, organic matter serves as an important reservoir of nutrients which can be gradually released in available form through decomposition. For this reason, as well as for prompt erosion control, it may be desirable to establish a fast-growing herbaceous cover crop at the outset, even where forest cover establishment is the long-term goal. Particularly in the case of very coarse textured materials, the accumulated decaying soil organic matter would assist in retaining soluble, readily leached fertilizer nutrients which could otherwise be subject to serious loss because of low nutrient uptake by slow-growing tree seedlings.

Optimum Soil Properties for Tree Nutrition

Several examples could be found of quantitative soil criteria for growth of trees and agricultural crops. For example, van den Driessche (1979) has suggested appropriate magnitudes of soil chemical properties for the growth of tree seedlings in forest nurseries (Table 3). These magnitudes might be considered nearly optimum for the establishment and early growth of trees in reclamation projects.

Agricultural criteria, as in Table 4 (Alberta Soils Advisory Committee 1979), might also be considered, although they would need some modification. For example, many forest trees grow best at soil pH too low for optimum growth of many agricultural crops, and the heavy metal criteria suggested for agricultural soils are based partly on concerns about toxicity in humans and livestock consuming the crops, rather than just on toxicity to the plants.

It is possible to identify clearly desirable and clearly undesirable magnitudes of various soil properties from the standpoint of tree nutrition. However, between such magnitudes, there is likely to exist a range of magnitudes which may or may not represent limitations to tree growth, depending on the site-specific combination of tree genetic

Table 3 Some soil chemical properties likely to be associated with good conifer tree seedling nutrition. (Based on van den Driessche (1979)).

pH	4.8 to 5.5
Organic matter	3 to 5%
Total N	0.20 to 0.25%
C/N	20 or less
Exchangeable Ca	3 to 8 m.e./100 g
Exchangeable Mg	0.4 to 2.0 m.e./100 g
Exchangeable K	0.2 to 0.3 m.e./100 g
Available P	100 to 150 ppm

Table 4 Some Agricultural Soil Chemical Criteria (Based on Alberta Soils Advisory Committee 1979)

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pH:	<4.5, >9.0: "severe limitations:, 4.5-5.4, 8.6 - 9.0: "moderate limitations"		
electrical conductivity:	<2 mmhos/cm: "no limitations", , 2 - 4 mmhos/cm: "slight limitations: (1 mmho/cm = 0.1 S/m)		
organic matter:	not less than 1.0% in the top 15 cm (about 20 t/ha)		
metals:	As	13	maximum ppm (total)
	Cd	1.4	
	Co	18	
	Cr	56	
	Cu	100	
	Hg	0.5	
	Mo	1.6	
	Ni	43	
	Pb	56	
	Se	1.6	
	Zn	216	
	Al	1	maximum ppm (extractable in 0.01 M $CaCl_2$)
	Mn	20	
wood waste or shavings:	not to exceed 200 t/ha over a 5-year period		

factors, climate and various soil factors. Hence, it may be possible to bracket the biological optimum, but difficult to specify it very exactly. Moreover, the growth response curve to various soil factors flattens as maximum growth is approached. This is one of several reasons why the economically optimum condition may differ greatly from the condition yielding maximum growth. These considerations emphasize the importance and value of reclamation field trials. Mathematical modelling and extrapolations from other areas are useful in defining the range of conditions to be tested, but they can seldom define appropriate operational practices unless confirmed by field trials.

Reclamation Time and Area Constraints

If the general objective is to restore the land, after mining, to its original level of productivity, some detailed specification of time and area constraints is essential. After all, the present level of land productivity in much of Canada can be viewed as the result of natural reclamation after "strip-mining" occurred by glacial action several thousand years ago. Thus, where the reclamation objective is not defined in terms of time constraints, it is difficult to specify how much human intervention is needed to accelerate the natural processes of plant succession and soil formation.

Area constraints are no less problematic. If the objective is to restore the original productivity of mined land, must the original productivity of each hectare be restored? Or merely the original productivity of the area as a whole? The former would be difficult to measure and extremely difficult to achieve. If the latter is sufficient, the rationale is likely to be restoration of lost productivity, regardless of where the restoration occurs. In this case, an equally acceptable, easier and less costly alternative may be merely to establish plant cover (for erosional control, aesthetics, etc.) on the mined lands and to restore the lost productivity through more intensive management of other, unmined lands where the economics are more favorable.

Decisions concerning the area and time constraints are important not only because of their social and economic implications, but because they influence the scope and intensity of feasible reclamation alternatives, including those which affect tree nutrition.

CONCLUSIONS

From this brief overview, it is clear that tree nutrition is complex. Although soil chemical properties are perhaps the most obvious factors in soil fertility, several physical and biological factors influencing tree nutrition and growth, together with the site-specific differences in costs of modifying these factors, make it impractical to specify the necessary, desirable, or optimal magnitudes of soil properties for reclamation purposes. This overview has identified some of the qualitative factors involved, but rather site-specific field trials are needed in order to identify cost-effective combinations of materials and management practices for reclamation where timber production is the objective.

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QUESTIONS

R. Johnson: For Dr. Ballard, I don't have any problems with the kind of general relationships that exist in Agricultural soils. However, after looking through the literature on forest soils, particularly those supporting Jackpine and Aspen, I can understand how things work, but I have difficulty in quantifying soil changes, both chemical and physical.

T. Ballard: That's my problem too. As you say, it's easy enough to qualitatively identify what's going on, but quantifying these processes is hard. It is particularly hard if you try to do so in a predictive way. Extrapolating from different studies and sites to a new condition is virtually impossible. It makes me think that it might be better to come back and ask the plants what's wrong nutritionally, rather than pretend that we can predict very well in advance how well a particular soil material is going to perform.

Qualitatively we can identify limiting factors. We can predict that a particular material will not perform well, but predicting a level of productivity is a very tricky business.

R. Johnson: Even when the stated goal is not a level of productivity, rather to develop a self-maintaining stand, I feel we should be able to specify soil quality criteria.

During your presentation, the only figures I saw were on the cycling of nutrients in a Douglas-Fir stand in British Columbia, and even that lacked probably one of the major components, namely, the rate of nutrient turnover once they are in the soil. I'm worried that we can conceptualize qualitatively very well, but critical data are missing. I wondered if you purposely did that because:

1) you didn't think the information was applicable.
2) you are not sufficiently familiar with the subject.
3) the data simply doesn't exist.

T. Ballard: The data exist, but it is difficult to find a rationale for extrapolating the data to other circumstances. This is particularly so where the objective is to make recommendations upon which management decision will be based.

R. Johnson: But hasn't the behavior of soils been studied sufficiently that we can avoid having to plant our trees in some reconstructed soil mix then wait 10 years to see if it worked or not?

T. Ballard: You do not have to gamble on a large area. Small, controlled test plot areas would suffice. And, I think this test plot stage is just about essential, because of this difficulty with extrapolation. In short, given the errors involved in single-factor analysis and errors introduced by extrapolation, we would be very hard pressed to make any useful predictions.

We really need to do plot work with the materials available for soil reconstruction, evaluate the nutritional problems or perhaps physical problems. These results could then be used to extrapolate in a limited way just with that kind of material. It will take time, but it is likely to be the most fruitful approach.

SOIL BUILDING RESEARCH AT SYNCRUDE USING SELECTED MINERAL SOIL MATERIALS

by

A.W. Fedkenheuer*

ABSTRACT

Consistent with government requirements, the main objective of the Syncrude Canada Ltd. reclamation program is the reclamation of a system to an accepted end land use, with a productivity "equal to or better than" that which was present in the pre-disturbed state. The lack of available information regarding the procedures necessary to permanently reclaim the tailings sand left after extraction of the oil prompted Syncrude to initiate this study in 1977. Four replicated soil amendment treatments were established on a one metre deep experimental area of tailings sand located on the lease area. The plots were subsequently seeded with a grass-legume mix in July 1977. Trees and shrubs were planted in August 1977 and June 1978. Results to date are presented and discussed regarding soil fertility, soil physical parameters, soil moisture limitation to growth, grass-legume top growth and woody plant survival. Comparisons are also made with naturally developed soils and their forest productivity is related to expected productivity of the amended tailings sand.

INTRODUCTION

Surface mining in the Athabasca oil sands deposit creates a variety of disturbed areas. The four basic types of disturbed areas associated with the Syncrude Canada Ltd. project are: water diversion disturbed areas, construction disturbed sites, the tailings pond dike and the mine site (Fedkenheuer and Langevin, 1978). These areas consist of overburden materials varying from sand to clay in texture and also of tailings sand itself.

During mining at Syncrude Canada Ltd., an average of 15 m of overburden is first stripped from over the oil sand layer. Then, the oil sand is stripped, stockpiled and later moved to the extraction plant. To assist in separating the oil from the sand, sodium hydroxide and hot water are added during the extraction process. Subsequently, the sand comes out of the extraction plant with a pH of 8-8.5 (Lesko, 1974). The fertility of this material is inherently low in the major plant nutrients (Takyi et al., 1977).

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* Formerly, Reclamation Research Scientist, Environmental Affairs, Syncrude Canada Ltd., 10030 - 107 Street, Edmonton, Alberta.

Presently, Head, Reclamation Section, Oil Sands Joint Venture, Nova, an Alberta Corporation. P.O. Box 2535, Calgary, Alberta.

It is generally accepted by those involved in oil sands reclamation, that to counter the undesirable properties of tailings sand, organic material (peat), and perhaps mineral soil material, need to be added to the tailings sand. A basic unanswered question is, how much and what kind of materials should be added to tailings sand to ensure successful soil reclamation?

Laboratory studies in the greenhousee (Vaartnou and Sons Enterprises Ltd., 1977), growth room (Massey, 1973) and in lysimeters (McGill et al., 1978) have generally shown that it is not a problem to grow some plants on tailings sand. The amount of moisture and fertilizer which can be added and maintained in the laboratory, make growing grasses a relatively easy task in the greenhouse.

Establishing plants on tailings sand in the field can be more difficult. Results from field experiments conducted by Massey (1973), McGill et al. (1978) and Logan (1978), showed that grass growth on unamended tailings sand was substantially lower than that obtained on tailings sand with peat or peat plus till mixed into it. Lesko (1974) concluded that grasses could be successfully established on unamended tailings sand if the sand was contour trenched to trap moisture.

Syncrude Canada Ltd. is commited to reclaiming systems to accepted end land uses, with a productivity "equal to or better than" that which was present in the pre-disturbed state. These systems are to be consistent with the regional surface hydrology, the natural vegetation and the end land uses of forest cover, wildlife and recreation. In addition, the plant communities are to be permanent self-supporting and maintenance free. This means they must also control erosion.

To attain the goal of equal productivity it must first be determined what the initial productivity of the area is. This is detailed in the environmental impact assessment report by Syncrude Canada Ltd. (1978). A synopsis only is provided in the next section for the vegetation and soils as well as a description of the climate.

DESCRIPTION OF AREA

The climate of the Fort McMurray area is generally cool - temperate, with long, cold winters and short summers, often with only brief periods of 24°C and above. There is a growing season of about 95 days, from late May through August, with an extended period of daylight of over 17 hours during June and July (Kumar, 1979). The total annual precipitation is approximately 44 cm with 30 cm of it recorded as rainfall (Longley and Janz, 1978).

Soils of the Brunisolic, Gleysolic, Luvisolic, Organic and Cryosolic Orders have been identified on the Syncrude project area (Lindsay et al., 1957, 1962; Twardy, 1978). Soil taxonomy follows the Canadian System of Soil Classification (Canada Soil Survey Committee, 1976).

The soils of the area are generally low in productivity (Regier, 1976; Twardy, 1978). The pH values range from strongly acidic to alkaline, nitrogen contents are low except in organic soils and organic matter contents are also low. The soils are non-saline and electrical conductivities are generally under 0.4 mmhos/cm. The cation exchange capacities (CEC) vary with the clay and organic matter contents, with soils of the Brunisolic Order having low CEC values due to their coarse texture and low organic matter contents (McGill et al., 1978; Twardy 1978).

Vegetation in the area falls into the Mixedwood Section of the Boreal Forest Region (Rowe, 1972). *Pinus banksiana* (jack pine) predominates on the Bruinsolic soils, while *Pinus banksiana-Populus tremuloides* (jack pine-trembling aspen) and *Populus termuloides-Picea glauca* (trembling aspen-white spruce) mixtures are dominant on Luvisolic soils. Communities of *Salix* spp. (willows) and *Alnus tenuifolia* (river alder) occupy areas along water courses and the *Picea mariana-Ledum groenlandicum* (Black spruce-Labrador tea) type dominates Organic soils (Syncrude Canada Ltd., 1975; Peterson and Levinsohn, 1977).

Almost one half of the entire Syncrude project area falls into the non-productive forest category of the Alberta Forest Service (Dai and Fedkenheuer, 1979). In its natural state it is unlikely that the majority of the area would ever have been productive for commercial timber.

PROGRAM BACKGROUND

Due to Syncrude's commitment to restore biological productivity on this project area, it initiated tailings sand research in 1975 on the Suncor Inc. tailings pond dyke (Takyi et al., 1977). This research was expanded in 1976, and is currently continuing (Rowell, 1977, 1978, 1979). The general objective is to assess amendment requirements and grass-legume response to the amendments.

In 1977, Syncrude expanded its tailings sand research to level tailings sand areas. The specific study area is located approximately 1 km northeast of the Syncrude plant site. The plot area is exposed to the prevailing south-westerly winds in the summer time, and to the north-westerly winds in the winter time.

An area with a well drained sandy soil (Eluviated Dystric Brunisol) having a water table deeper than three metres was selected for the study. This area was stripped of vegetation and soil well down into the C horizon. Tailings sand was then trucked in from the Suncor Inc. plant in 1977, and spread to a depth of one meter over the well-drained medium sand base (97% sand particles). An attempt was made to match the tailings sand particle size with the base material as closely as possible, to reduce the possibility of build-up of an artificial water table in the tailings sand just above the interface with the base materials. The tailings sand surface was subsequently divided into a series of plots, each six by seven metres, and soil amendment treatments were assigned to each plot using a randomized complete block design. The plot treatments were 10 cm of mineral fines (glaciolacustrine clay), 10 cm of native sand (Eluviated Dystric Brunisol) or 10 cm of lean tar sand (less than 6% bitumen content) applied over the tailings sand. Subsequently, 15 cm of peat was placed over each plot, 50 kg/ha of nitrogen, phosphorus and potassium fertilizer, respectively, were applied and the soil was rotovated to a depth of about 30 cm. All soil amendment materials used were from Syncrude's 25-year mine area.

The soil system was designed to be elevated above the surrounding landscape so it would not obtain surface runoff water from the surrounding area and also to reduce the possibility of ground water affecting the plots. The intent was to simulate a dry soil situation which might occur in the tailings sand placed in the mine after all artificial inputs were discontinued.

The plots were subsequently drill seeded at 10 kg/ha with a grass-legume mixture and then planted with native tree and shrub seedlings which are being monitored twice a year. Details about the performance of the trees and shrubs can be obtained elsewhere (Fedkenheuer, 1979a, 1979b).

All soil materials used as amendments, as well as the tailings sand and the base sand, were sampled prior to covering them up or rotovating them into the various plots. These materials were subsequently analyzed for physical and chemical characteristics by Norwest Soil Research Ltd. of Edmonton. Methods of analysis used follow those of McKeague (1978) and Black (1965).

Soils were sampled for later chemical and physical analysis in fall 1977 following rotovating and also in fall 1978. Soil moisture is being monitored using soil psychrometers and tensiometers. Soil temperature is being monitored down to a depth of 50 cm using thermocouples.

One set of plots (three replicates per treatment) has been fertilized annually and will continue to receive fertilizer on an annual basis. Another set of replicated plots (three replicates per treatment) has not and will not receive fertilizer beyond the initial addition prior to rotovating.

The percent cover and standing crop of grasses and legumes are being assessed by species each fall. Rooting depth of grasses and legumes is evaluated on an irregular basis, with the first evaluation conducted in fall 1979. Shrub and tree survival is assessed each spring and fall. Woody plant heights are also measured each fall.

RESULTS AND DISCUSSION

The material presented in this section covers soil chemical properties, soil physical properties, soil moisture, herbage production and woody plant survival.

SOIL CHEMICAL PROPERTIES

The results of chemical analysis for selected soil characteristics are presented in Table 1. Included are results for the base soil material (peat, mineral fines [clay], lean tar sand and native sand), tailings sand and the tailings sand amended with the different minerals materials and peat. The results for the amended tailings sand are for samples from the zero to 15 cm depth.

The initial overall fertilizer application was apparently still providing sufficient nutrients in 1979 to mask differences between the fertilized and unfertilized plots. As a result, the fertilized and unfertilized plot results within treatments have been averaged together and presented on a yearly basis.

Examination of the pH found in the analyzed materials shows that the base materials varied from a low of 6.3 for the lean tar sand to a high of 8.3 in the clay (Table 1). In the fall of 1977, a couple of months after the peat and other mineral materials were added to the tailings sand, the pH was very close to 7.3 for all treatments, including lean tar sand. By fall 1978, the lean tar sand plots had dropped to a pH of 7.1 and stayed there in 1979.

The highest value of electrical conductivity was reported where lean tar sand was involved. This occurred in the base materials, 1.77 mmhos/cm, and also where it was used as a tailings sand amendment, 1.41 mmhos/cm (Table 1). These values are all considerably below the value of 4.00 mmhos/cm generally considered to indicate potential salt damage to growing plants (U.S. Salinity Laboratory Staff, 1954).

The soil SAR values are all below two (Table 1). This is sufficiently low to have no detrimental effect on physical soil properties. An SAR of six is usually defined as the point at which detrimental effects become noticeable (Alberta Department of Agriculture, 1968).

Exchangeable sodium was highest in the unmixed peat and clay materials, 0.96 and 0.93 me/100 gm, respectively. This translates to 221 and 214 ppm of exchangeable sodium. Once the base soil materials were rotovated with the tailings sand in 1977, the sodium levels dropped to a low of 0.28 me/100 gm on the plots amended with native sand to a high of 0.66 me/100 gm on the plots with peat plus 20 cm of mineral fines.

A little over one year after mixing, the 1978 values all showed an increase in sodium levels (Table 1). The values reported for 1979 decreased to the 0.08 to 0.28 me/100 gm range over the treatments. These sodium concentrations are well below the 2 to 3 me/100 gm that the U.S. Salinity Laboratory Staff (1954) feel may be a critical limit.

Doll and Lucas (1973) suggest that adequate levels of exchangeable potassium, calcium and magnesium are approximately 150 ppm (0.4 me/100 gm), 200 ppm (1.0 me/100 gm) and 50 ppm (0.4 me/100 gm), respectively. These levels are suggested for agricultural crops. Wilde et al. (1964b) recommend about 25 ppm (0.06 me/100 gm), 100 ppm (0.50 me/100

Table 1. Results of analyses for selected chemical characteristics of the base soil materials and the surface 15 cm of tailings sand amended with these base soil materials.

Soil Chemical Characteristic / Soil Material	pH	E.C. (mmhos/cm)	SAR	Exchangeable Cations (me/100 g) Na	K	Ca	Mg	C.E.C. (me/100 g)	Total N (%)	Organic C (%)	C:N Ratio	Org. Matter (%)	Avail. P (ppm)
Base Soil Materials													
Peat	7.5	0.42	1.25	0.96	0.23	27.25	8.23	47.95	0.36	23.36	65:1	40.2	0.0
Tailings Sand	7.5	0.24	0.60	0.25	0.08	1.35	0.77	2.35	0.01	0.20	20:1	0.3	11.2
Native Sand	7.2	0.27	1.80	0.29	0.04	0.45	0.15	1.50	0.01	0.25	25:1	0.4	1.0
Lean Tar Sand	6.3	1.77	0.45	0.33	0.26	2.40	1.57	5.40	0.05	4.80	96:1	8.3	6.5
Mineral Fines (Clay)	8.3	0.40	3.45	0.93	0.40	21.20	4.17	13.10	0.03	1.15	38:1	2.0	2.0
Amended Tailings Sand*													
10 cm Native Sand													
1977	7.3	0.79	0.90	0.28	0.12	12.61	1.78	12.12	0.19	3.77	21:1	6.5	33
1978	7.3	0.51	0.89	0.34	0.08	14.54	2.37	-	-	-	-	-	7
1979	7.3	0.56	0.22	0.08	0.22	9.56	2.45	-	0.19	2.23	13:1	3.8	15
10 cm Lean Tar Sand													
1977	7.3	1.41	0.71	0.35	0.15	10.87	2.58	13.23	0.15	5.03	33:1	8.7	25
1978	7.1	0.82	0.53	0.36	0.11	18.64	3.17	-	-	-	-	-	5
1979	7.1	1.11	0.10	0.06	0.22	8.77	2.39	-	0.16	3.75	24:1	6.5	13
10 cm Mineral Fines													
1977	7.3	0.92	1.71	0.54	0.18	18.18	3.40	16.24	0.19	4.01	23:1	6.9	47
1978	7.4	0.50	1.31	0.60	0.16	28.05	4.05	-	-	-	-	-	5
1979	7.5	0.59	0.37	0.17	0.23	12.26	2.99	-	0.15	2.3	16:1	4.0	9
20 cm Mineral Fines													
1977	7.3	0.86	1.97	0.66	0.21	19.73	3.67	16.05	0.15	3.22	21:1	5.5	33
1978	7.3	0.53	1.50	0.85	0.20	28.23	4.50	-	-	-	-	-	7
1979	7.5	0.63	0.50	0.26	0.30	13.99	3.51	-	0.19	2.90	16:1	5.0	9

* All treatments include 15 cm of peat.

gm) and 25 ppm (0.20 me/100 gm) of potassium, calcium and magnesium, respectively, for field plantations of pioneer species such as Pinus banksiana. For plantations of moderately demanding species like Picea glauca they recommend potassium, calcium and magnesium levels of 50 ppm (0.13 me/100 gm), 250 ppm (1.25 me/100 gm) and 60 ppm (0.5 me/100 gm), respectively. Results of soil analysis of the base soil materials shows the level of potassium ranging from a low of 0.04 me/100 gm for the native sand to a high of 0.40 me/100 gm for the mineral fines portion. Calcium concentrations ranged from a high of 27.25 me/100 gm in the peat, to a low of 0.45 me/100 gm in the native sand. A similar pattern was observed for magnesium. In the amended tailings sand treatments, exchangeable potassium levels showed a slight decline in 1978 on all treatments. In 1979, the concentrations increased and ranged from 0.22 me/100 gm to a high of 0.30 me/100 gm in the 20 cm mineral fines treatment. In 1978, all of the calcium levels increased from 1977, followed by a substantial decrease in concentration in 1979. The 1979 range went from a low of 8.77 me/100 gm for the lean tar sand treatment to a high of 13.99 me/100 gm in the 20 cm mineral fines treatment. Magnesium concentrations followed a similar trend.

The cation exchange capacity of the peat material was substantially higher than any of the other base soil materials, with a capacity of 47.95 me/100 gm. The mineral fines were the next highest at 13.10 me/100 gm. Mixing these materials together in the amended tailings sand treatments served to substantially upgrade the mineral soil materials (Table 1). The range present over the treatments was from 12.12 me/100 gm on the 10 cm native sand treatment to 16.24 me/100 gm on the 10 cm mineral fines material. These levels are more than adequate for forest conditions as Wilde (1958) recommends a range of 7 to 10 me/100 gm for tree nurseries. The levels required for outplanting in a more natural situation would be lower than that.

The percent total nitrogen was low for the base mineral materials ranging from 0.01 to 0.05 percent, and substantially higher for the peat material, 0.36 percent (Table 1). Upon addition and mixing of these materials in the amended tailings sand treatments, the percent total N was increased from 0.15 to 0.19 percent. The results of total nitrogen analysis performed in 1979 indicate that the percentage has been stable over the duration of the experiment, as the range for 1979 was from 0.15 to 0.19 percent. Wilde et al. (1964b), recommend surface total nitrogen contents of 0.04 percent as the minimum level for trees such as Pinus banksiana and a level of 0.10 percent for Picea glauca. The experimental plots have a very adequate supply of total nitrogen at this point. Organic carbon levels appear to be adequate for even more exacting species such as Picea glauca. Wilde et al. (1972), state that satisfactory growth of less demanding species such as Pinus banksiana can be obtained on soils having a minimum of one percent organic matter. They add that more nutrient demanding plants such as Picea glauca exhibit their best growth on soils with organic matter contents near four percent. Multiplying the organic carbon percent by 1.724 gives an approximation of the organic matter content (Black, 1965). Making these calculations gives an organic matter percent range of 5.5 to 8.7 percent on the amended tailings sand treatments in 1977 (Table

1). The values reported for 1979 are somewhat less than for 1978, and cover the range from 3.8 to 6.5 percent, with the lowest values being recorded on the 10 cm of native sand and 10 cm mineral fines treatments.

A balanced carbon to nitrogen (C/N) ratio in the surface 15 cm of an average soil is close to 10:1 to 12:1 (Brady, 1974; Wilde et al., 1972). The C/N ratios in the base materials range all the way from 20:1 to 65:1 for the native sand and peat materials, respectively. These ratios decreased once the materials were mixed, with the 1977 C/N ratios ranging from 21:1 to 33:1, the latter value being reported for the 10 cm lean tar sand treatment. The C/N ratios were determined in 1979, and all ratios had decreased with the range for 1979 going from 13:1 on the 10 cm native sand treatment to 24:1 on the 10 cm lean tar sand treatment. As the C/N ratio decreases, the competition for the available nitrogen by the soil micro-organisms and the plants should decrease and more nitrogen should be available to the plants.

The available phosphorus levels were generally low in the base soil materials (Table 1). They covered the range from zero in the peat material to a high of 11 ppm for the tailings sand material. Upon fertilization and incorporation, these values were increased on the amended tailings sand treatments to a range of from 25 to 47 ppm in 1977. In 1978, values dropped considerably, to a range of 5 to 7 ppm available phosphorus. The values generally were increased over the treatments in 1979, with the range going from 9 to 15 ppm available phosphorus, with the higher values reported for the native sand and lean tar sand treatments. Wilde et al. (1964b) recommended approximately 5 and 12 ppm of available phosphorus for *Pinus banksiana* and *Picea glauca*, respectively. Using this yardstick, the phosphorus levels should be sufficient for the materials being grown on these plots.

SOIL PHYSICAL CHARACTERISTICS

In discussing the moisture contents, the 0.1 bar moisture percentage is used to indicate field capacity. It has been found, generally, to be closely correlated to field capacity of more coarse textured material (Black, 1965). The 15 bar percentage is assumed to be approximately equivalent to the permanent wilting point as reported by Lehane and Staple (1960). The potentially available water is assumed to be that water between 0.1 bar and 15 bars. It should be pointed out that these are not magical figures, and some plants do not adhere to these two moisture percentage levels. However, for the purposes of comparison of one treatment with another, the values should be comparable on a relative basis.

As expected, the moisture content values for the base soil materials are greatest for peat. Its available water percentage is three times greater than for the clay material which has the second highest amount of available water (Table 2). The native sand material has the least amount of available water, at less than one percent. As initial bulk densities were not determined, the values presented in Table 2 are on a weight basis, rather than a volume basis.

Table 2. Results of analyses for selected physical characteristics of the base soil materials and the tailings sand amended with these base soil materials (collected in 1977).

Soil Material	Moisture Content (% by wt.)		Available Water (% by wt.)	Particle Size Analysis (%)			Bulk Density* (g/cc)		
	0.1 bar	15 bars		Clay	Silt	Sand	2 cm	18 cm	38 cm
Base Soil Materials									
Peat	89.0	52.6	36.4	6	24	70	-	-	-
Mineral Fines (Clay)	29.5	13.6	15.9	49	14	37	-	-	-
Lean Tar Sand	16.0	4.4	11.6	6	23	71	-	-	-
Native Sand	1.5	0.6	0.9	1	2	97	-	-	-
Tailings Sand	4.0	1.3	2.7	4	5	91	-	-	-
Amended Tailings Sand**									
10 cm Native Sand									
Fertilized	18.0	9.0	9.0	2	9	89	1.22	1.23	1.43
Unfertilized	18.2	8.7	9.5	2	9	89	1.20	1.28	1.47
10 cm Lean Tar Sand									
Fertilized	26.3	13.3	13.0	6	19	75	0.84	1.14	1.48
Unfertilized	19.0	8.8	10.2	5	17	78	0.98	1.21	1.49
10 cm Mineral Fines									
Fertilized	36.2	16.2	20.0	16	14	70	1.12	1.12	1.46
Unfertilized	21.3	11.5	11.3	17	11	72	1.06	1.29	1.48
20 cm Mineral Fines									
Fertilized	29.8	13.5	16.3	25	15	60	0.96	0.94	1.48
Unfertilized	30.3	13.8	16.5	18	14	68	1.16	1.28	1.47

* Samples collected 25 months after rotovating.
** All treatments include 15 cm of peat.

When the base materials were added to the tailings sand, there was a favorable increase in the potential water-holding capacity of the native and lean tar sand treatments. The resultant available water percentages ranged from an average of nine percent on the native sand fertilized plots to a high of 20 percent on the treatment utilizing fertilizer and 10 cm of mineral fines (Table 2). These values are somewhat higher than were reported by Fedkenheuer (1979c) using the 1/3 bar percentage as the field capacity.

Particle size analysis confirms the sandy qualities of the tailings sand and native sand. Tailings sand has slightly more clay and silt particles than the native sand, while lean tar sand is relatively high in silt content (Table 2).

The rotovating of 10 cm of native sand and 15 cm of peat into tailings sand only slightly changes the proportion of sand particles in the tailings sand, decreasing it from 91 percent to 89 percent (Table 20). Adding the other materials to tailings sand noticeably improves the percentage of silt and clay particles present in the soil mix. The soil texture changes to a loamy sand for the 10 cm native sand plots and to a sandy loam for the other three treatments.

Bulk density samples were collected for the first time in fall 1979, and the results of this analysis are presented in Table 2. Samples were collected from three depths, 2, 18 and 38 cm. The 2 and 18 cm samples were collected from the rotovated or mixed layer, while the 38 cm sample was taken from the tailings sand below. Samples collected from the 2 and 18 cm depths generally were similar for the same treatment, however, there appears to be a difference between fertilized and unfertilized bulk density values, with the unfertilized samples generally having a slightly greater bulk denstiy value than was found for fertilized plots. This may be due to a greater amount of roots present, which make the fertilized plots less dense. The bulk densities for the 2 and 18 cm depths ranged from a low of 0.84 g/cc to a high of 1.29 g/cc. The higher values were generally found on the unfertilized 18 cm sample. The bulk densities at the 38 cm level in straight tailings sand were quite uniform, as they covered a range of only 1.43 to 1.49 g/cc. According to information provided by Wilde (1958), bulk densities greater than 1.75 g/cc for sand and 1.55 g/cc for clay can be expected to possibly prevent penetration of roots. A study by Fedkenheuer (1968) provides an illustration of a sparse, twisted root system from tree seedlings planted in undisturbed clay soils with a bulk density of 1.56 g/cc at 30 cm. The bulk densities reported for these amended tailings sand treatments should not be limiting to penetration of tree roots if they try to move downward in the soil material.

In fall 1979, the thickness of the rotovated layer was again determined to try and evaluate the amount of subsidence over the 26 months following rotovating. The average thickness for all treatments was in the 23 to 25 cm range, except for the 20 cm mineral fines unfertilized plots, where the average thickness remaining was only 20 cm. The range of measurements over all of the treatments went from a low of 18 cm on one of the 20 cm mineral fines unfertilized plots to a high of 28 cm on one of the 20 cm mineral fines fertilized plots. All of the other measurements were in the 20 to 25 cm range. The surface rotovated layer has subsided an average of 3.5 cm over the 26 months for a subsidence of approximately 15 percent.

The maximum grass-legume rooting depths were also determined in fall 1979 (Table 3). This shows the maximum extension of herbaceous roots at this time. Approximately 15 percent of the root mass was observed in the tailings sand below the rotovated layer. The depths to which penetration of roots has taken place is fairly consistent over all of the treatments, as indicated by the average rooting depth range of 38 to 48 cm. The deepest average rooting depth of 48 cm was found on the 10 cm mineral fines fertilized plots and the shallowest average rooting depth of 38 cm was found on the unfertilized 10 cm lean tar sand treatment. In general, the rooting depth ranged from a minimum of 33 cm to a maximum of 51 cm. The percentage distribution was visually observed and no actual measurements were taken, this will be rectified in 1980. However, based on the observations in Table 3, there does not seem to be an inhibition of the rooting of grasses into the tailings sand below the rotovated layer.

HERBAGE PRODUCTION

One measure of soil productivity of the amended tailings sand plots is the amount of above ground plant biomass or herbage produced during the year. The results of the 1978 and 1979 growing seasons are presented in Table 4.

In establishing the plots, an attempt was made to seed an approximately equal number of seeds for each grass species. The resulting percent composition of the seed mix, by weight, was *Agropyron violaceum* - 25 percent, *Agropyron cristatum* - 12 percent, *Elymus innovatus* - 20 percent, *Bromus inermis* - 5 percent and *Poa ampla* - 3 percent. The legume portion of the seed mix consisted of *Onobrychis viciaefolia* - 20 percent, *Astragalus cicer* - 10 percent and *Trifolium repens* - 5 percent.

It is evident in Table 4, that the legume portion of the ground cover is relatively insignificant compared to the grasses. Except for the unfertilized lean tar sand plots in 1978, where the legumes comprised 36 percent of the production, the legume portion never consisted of more than five percent of the production. The production of legumes generally declined in 1979, except in the case of the 20 cm mineral fines unfertilized treatment, where the legume component acually increased. It is evident in the table, that the plant top growth was

Table 3. Results of 1979 field measurements of rotovated surface thickness and the maximum rooting depth of grasses and legumes 26 months after plot establishment.

Soil Amendment	1979 Thickness of Rotovated Layer (cm)		Maximum Grass-legume Rooting Depth (cm)	
	Average	Range	Average	Range
10 cm Native Sand				
Fertilized	24	23-25	41	38-43
Unfertilized	23	20-25	41	36-46
10 cm Lean Tar Sand				
Fertilized	24	23-25	43	38-51
Unfertilized	23	20-25	38	36-41
10 cm Mineral Fines				
Fertilized	25	23-31	48	43-51
Unfertilized	23	20-25	40	33-48
20 cm Mineral Fines				
Fertilized	24	23-28	43	38-51
Unfertilized	20	18-25	42	36-48

Table 4. Air dry weight of herbage produced in 1978 and 1979 on amended tailings sand plots.

Soil Amendment	Plant Top Weight (kg/ha) 1978 Grasses	1978 Legumes	1979 Grasses	1979 Legumes	Change in Total Weight (%)
10 cm Native Sand					
Fertilized	4748	60	892	65	-80
Unfertilized	5282	12	1242	1	-77
10 cm Lean Tar Sand					
Fertilized	2612	58	504	55	-79
Unfertilized	262	148	191	0	-53
10 cm Mineral Fines					
Fertilized	3198	26	1111	10	-65
Unfertilized	3860	128	1094	7	-72
20 cm Mineral Fines					
Fertilized	3676	14	1446	0	-60
Unfertilized	4176	74	876	137	-76

substantially lower than in 1978, as indicated in the last column of Table 4. The percent decrease in total weight on the plots, ranged from 53 percent less on the unfertilized lean tar sand treatment to 80 percent less on the 10 cm native sand fertilized treatment. It is not clear at this point in time why the plant top growth decreased so dramatically in 1979. Possibly, it was due to the shortage of soil moisture which is discussed later in the text.

As was the case in 1978, the lean tar sand unfertilized plots produced the least amount of plant top growth with only 410 kg/ha in 1978 and 191 kg/ha in 1979. The reason for the lower production on the unfertilized lean tar sand treatment is not clear at this time, however, this lower production of herbage is not necessarily detrimental. The end land use of a major part of Syncrude's reclaimed area is to be productive forest cover and the highest survival of trees and shrubs to date has been reported on the unfertilized tailings sand amended with lean tar sand (Fedkenheuer, 1979b). The reduced cover means less competition from grasses for moisture and nutrients.

WOODY PLANT SURVIVAL

The woody plants on this experimental area are being assessed each spring and fall. Only the fall 1978 and 1979 assessment figures are going to be discussed here. The results of the spring 1978 assessment are presented elsewhere (Fedkenheuer 1979b). It should be pointed out that following assessment in the spring of 1978, all dead woody plants were replaced with live plants and also five additional species were planted, *Amelanchier alnifolia*, *Betula pumila*, *Prunus virginiana*, *Salix sp.* and *Shepherdia canadensis*. The spring-planted material was included in the fall assessment. This was done in both spring of 1978 and 1979, thus it is possible to have a larger survival figure for some species for fall than what is recorded for spring.

The fall evaluation of tree and shrub survival was conducted in mid-September of 1978 and 1979. Survival in spring 1978 was generally very good (Fedkenheuer, 1979b), however, a drastic change in survival of woody plants occurred over summer 1978. *Alnus crispa* has shown consistently poor results over the 1978 and 1979 growing seasons as shown in Table 5, with its survival ranging from zero to 44 percent. *Betula pumila*, *Cornus stolonifera*, *Prunus virginiana* and *Shepherdia canadensis* were highly variable over 1978 and 1979 in terms of survival percentages. *Betula pumila* survival averaged from a low of zero on seven of the situations shown in Table 5 to a high of 78 percent on the unfertilized native sand plots. The highest survival for *Cornus stolonifera* was 89 percent on the native sand fertilized plots in 1978 and in 1979 its survival on those same plots has dropped to 22 percent.

Its highest and most consistent survival has been on the lean tar sand treatment, where it has been at a consistent 67 percent survival. *Prunus virginiana* has also shown its best and most consistent success on the unfertilized lean tar sand treatment. *Shepherdia canadensis* responded very well in 1978, however, in 1979 its survival decreased very dramatically to only 33 percent at the upper end of the range, and its survival averaged only 16 percent across all of the treatments.

Table 5. Percent survival of native shrubs and trees planted on amended tailings sand when assessed in fall 1978 and 1979.

Soil Amendment* / Species	10 cm Native Sand				10 cm Lean Tar Sand				10 cm Mineral Fines				20 cm Mineral Fines			
	Fert.**		Unfert.		Fert.		Unfert.		Fert.		Unfert.		Fert.		Unfert.	
	78	79	78	79	78	79	78	79	78	79	78	79	78	79	78	79
Shrubs																
Alnus crispa	44	11	0	11	22	0	44	44	11	22	22	44	0	0	22	0
Amelanchier alnifolia	78	78	89	78	89	67	100	89	100	89	100	78	100	78	89	56
Betula pumila	56	33	78	0	67	0	0	33	56	0	33	44	0	0	33	0
Cornus stolonifera	89	22	11	11	44	11	67	67	22	0	44	56	44	0	56	0
Prunus virginiana	78	44	67	67	56	33	100	100	56	22	78	56	44	11	78	56
Rosa acicularis	100	89	78	78	100	89	100	89	100	67	100	100	78	67	100	78
Shepherdia canadensis	89	0	42	11	100	11	100	33	78	0	89	33	89	11	100	33
Trees																
Larix laricina	8	0	0	0	42	8	58	33	33	0	8	0	0	0	0	0
Picea glauca	42	17	17	33	75	75	83	83	25	33	50	50	42	42	17	25
Picea mariana	33	0	0	0	67	17	83	83	17	0	8	0	25	0	8	0
Pinus banksiana	83	58	92	58	83	83	75	92	58	17	50	67	8	8	33	33
Populus tremuloides	33	8	17	8	42	17	83	83	8	0	0	25	25	8	17	17

* 15 cm of peat was placed over all plots prior to rotovating.
** Fert.= Fertilized in 1978 and 1979. Unfert. = Not fertilized in 1978 or 1979.

Amelanchier alnifolia and Rosa acicularis have consistently demonstrated the greatest ability to survive. They have generally survived well on all treatments, with the lowest survival of 56 percent for Amelanchier alnifolia being recorded on the unfertilized 20 cm mineral fines treatment. The survival rates for Rosa acicularis ranged from 67 to 100 percent across the treatments.

Tree seedling survival also changed substantially over the summer of 1978. The survival rates for Larix laricina in 1978 ranged from zero on most plots, to a high of 58 percent on the lean tar sand unfertilized plots and a high of 33 percent on those same plots in 1979. Populus tremuloides survival was also generally poor over the two periods in question. The survival percentages for 1978 ranged from a low of zero to 83 percent on the plots in 1978 and 1979, with the survival being highest in both years on the lean tar sand unfertilized treatment.

Picea mariana success was also highly variable and covered the range from zero to 83 percent, with the best survival in both years being on the lean tar sand unfertilized treatment. Picea glauca was somewhat better with the survival rates ranging from a low of 17 percent to a high of 83 percent in 1978 and 1979 the high figures for both years also being on the lean tar sand unfertilized treatment. It also showed a relatively good success level of 75 percent in both years on the fertilized lean tar sand treatment. Pinus banksiana showed the most consistent survival rate of any of the tree species as it ranged from 8 to 92 percent success in 1978, with the lowest value being on the 20 cm mineral fines treatment and the highest value being on the native sand unfertilized treatment. For 1979, the survival rate ranged from 8 to 92 percent as well, with the 92 percent rate recorded on the lean tar sand unfertilized treatment in 1979. In another subexperiment, using only 10 cm of mineral fines, Pinus contorta exhibited a 59 percent survival rate in both 1978 and 1979. Elaeagnus commutata, Salix sp. and Vaccinium vitis-idaea showed very poor survival rates in this sub-experiment, with their survival ranging from 17 to 33 percent in 1979 after a survival rate range of 25 to 67 percent in 1978. Potentilla fruticosa and Symphoricarpos albus both exhibited good survival rates in this sub-experiment, with survival rates of 100 and 75 percent, respectively, in 1978 and 92 percent for both species in 1979.

The woody shrubs showing the best survival to this point, are Amelanchier alnifolia, Potentilla fruticosa, Rosa acicularis and Symphoricarpos albus. Examining the data in Table 4 and Table 5 shows that where the grass-legume herbage production was the lowest, the tree and shrub survival was highest. The lean tar sand treatment consistently produced the best survival rates for the woody plant species.

SOIL MOISTURE

Soil moisture appeared to be the main factor affecting woody plant survival on a soil amendment basis. In Table 6, the results of gravimetric moisture determinations taken at several times during 1978 and 1979 are shown in relation to the water content remaining in the soil after application of 15 bars of suction to soil samples in the laboratory. The 15 bar moisture content for each soil amendment was used as the dividing point between unavailable and available water. A negative sign in front of a number indicates a moisture deficit and the number indicates the magnitude of the water deficit on a percent by volume basis. Conversely, a positiive sign preceding the number indicates that water was available to the plant at less than 15 bars of suction and the number indicates the magnitude of the available water surplus.

As shown in Table 6, there was a lack of available water to the plants on July 13 and on August 2, 1978, for the zero to 2.5 cm depth for all amendments and in most cases also at the 25 cm depth. This indicates that if the plants were to be receiving moisture at this time they would have to exert more than 15 bars of suction. By the October 4, 1978 measurement, all of the soil treatments had water which would have been available to the plants. A similar situation occurred in 1979. As shown in Table 6, all of the soil samples collected on July 4 and July 17, 1979, showed a moisture stress situation for plants. By August 7, 1979, all of the soil treatments basically had water available in the surface 2.5 cm at the 15 bar level. However, some of the soil treatments still did not have moisture available at 25 cm at the 15 bar level on August 7, 1979. The treatments in this category were the native sand unfertilized, lean tar sand fertilized and unfertilized 20 cm mineral fines.

Examination of the lean tar sand soil moisture status in relation to the 15 bar moisture content reveals that on the unfertilized plots, moisture conditions appeared to fluctuate less than on most of the other plots. In periods of low amounts of water in the rotovated layer, the lean tar sand treatment shows more water available and conversely, when there was ample water available, as on August 7, 1979, it had less water present than most of the other treatments in the surface samples. This was not true on the same date at the 25 cm depth. This deeper sample on the lean tar sand plots had more water available on that date than most of the other soil treatments.

Examination of the figures in Table 6 shows that almost without exception, the 20 cm mineral fines treatment had a lower amount of water present on a given date than any of the other treatments. This soil treatment also had the highest amount of plant top growth as shown in Table 4.

The importance of weeds, defined as any vegetation growing in a place where it is unwanted, in competing for soil moisture with woody plants in not a new discovery. Wilde et al. (1968), point out the effect of competing vegetation on tree survival and growth. In one of their red

Table 6. The percent soil water in amended tailings sand soils over summer and early fall 1978 and 1979 in relationship to the percent water (by volume) present at 15 bars tension.

Treatment[a]		Percent Soil Water Content in Relation to 15 Bar Water Content (% by vol.)							
		10 cm Native Sand		10 cm Lean Tar Sand		10 cm Mineral Fines		20 cm Mineral Fines	
Sampling Date	Sampling Depth (cm)	Fert.[b]	Unfert.	Fert.	Unfert.	Fert.	Unfert.	Fert.	Unfert.
July 13/78	0 - 2.5	-8.3[c]	-8.3	-9.3	-6.9	-12.6	-9.5	-9.1	-10.5
	25	-5.8	-[d]	-1.4	-0.6	-3.9	-4.2	-5.1	-5.5
Aug. 2/78	0 - 2.5	-5.7	-4.4	-2.6	2.7	-2.0	-5.0	-5.2	-9.0
	25	-6.2	-4.5	-2.6	+4.7	-2.1	+0.2	-6.2	+3.2
Oct. 4/78	0 - 2.5	+17.9	+13.6	+17.0	+11.0	+11.9	+13.4	+7.9	+11.3
	25	+31.3	+0.2	+16.5	+3.3	+0.1	+1.1	+20.4	+3.1
July 4/79	0 - 2.5	-8.5	-7.9	-9.5	-6.7	-13.1	-9.1	-9.7	-12.8
	25	-8.1	-5.6	-5.2	-6.0	-9.8	-6.8	-8.1	-7.9
July 17/79	0 - 2.5	-7.3	-5.6	-6.5	-3.8	11.7	-7.1	-9.7	-11.9
	25	-0.8	-5.6	-5.2	-0.5	-	-5.6	-8.1	-7.0
Aug. 7/79	0 - 2.5	+19.5	+10.3	+13.6	+6.1	-0.1	+10.6	+16.9	+5.2
	25	+0.4	-1.7	-2.3	+5.9	+2.5	+10.9	+1.4	-3.4
Sept. 13/79	0 - 2.5	+12.6	+7.4	+9.9	+14.1	+10.7	+7.4	+6.8	+6.4
	25	+0.4	+3.3	+1.7	+6.1	-4.2	+2.7	+1.4	+5.2

(a) 15 cm of peat was placed over all plots prior to rotovating.
(b) Fert. = Fertilized in 1978 and 1979. Unfert. = Not fertilized in 1978 or 1979.
(c) Minus indicates moisture deficit, plus indicates moisture is available and number indicates magnitude of deficit or availability (15 bar water content was used as the zero point).
(d) No data available.

pine stands, which received early cultivation to control competing vegetation, the average height was 45 ft. at age 28, with a volume of 2,750 cu. ft. of wood/acre. On the uncultivated stand immediately adjacent to it, the trees had attained an average height of approximately 30 ft. and a volume of 1,080 cu. ft./acre, a difference of 1,670 cu. ft./acre. Most of this difference as attributed to the difference in available water (Wilde et al., 1968).

EXPECTED REBUILT SOIL PRODUCTIVITY

The levels of soil chemical and physical factors found in the surface 15 cm of soils in Wisconsin, Minnesota and the oil sands, are presented in Table 7. For the two soils from Twardy (1978), forest cover type designations were assigned based on the author's experience in the area.

The pH levels for the cover types in Table 7 range from 3.8 to 5.5, and all are well below the 7.1 to 7.5 pH range in the amended tailings sand (Table 1). Organic matter contents shown for the Minnesota soils are probably slightly higher than they actually are in the field, as they were determined by the loss on ignition method, which tends to give slightly inflated values (Black, 1965).

Nevertheless, with the exception of the Larix laricina-Picea mariana organic soils, the naturally occurring organic matter contents range from 0.9 to 3.7 percent. This range is below the 3.8 to 6.5 percent organic matter content range reported for the soils being reconstructed on the experimental tailings sand plots (Table 1).

Phosphorus values for the Wisconsin and Minnesota sites ranged from less than one ppm P_2O_5 in the organic soil, to an average of 82 ppm under Betula papyrifera stands (Table 7). For the sandy Pinus banksiana sites, the average P_2O_5 concentration was about 35 ppm. The 1979 levels on Syncrude's experimental amended tailings sand plots ranged from 34 ppm P_2O_5 on the 10 cm native sand treated plots to a low of 21 ppm P_2O_5 on those plots amended with mineral fines (Table 1). It is possible the phosphorus is being tied up in an unavailable form in complex insoluble calcium phosphates (Brady, 1974). Higher levels of phosphorus fertilizer could be applied prior to mixing in amendments. Available potassium concentrations ranged from 27 to 46 ppm K_2O for Wisconsin sites, 90 to 156 ppm K_2O on the Minnesota mineral soils and 154 to 234 ppm K_2O for the Athabasca oil sands soils (Table 7). The range reported for 1979 samples from the tailings sands experimental plots was 86 to 117 ppm K_2O. The tailings sand plot levels of available potassium are adequate for forest growth as they meet the level requirements described by Wilde (1958).

Exchangeable calcium and magnesium levels given for Minnesota soils range from 1.13 to 1.26 g/cc for the mineral soils (Table 7). On the reconstructed tailings sand, soil bulk densities ranged from 0.84 to 1.29 g/cc in the surface 18 cm (Table 2), a very favorable comparison for the amended tailings sand plots.

Table 7. Levels of soil chemical and physical factors in the surface 15 cm of selected forest cover types from Wisconsin, Minnesota and the Athabasca Oil Sands and for the amended tailings sand.

Forest Cover Type	Geographical Location	pH	Org. Matter (%)	Avail. P_2O_5 (ppm)	Avail. K_2O (ppm)	Exch. Ca (me/100 g)	Exch. Mg (me/100 g)	Bulk Density (g/cc)	Silt Plus Clay (%)	Avail. Moisture (% by wt.)
Pinus banksiana[a]	Wisc.	4.9	0.9	11	27	0.64	0.17	-[b]	7	-
Pinus banksiana[c]	Wisc.	5.1	1.8	31	40	1.33	0.26	-	9	-
Pinus banksiana[d]	Wisc.	5.2	1.5	35	46	1.44	0.33	-	10	-
Pinus banksiana[e]	Minn.	5.3	3.1	66	90	2.15	0.75	1.26	22	4.1
Pinus banksiana - *Populus tremuloides*[f]	Atha.O.S.	5.5	1.5	-	154	2.37	0.80	-	13	-
Betula papyrifera[e]	Minn.	5.3	3.5	82	156	2.89	1.01	1.17	38	9.3
Populus tremuloides	Minn.	5.0	3.7	55	102	1.90	0.68	1.13	34	7.5
Picea glauca - *Populus tremuloides*[f]	Atha.O.S.	5.5	1.5	-	234	6.30	2.70	-	67	-
Larix laricina - *Picea mariana*[e]	Minn.	3.8	88.3	<1	0	0.28	0.07	0.12	-	231.1
Amended tailings sand	Atha.O.S.	7.1-7.5	3.8-6.5	21-34	103-140	8.77-13.99	2.39-3.51	1.05-1.23	11-36	9.3-16.4

(a) Wisconsin - Wilde et al. 1964a, Site 45.
(b) No data.
(c) Wisconsin - Wilde et al. 1964a, Site 53.
(d) Wisconsin - Wilde et al. 1968.
(e) Minnesota - Fedkenheuer 1975.
(f) Athabasca Oil Sands - Twardy 1978.

Silt plus clay percentages ranged from 7 to 10 percent for Wisconsin soils, 22 to 38 percent for Minnesota and 13 to 67 percent for Athabasca oil sands soils (Table 7). On the native sand and lean tar sand amended tailings sand treatments, the silt plus clay levels ranged from 11 to 25 percent and on the mineral fines amended plots the range increased to 28 to 40 percent (Table 2). The amended tailings sand compares favorably to the Wisconsin, Minnesota and Athabasca oil sands in the silt plus clay content.

Potentially available moisture percentages, by weight, range from 4.1 to 9.3 percent for the Minnesota soils in Table 7. The levels for amended tailings sand in Table 2 are misleading as the 0.1 and 15 bar reading is used. Data presented by Fedkenheuer (1979c) is based on the 1/3 and 15 bar readings, and show available water precentages by weight, ranging from 6.3 to 13.9 percent for amended tailings sand treatments. These latter values are as good or better than those reported from Minnesota by Fedkenheuer (1975).

The preceding chemical and physical properties of the mineral soil amended tailings sand are all at least as good, and most are better, than the same properties of native soils in Wisconsin, Minnesota and the Athabasca oil sands under forest communities similar to those on Syncrude's mining operation. This is true whether native sand, lean tar sand, 10 cm or 20 cm of mineral fines were added to the tailings sand.

VEGETATION

Examining the growth characteristics of the forest communities growing on the soils presented in Table 7 provides an indication of the growth rates and tree productivity which can be anticipated on soils with similar characteristics in the Athabasca oil sands.

The *Pinus banksiana* stands in Wisconsin were growing at a rate of 30 to 38 cm per year and had produced from 40 to 63 m^2/ha of basal area of wood (Table 8). *Pinus banksiana*, *Betula papyrifera* and *Populus tremuloides* stands in Minnesota were growing at a rate of 48, 42 and 45 cm per year, respectively. Basal area production was 41, 62 and 45 m^2/ha, respectively. The height growth per year for forest communities in the Athabasca oil sands was 35 and 24 cm per year for *Populus tremuloides* and *Picea glauca*, respectively. Basal area production was 26 and 34 m^2/ha, respectively.

The productivity per year, as measured by the average increase in basal area per ha per yr., shows a range of 1.80 to 2.53 m^2/ha/yr. for the Wisconsin forest communities (Table 8). The Minnesota stands were increasing at a rate of 1.58, 1.45, 1.15 and 0.28 m^2/ha/yr. for *Pinus banksiana*, *Betula papyrifera*, *Populus tremuloides* and *Larix laricina-Picea mariana*, respectively. The corresponding yearly basal area increases reported for *Populus tremuloides* and *Picea glauca* communities in the Athabasca oil sands were 0.72 and 0.37 m^2/ha/yr. These latter values are the lowest basal area increase rates of all forest cover types in Table 8, except for the *Larix laricina-Picea mariana* community located in Minnesota.

Table 8. Growth characteristics of selected forest cover types from Wisconsin, Minnesota and the Athabasca Oil Sands.

Forest Cover Type	Geographical Location	Trees (no./ha)	Ave. age (yrs)	Ave. Height (m)	Ht/Age (cm/yrs.)	Ave. Diam. (cm)	Basal Area (m^2/ha/yr)
Pinus banksiana [a]	Wisc.	3066	22	6.7	30	8.6	1.80
Pinus banksiana [b]	Wisc.	2908	24	9.2	38	10.4	2.53
Pinus banksiana [c]	Wisc.	2066	33	12.0	36	12.8	1.92
Pinus banksiana [d]	Minn.	2000	26	12.4	48	11.7	1.58
Betula papyrifera [d]	Minn.	2538	43	17.9	42	11.8	1.45
Populus tremuloides [d]	Minn.	1368	39	17.6	45	13.4	1.15
Populus tremuloides [e]	Atha.O.S.	- [f]	36	12.8	35	-	0.72
Picea glauca [e]	Atha.O.S.	-	92	22	24	-	0.37
Larix laricina - *Picea mariana* [d]	Minn.	4071	87	11.2	13	6.0	0.28

(a) Wisconsin - Wilde et al. 1964a, Site 45.
(b) Wisconsin - Wilde et al. 1964a. Site 53.
(c) Wisconsin - Wilde et al. 1968.
(d) Minnesota - Fedkenheuer 1975.
(e) Athabasca Oil Sands - Peterson and Levinsohn 1977.
(f) No data.

From these productivity comparisons, it can be concluded that, if the appropriate forestry species are utilized and matched with the site, any of the soil amendment treatments discussed in this paper can be expected to be more than adequate for the re-establishment of forest communities previously found on Syncrude's disturbed areas.

SUMMARY

The results of this study to investigate improving tailings sand properties and hasten its development as soil shows that soil materials added to the tailings sand have improved it and the treatments continue to retain that improvement after 2.5 growing seasons.

Soil chemical properties are generally satisfactory. The pH levels are steady and acceptable. Electrical conductivity values are well below harmful levels as are SAR values. Exchangeable sodium has decreased. Exchangeable potassium, magnesium and calcium levels in 1979 increased from the 1978 levels and are satisfactory. The 1979 percent total nitrogen results show that the percentage has remained stable since 1977. Organic carbon levels have decreased, but are still at satisfactory levels. Available phosphorus levels increased in 1979 and should be sufficient for the native plant materials.

Soil physical properties are considerably improved when peat is added to the tailings sand. The available water percentages range from 9 to 20 percent on the amended tailings sand, compared to 2.7 percent on tailings sand alone. Soil texture was improved to a loamy sand on plots amended with native sand and to sandy loam on the other three treatments. Bulk density values ranged from 0.84 to 1.29 g/cc in the surface 18 cm and from 1.43 to 1.49 g/cc at 36 cm, not sufficient to create root penetration problems. Grass-legume roots have penetrated as deep as 48 cm and the rotovated surface has subsided approximately 15 percent over 2.5 growing seasons.

Herbage production in 1978 was over 2600 kg/ha on all plots, except the unfertilized lean tar sand treatment, where it was just over 400 kg/ha. Production dropped by 53 to 80 percent over the four treatments in 1979.

Amelanchier alnifolia, *Potentilla fruticosa*, *Rosa acicularis* and *Symphoricarpos albus* have been the most successful in terms of survival. *Pinus banksiana*, *Pinus contorta* and on some treatments, *Picea glauca* have exhibited the best tree survival. The lean tar sand treatment consistently produced the best survival rates for the woody plant species.

Soil moisture was probably the main factor affecting woody plant survival. A period of moisture stress existed on the experimental plots in summer 1978 and 1979.

Comparison of soil parameters, in terms of plant growth capabilities, on the experimental area with soils in Wisconsin, Minnesota and Athabasca oil sands was generally favorable. Soil nutrient levels and physical factors were as good or better on the experimentally amended plots as on the naturally developed soils.

Forest productivity comparisons of these same stands, with those reported for the Athabasca oil sands, shows better growth rates on somewhat less fertile soils in Wisconsin and Minnesota.

Based on the preceding comparisons, there does not appear to be a need to add more than 15 cm of organic material and 10 cm of mineral material to tailings sand in order to return the area to a state at least equal in productivity to that which existed prior to mining.

This study will be continued over the next few years to determine longer term effects of the treatments employed. The effects of fertilizing and no fertilizing are of special interest, as is the organic matter content.

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SOIL AND ROOTING DEPTH PATTERNS IN NORTH EAST ALBERTA

by

GEORGE J. KRUMLIK*

ABSTRACT

A project with an objective to develop ecological classification of forested land in Alberta has been undertaken jointly by the Alberta Forest Service and the Canadian Forestry Service. As a part of this project, description of soils and vegetation, including rooting patterns, were obtained in north east Alberta.

Fourteen types were tentatively recognized in north east Alberta, with mean depth of soil from 36 cm to 96 cm, mean rooting depth from 20 cm to 80 cm. The relationship between soil depth and tree growth appears to be rather loose; other soil parameters, such as soil moisture regime, soil texture and structure, pH, mineral composition of soil particles and soil temperature regime appear to strongly influence tree growth. This relationship shall be quantified after data analysis is completed.

INTRODUCTION

The data on soil and rooting depth patterns in north east Alberta were collected as a part of a project on ecological classification of forested land in Alberta. This project has been undertaken jointly by the Alberta Forest Service and the Canadian Forestry Service, with an objective to develop an ecologically sound classification system which will be used in forest management (Kojima and Krumlik, 1979).

Forty sample plots were established in the Fort McMurray Forest District during the summer, 1978. Sample plots were located subjectively in well developed, mature, homogeneous forest types, which were located either by a road or within walking distance from fire lookouts or air strips. The size of sample plots was from 0.01 ha to 0.06 ha. The size was determined mainly by tree density. It was our objective to have at least 25 trees on each plot to get reliable information on tree biomass and growth. Besides tree mensuration, a complete list of plant species was made on each plot and a soil pit was dug to prepare descriptions of soil profiles and take soil samples for physical and chemical analysis. As a part of soil profile description, soil depth and rooting depth were recorded. However, only one measurement on soil depth and rooting depth was taken on each plot. No attempt was made to determine variability within a plot.

* Formerly: Canadian Forestry Service, Northern Forest Research Centre
5320 - 122nd. Street, Edmonton, Alberta

Present: Norwest-Priva Plant Laboratories Inc., #203, 20771
Langley Bypass,
Langley, B.C. V3A 5E8

Soil samples for physical and chemical analysis were obtained from each horizon. Samples were analyzed for particle size distribution, pH, total N, extractable P, %C, CEC, and base saturation. Results of these analyses can be obtained from the Northern Forest Research Centre in Edmonton, Alberta.

The analysis of data from the 1978 field season is not completed yet, and therefore, the results presented here are of a tentative nature. Data on soil and rooting depth and on tree growth by plot are presented in Table 1.

RESULTS

Fourteen forest types associated with thirteen soil subgroups were tentatively recognized in north east Alberta. Their soil characteristics and tree growth are briefly discussed in this section.

1.1 Jack pine - bearberry - lichen forest type.

Dominant tree species is Jack pine. Characteristic species in understory vegetation are *Arctostaphylos uva-ursi* (L) Spreng, *Vaccinium vitis-idaea* L. var-*minus* Lodd., and lichens (*Cladonia* spp. and *Cladina* spp.).

Soils associated with this type were classified as Eluviated Dystric Brunisol and Orthic Regosol. Average soil depth was 60 cm (range 48-77 cm), average rooting depth was 42 cm (range 10-62 cm), LFH layer was very thin, 1 to 5 cm. Soils were coarse textured, sand up to 99%, clay 1% to 5%. It is a very dry, poorly productive forest type with low timber volume and low mean annual increment.

1.2 Jack pine - bearberry - bog cranberry - moss forest type.

Dominant tree species is Jack pine. Characteristic species in understory vegetation are *Arctostaphylos uva-ursi*, *Vaccinium vitis- idaea*, *Geocaulon lividum* (Richards) Fern., *Linnaea borealis* L. var. *americana* (Forbes) Rehd., moss (*Pleurozium schreberi* [Brid.] Mitt.), and lichens (*Cladonia* spp. and *Cladina* spp.). Lichens in this forest type have considerably smaller cover values than in the previous type.

Soils associated with this type were classified as Eluviated Dystric Brunisol. Average soil depth was 35 cm (range 30-41 cm), average rooting depth was 31 cm (range 30-32 cm), LFH layer was thin, 3-6 cm. Soils were coarse textured, sand up to 93%, clay 2% to 3%.

This forest type is also poorly productive with low timber volume and low mean annual increment.

TABLE 1 - SOIL AND ROOTING DEPTH IN RELATION TO TREE GROWTH IN NORTH EAST ALBERTA

FOREST TYPE	SOIL SUBGROUP*	PLOT NO.	AVERAGE DEPTH LFH cm	SOLUM cm	ROOTING cm	AVERAGE TREE DBH cm	H m	VOL m^3	MAI $m^3 h.ha^{-1}$	TREE AGE YEARS
1.1 Jack pine - bearberry lichen	E.DYB	1821	2	62	62	11	11	74	2.2	33
	O.R	1823	3	0	10	12	10	82	0.6	129
	E.DYB	1826	5	77	40	20	17	168	1.5	111
	E.DYB	1839	1	62	44	15	11	58	1.5	41
	E.DYB	2829	1	48	48	11	8	29	1.0	30
	E.DYB	2832	3	49	49	10	9	77	1.1	73
mean			2.5	60	42	13	11	81	1.3	70
range			1-5	48-77	10-62	10-20	8-17	29-168	0.6-2.2	30-129
1.2 Jack pine - bearberry-bog cranberry - moss	E.DYB	1825	6	41	32	16	14	145	1.2	113
	E.DYB	2835	3	30	20	18	11	106	0.8	90
mean			4.5	36	31	17	12	125	1.0	102
1.3 Jack pine - alder - bog cranberry - moss	E.DYB	1828	4	69	40	12	13	108	1.2	68
	E.DYB	1830	6	76	80	12	13	208	2.4	84
	E.DYB	1933	3	91	91	17	14	271	3.3	80
	O.HFP	2840	7	41	41	9	10	98	1.0	99
mean			5	69	63	12	12	171	2.0	83
range			3-7	41-91	40-91	9-17	10-14	98-271	1.0-3.3	68-99

* For abbreviations of soil subgroups see the Canadian System of Soil Classification (1978)

Table 1 cont'd

FOREST TYPE	SOIL SUBGROUP	PLOT NO.	AVERAGE DEPTH LFH cm	SOLUM cm	ROOTING cm	AVERAGE TREE DBH cm	H m	VOL m^3	MAI $m^3 h.ha^{-1}$	TREE AGE YEARS
1.4 Jack pine - bog cranberry	E.DYB	1829	3	93	50	12	12	127	1.4	89
- twinflower - feathermoss	E.DYB	2834	12	100	45	10	12	97	1.3	72
mean			7.5	96	48	11	12	112	1.3	80
3.1 Aspen - low-bush cranberry - wild sarsaparilla	CU.R	1832	5	80	80	19	28	421	8.0	49
3.2 Aspen/paper birch - low-bush cranberry - stiff club - moss - wild sarsaparilla	O.HFP	2830	4	67	67	17	13	126	0.9	90
	O.HFP	2831	5	39	39	- - - - - - missing data - - - - - - -				
mean			4.5	53	53					
4.1 White spruce - moss	E.DYB	1836	12	98	70	21	21	416	3.3	108
	E.DYB	1822	11	82	30	11	11	73	0.6	125
	E.DYB	1824	6	59	59	24	16	270	1.4	191
	O.R	1831	1	0	80	22	23	303	4.3	70
	E.DYB	1834	12	72	60	26	22	612	4.5	139
	E.DYB	2828	13	35	45	26	26	440	2.7	140
	GL.GL	2841	10	55	45	21	21	589	4.4	117
	E.DYB	2842	10	69	60	21	19	430	3.4	116
	E.DYB	2836	8	38	38	33	27	382	2.1	119
mean			9.2	63	54	23	21	391	3.0	125
range			1-13	35-98	30-80	11-33	11-27	73-612	0.6-4.5	70-191

Table 1 cont'd

FOREST TYPE		SOIL SUBGROUP	PLOT NO.	AVERAGE DEPTH LFH cm	SOLUM cm	ROOTING cm	AVERAGE TREE DBH cm	H m	VOL m^3	MAI $m^3 h.ha^{-1}$	TREE AGE YEARS
4.2	White spruce - low-bush cranberry - wild sarsaparilla - feathermoss	O.GL	1837	10	93	70	35	24	916	5.4	137
		O.R	1838	14	0	65	34	28	973	7.1	129
		D.GL	2846	8	63	50	24	28	347	3.3	104
	mean			11	78	55	31	27	745	5.3	123
	range			8-14	63-93	50-70	24-35	24-28	347-916	3.3-7.1	104-137
4.3	White spruce - low-bush cranberry - blue joint grass - feathermoss	O.GL	1841	13	75	40	22	16	400	4.4	80
4.4	White spruce - horsetail feathermoss	CU.R	1835	20	0	30	23	21	542	4.7	114
		O.EUB	1840	22	50	17	23	21	916	5.4	164
	mean			21		23	23	21	729	5.0	139
5.1	Black spruce - Labrador tea - bog cranberry - feathermoss	E.DYB	2833	7	57	45	10	10	60	0.9	67
		E.DYB	2837	14	40	35	18	17	366	2.1	171
	mean			11	48	40	14	14	213	1.5	119
5.3	Black spruce - horsetail - feathermoss	THU.OC	2839			20	9	10	98	1.0	99

Table 1 cont'd

FOREST TYPE	SOIL SUBGROUP	PLOT NO.	AVERAGE DEPTH LFH cm	SOLUM cm	ROOTING cm	AVERAGE TREE DBH cm	H m	VOL m^3	MAI $m^3 h.ha^{-1}$	TREE AGE YEARS
5.5 Black spruce - Labrador tea - Sphagnum moss	FI.OC	1827	-	-	25	14	12	73	0.8	101
	HU.OC	2838	-	-	30	*	*	*	*	*
	T.H	2843	-	-	75	*	*	*	*	*
	HY.M	2844	-	-	61	11	10	135	1.4	98
mean			-	-	48	-	-	-	-	-
range			-	-	25-75	-	-	-	-	-
6.1 Balsam fir - moss	O.GL	2845	14	61	61	20	19	553	5.6	92

* Trees over 5 m in height are not present

1.3 Jack pine - alder - bog cranberry - moss forest type.

Dominant tree species is Jack pine. Characteristic species in shrub layer is Alnus crispa (Aib.) Pursh. (cover up to 75%), in herb layer are Vaccinium vitis-idaea, Arctostaphylos uva-ursi, and moss (Pleurozium schreberi). Lichens are scarce.

Soils associated with this type were classified as Eluviated Dystric Brunisol, and Orthic Humo-Feric Podsol. Average soil depth was 69 cm (range 41-91 cm), average rooting depth was 63 cm (range 40-91 cm), LFH layer was thin, 3-7 cm. Soils were coarse textured, sand 67%-97%, clay 1%-8%.

It is a poorly productive forest type, with low timber volume and low mean annual increment. Tree growth is slightly better than on previous two types due to presence of alder.

1.4 Jack pine - bog cranberry - twinflower - feathermoss forest type.

Dominant tree species is Jack pine. Characteristic understory species are Vaccinium vitis-idaea, Linnaea borealis, and moss (Pleurozium schreberi), (cover up to 80%), and Hylocomium splendens (Hedw.) B.S.G. Lichens are absent.

Soils associated with this type were classified as Eluviated Dystric Brunisol. Average soil depth was 96 cm (range 93-100 cm), average rooting depth was 48 cm (range 45-50 cm), LFH layer was thin to medium thick, 3-12 cm. Soils were coarse textured, sand 72%-97%, clay 1%-2%. This is also a poorly productive forest type, with low timber volume and low mean annual increment.

*3.1 Aspen - low-bush cranberry - wild sarsaparilla forest type.

Dominant tree species is aspen. Characteristic understory species are Viburnum edule (Michx.) Raf., and Aralia nudicaulis L. Soils associated with this type were classified as Cumulic Regosol. Soil depth was 80 cm, rooting depth was the same. LFH layer was thin, 5 cm. Soil was coarse textured, 71%-97%, clay 1%-13%.

This is a highly productive forest type on alluvial terrace with very high mean annual increment.

3.2 Aspen/paper birch - low-bush cranberry - stiff club-moss - wild sarsaparilla forest type.

Dominant tree species are aspen and paper birch. Characteristic understory species are Viburnum edule, Lycopodium annotinum L. and Aralia nudicaulis.

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* Numbering of forest types is not continuous since not all types tentatively recognized in the boreal part of Alberta were present in north east Alberta.

Soils associated with this forest type were classified as Orthic Humo-Feric Podsol. Soil depth was 53 cm (range 39-67 cm), rooting depth was the same. LFH layer was thin, 4-5 cm. Soil was coarse textured, sand 75%-85%, clay 1%-10%.

This is a poorly productive forest type with low mean annual increment.

4.1 White spruce - feathermoss forest type.

Dominant tree species is white spruce, often with admixture of black spruce. Characteristic understory species are Cornus canadensis, Linnaea borealis, and thick carpet of moss (Hylocomium splendens, and Pleurozium schreberi).

Soils associated with this forest type were classified as Eluviated Dystric Brunisol, Orthic Regosol, and Gleyed Gray Luvisol. Soil depth was 63 cm (range 35-98 cm, rooting depth was 54 cm (range 30-80 cm). Average thickness of LFH layer was 9 cm (range 1-13 cm). Soil was coarse to medium textured, sand 45%-90%, clay 2%-25%.

This is a productive forest type, with medium to good timber volume and medium to good mean annual increment.

4.2 White spruce - low-bush cranberry - wild sarsaparilla - feathermoss forest type.

Dominant tree species is white spruce. Characteristic understory species are Viburnum edule, Aralia nudicaulis, and well developed layer of moss (Hylocomium splendens, and Pleurozium schreberi).

Soils associated with this forest type were classified as Orthic Gray and Dark Gray Luvisol, and Orthic Regosol. Soil depth was 78 cm (range 63-98 cm), rooting depth was 55 cm (range 50-70 cm). LFH depth was 8-14 cm. Soil was medium to fine textured, sand 20%-60%, clay 20%-50%.

This is a highly productive forest type, with high timber volume and high mean annual increment.

4.3 White spruce - low-bush cranberry - bluejoint grass - feathermoss forest type.

Dominant tree species is white spruce. Characteristic understory species are Viburnum edule, Calamagrostis canadensis (Michx.) Beauv. Rubus pubescens Raf. and moss (Hylocomium splendens).

Soil associated with this forest type was classified as Orthic Gray Luvisol. Soil depth was 75 cm, rooting depth was 40 cm, LFH depth was 13 cm. Soil was fine textured, sand 22%, clay 32%. It is a highly productive forest type, with high timber volume and high mean annual increment.

4.4 White spruce - horsetail - feathermoss forest type.

Dominant tree species is white spruce with admixture of black spruce. Characteristic understory species are Equisetum sylvaticum L. and E. arvense L., Calamagrostis canadensis, and Carex spp.

Soils associated with this forest type were classified as Orthic Eutric Brunisol and Cumulic Regosol. Soil depth was 50 cm, rooting depth 17-30 cm. LFH layer was thick, 20-22 cm. Soil was medium to coarse textured, sand 15%-60%, clay 5%-27%. It is a highly productive forest type with high timber volume and high mean annual increment.

5.1 Black spruce - Labrador tea - bog cranberry - feathermoss forest type.

Dominant tree species is black spruce. Characteristic understory species are Ledum groenlandicum Oeder, Vaccinium vitis-idaea, and feathermoss.

Soils associated with this forest type were classified as Eluviated Dystric Brunisol. Soil depth was 48 cm (range 40-57 cm), rooting depth was 40 cm (range 35-45 cm). LFH layer was medium deep, 7-14 cm. Soil was medium to coarse textured, sand 40%-80%, clay 2%-28%. It is a poorly productive forest type with low to medium high timber volume and low to medium high mean annual increment.

5.3 Black spruce - horsetail - feathermoss forest type.

Dominant tree species is black spruce. Characteristic understory species are Ledum groenlandicum, Equisetum sylvaticum, feathermoss, and Sphagnum moss (up to 20% cover).

Soil associated with this type was classified as Terric Humic Organic Cryosol. Rooting depth is very shallow, 20 cm, restricted by a frozen layer. It is a poorly productive, non-commercial forest type.

5.5 Black spruce - Labrador tea -- Sphagnum forest type.

Dominant tree species is black spruce. Characteristic understory species are Ledum groenlandicum, Rubus chamaemorus L. and an abundance of Sphagnum moss.

Soils associated with this type were classified as Fibric and Humic Organic Cryosol, Terric Humisol and Hydric Mesisol. Rooting depth is restricted by either frozen layer or soil water level and is highly variable, 25-75 cm. It is an extremely poorly productive, non-commercial forest type.

6.1 Balsam fir - moss forest type.

Dominant tree species is balsam fir. Characteristic for understory is a thick carpet of mosses, dominated by *Hylocomium splendens*.

Soils associated with this type were classified as orthic Gray Luvisol. Soil depth was 61 cm, rooting depth was the same. LFH layer was 14 cm thick. Soil was medium textured, sand 40%-57%, clay 21%-33%. It is a highly productive type, with high timber volume and high mean annual increment.

DISCUSSION

Soil depth is just one out of many important soil parameters determining tree growth and cannot, therefore, be considered alone. Other soil factors equally important for tree growth are: 1. soil moisture regime, 2. soil texture and structure, 3. mineral composition of soil particles, 4. soil pH, 5. amount of soil organic matter, and 6. soil temperature regime.

In other words, the quality of soil is at least as much or more important than the quantity, and this becomes obvious by comparing soil depth and mean annual increment of the above listed forest types. Soil depth of some forest types is within a 10 cm range, yet mean annual increment is 2 to 3 times higher (forest types 1.1 and 4.1).

Tree rooting depth depends on soil depth, soil moisture regime, soil aeration, soil temperature regime, and availability of macro- and micronutrients. Rooting depth is also species specific, different species produce a rooting system of a different shape.

Soil parameters most susceptible to change by mining and soil reclamation are soil moisture regime, soil structure, soil pH, and amount of soil organic matter. In some mining operations, toxic elements may be accumulated in tailing deposits.

Future research should quantify the relationship between the above mentioned crucial soil factors and forest productivity in north east Alberta and also determine how changes in important soil factors would influence forest productivity.

CONCLUSIONS

From the observations collected in north east Alberta, the following conclusions were derived:

1) Soil depth is a highly variable parameter, which alone is a poor indicator of forest site productivity. Additional soil parameters, such as soil moisture regime, texture and structure, mineral composition of soil particles, pH, amount of organic matter, and soil temperature regime have to be considered in evaluation of forest site productivity.

2) Plant rooting depth does not appear to be determined by soil depth only. Other factors strongly influencing rooting in north east Alberta appear to be soil moisture regime, soil aeration, soil temperature regime, availability of plant nutrients in soil profile, and characteristic root formation of different plant species.

3) Future research should quantify the relationship between soil parameters determining tree growth and productivity of different tree species in north east Alberta.

LITERATURE CITED

Canada Soil Survey Committee: The Canadian System of Soil Classification. Research Branch, Canada Department of Agriculture, 1978.

Kojima, S. and G.J. Krumlik. 1979. Biogeoclimatic classification of forests in Alberta. For Chron. 55(4): 130-132.

QUESTIONS

R. Johnson: How can you say that in one case enhanced productivity is due to seeping water, and in another case it isn't? Do you have any quantitative data to indicate when seepage water has ehnanced production and how significant the enhancement might be? In short, it seems you are assuming quite a bit here about seepage water.

G. Krumlik: In most cases, seeping water increases productivity of a site. The increase in productivity does not happen when the seeping water is so slow that it resembles stagnant water rather than seeping water and productivity is then limited by reduced soil aeration.

We do not have quantitative data to demonstrate enhancement of productivity due to seeping water. Quantitative evaluation of soil moisture regime and tree productivity shall be researched in future.

FOREST-SOIL RELATIONSHIPS IN WESTERN ALBERTA AND RECONSTRUCTION OF FOREST SOILS IN RECLAMATION

By

W.D. Holland and Ian G.W. Corns*

I GENERAL

Reclamation of disturbed land to a level of productivity equal or greater than what which existed prior to disturbance, requires a plan before industrial activity begins. The appropriate natural resource inventory will quantify the kinds and amounts of materials available to be managed and the ecological variations present before disturbance. It also provides information on the distribution of renewable resources and an insight into forest-soil relationships and the interpretations for future land use. The materials handling plan requires a decision on what product is appropriate after disturbance, the best suited vegetation and animal species, and how the maximum results can be obtained from the available materials and other resources. Once the desired product has been selected and the required substrate (soil, climate, ground-water) has been ascertained, then a suitable materials handling plan can be developed for removal and storage of overburden and substrate and the subsequent reshaping of the landscape to provide the desired product.

There are some useful reviews and summaries of the substrate requirements of trees (Pritchett 1979, Armson 1977), but there is still incomplete understanding of Alberta conditions and ecosystems. Some fundamental obersvations relative to lodegpole pine were made by Duffy (1964) and more recently for lodgepole pine and other species by Corns (1978).

II OBSERVED FOREST-SOIL RELATIONSHIPS IN BANFF AND JASPER

Observation of forest-soil relationships have occurred during the Banff-Jasper ecological inventory. The field work was completed in October 1979, and analyses and reporting are currently underway. Hence, this section reported some single factor relationships, using slides of Banff and Jasper. The air photos indicate that many of the observations made inside the Parks can be extended for considerable distances into the East Slopes.

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* Canadian Forestry Service
Northern Forest Research Centre
5320 - 122 Street
Edmonton, Alberta

III FOREST-SOIL RELATIONSHIPS IN WESTERN ALBERTA (WAPITI SHEET)

In order to restore a forest site to a level of productivity equal or greater than that of the forest on the site prior to mining, it is necessary to have an appreciation of factors that may limit or control the potential forest productivity on that site for a particular tree species in question or conversely, given a particular set of site conditions such as reconstructed "soil", which tree species is best suited and most likely to achieve optimum productivity on that site?

A variety of approaches have been employed to estimate forest growth potential using direct or indirect methods (Rennie 1963, Ralston 1964, Jones 1969). Direct methods of site elevation usually involve establishment of permanent sample plots within mature forest stands and periodic remeasurement of the trees of the sample plot to subsequently calculate growth increments. Indirect methods for estimation of site productivity utilize a related attribute as a criterion. Four attribute groupings may be recognized: climate, ground vegetation, soil properties and foliar characteristics (Rennie, 1963).

This discussion will attempt to demonstrate which soil and site properties are important in determining forest productivity and in determining some common forest types in the western Alberta foothills area. The research reported here today was the basis for a Ph.D. dissertation by Corns (1978), and was conducted in conjunction with a reconnaissance soil survey of the Wapiti may area (Twardy and Corns *in press*).

The direct methods of assessing forest-soils relationships are discussed: 1) Stepwise multiple regression and 2) the forest vegetation type approach.

The multiple regression approach to forest growth prediction as discussed in this paper, was first tested statistically by Coile (1935) and is based upon empirical relations between site attributes and tree growth. Most studies using the multiple regression approach have used soil criteria as independent variables to predict a dependent variable, commonly site index. The conventional soil criteria include pH, available nutrients, moisture regime, texture and soil depth, although virtually any factor can be designated as an independent variable.

This paper considers abundance of understory species and other vegetation related attributes in one multivariate analysis method for prediction of tree growth, viz. stepwise multiple regression. The objective for the inclusion of percent ground cover of individual species and independent variables in addition to some conventional soil and site attributes is to increase the precision of estimates of growth parameters.

Study Area

Location - The study area is in western Alberta, within the Wapiti map area (National Topographic Series 83L) between 118° and 120°W longitude, and between 54° and 55°N latitude, covering an area of approximately 17,500 km^2. It is bordered to the west by the British Columbia boundary.

Surficial Geology and Soils - Both Cordilleran and Keewatin glacial ice covered parts of the study area. The influence of the Cordilleran ice is restricted to terrain that includes one-fourth to one-third of the map area in the south and west (Bayrock, 1972). The remainder of the area was covered by the Keewatin ice sheet in at least two ice advances. Surficial deposits include glacial till of Keewatin and Cordilleran origin occurring as ground moraine, glaciolacustrine silts and clays with bedding, glaciofluvial coarse gravels occurring as river terraces, aeolian sands and recent alluvial deposits. A few small areas of shale, sandstone, coal and conglomerate outcrops are present in the more mountainous areas in the south western portion of the map sheet.

Soils of the Luvisolic, Brunisolic, Gleysolic, Regosolic, Podzolic, and Organic orders of the Canadian soil classification system (Canada Soil Survey Committee, Subcom. Soil Classification, 1978) are represented in the Wapiti map area. The dominant soil subgroups ranked in order of decreasing abundance are Orthic Gray Luvisols, Brunisolic Gray Luvisols, Gleyed Gray Luvisols, Podzolic Gray Luvisols and Orthic Eutric Brunisols.

Methods

1. Stepwise Multiple Regression

Plot areas were selected from Alberta Forest Service forest cover maps (1:126,720) and aerial photographs supplied by the Alberta Forest Service and Proctor and Gamble Cellulose Ltd. These plots encompassed a wide variety of vegetation, soil and landform types within uniform, even-aged and normally stocked stands, ranging from 45 to over 200 years old, with concentration within the modal age classes (70-80 years for the Wapiti map area). Sampling was primarily within the Upper Foothills (B.19c) and Lower Foothills (B.19a) Sections of the Boreal Forest Region (Rowe 1972) and to a much lesser extent in the East Slope Rockies Section (Sa.1) of the Subalpine Forest Region.

Within each sample plot, the soil profile at a representative location was examined and its morphology described according to procedures of the Canada Soil Survey Committee, Subcom. Soil Classification (1978).

Vegetation sampling was done on Circular 0.04 ha plots. Diameters and heights of all trees over 1 cm at breast height (140 cm) were tallied by species. When the tree tally was completed, five to seven healthy dominant and codominant trees, somewhat representative of diameter-height classes in the plot, were felled and sectioned at 0.3 m, 1.4 m and 1.8 or 3.7 m intervals upwards for stem analysis. Tree canopy cover was visually estimated at 12 random points in the centre of the quadrats used for analysis of subsidiary vegetation. Tree basal area was estimated with a Spiegel relaskop.

Tree growth parameters derived from stem data such as mean annual increment in total volume, were computed through the use of a stem analysis program (Pluth and Cameron, 1970). A simple FORTRAN program calculated total volume, merchantable volume, mean annual increment and basal area for the individual plots.

A stepwise multiple linear regression of the abbreviated Doolittle method (Steele and Torrie, 1960), was computed to relate the expression of forest productivity to soil, site and vegetation data collected from the stem analysis plots.

Options within the computer program allowed selection of the dependent and forced independent variables, and deletion of specific variables. If two variables were statistically intercorrelated or had similar known or inferred biological relationships to tree growth, one of the variables would be deleted from regression analysis. Prior to running the stepwise regression program, independent variables were plotted against the dependent variables using a bivariate plotting program. In cases of non-linear relationships, as apparent from an inspection of the bivariate plots, the appropriate linear or non-linear transformation was applied to the independent variable to best approximate a linear relationship. The criterion for the sequence of addition of the independent variables in the multiple regression was the magnitude of the given variables' contribution to R^2. In other words, the greater the contribution to R^2, the greater the correlation of that variable to variations in the dependent variable.

Regression equations presented for lodgepole pine (*Pinus contorta* var. *latifolia*) and white spruce (*Picea glauca*) give the dependent variable as a function of the nine independent variables accounting for the greatest proportion of R^2. The choice of nine independent variables is somewhat arbitrary.

2. Classification of the Forest Vegetation

Subsidiary vegetation, or the forest understory components, were sampled by visual estimates of percent cover by species within height strata. Cover of terrestrial bryophytes, herbs and dwarf shrub species (0.5 m tall) was estimated within 12 randomly-placed 1 x 1 m quadrats; that for shrub cover (0.5 m tall) in 5 x 5 m quadrats centred around the 1 x 1 m quadrats. Tree regeneration density was tallied by species and height class within the 5 x 5 m quadrats for individuals 1.5 m tall. Predominant plot aspects, slope angle, amount of deadfall and evidence of disease were also recorded.

The forest vegetation of the Wapiti map area was classified into 15 forest types on the basis of the dominant tree species, floristic composition and by environment as inferred from soils. The floristic classification was patterned after Braun-Blanquet's methods as described by Meuller-Dombois and Ellenberg (1974) and after a Bray and Curtis (1957) ordination. The concepts of the forest types were developed both during field investigations and after the plots were sampled and the data analyzed. No attempt was made to restrict sampling to certain forest types nor to exclude certain forest types from sampling, though certain forest types are not well represented, particularly those at high elevations.

Results and Discussion

1. Stepwise Multiple Regression

Variables entering the multiple regression equations can be classified as topographic, edaphic or vegetational (Tables 1 and 2). The proportion of the variation in the dependent variable, accounted for by an independent variable, depends upon the individual equation. The sequence for addition of the variables to the equations is according to their contribution to the R^2 value and is indicated in Tables 1 and 2.

Topographic variables used include elevation, slope angle and slope aspect. In general, productivity for lodgepole pine and white spruce is greater at lower elevation, a reflection of more favorable climate. Climate is usually the most important factor in determining forest productivity in Alberta. Both pine and spruce seem to prefer northerly aspects, and moderate slopes where favorable soil drainage is likely to occur.

Edaphic variables include horizon thicknesses, textures, products of thickness and texture, colors, consistence and structure. In addition, soil profile internal drainage is expressed through depth to mottles, drainage class and inferred hydraulic conductivity of the parent material. In general, the edaphic variables that appear to be important to pine and spruce productivity are those that indicate favorable soil moisture regime and conditions for good root penetrability. These factors and their relative importance can be determined from examination of Tables 1 and 2.

Vegetation related variables were introduced into the multiple regression equations in an attempt to increase the precision of the estimate of the dependent variable. The contribution of the vegetational variables to the precision of the regression is apparent (Tables 1 and 2). Independently calculated equations for lodgepole pine and white spruce mean annual increment in total volume (MAI) and site index (SI) at 70 years, indicates that a contribution of up to 0.42 (0.66 vs. 0.24) to the R^2 value in the case of lodgepole pine MAI (Table 1), can be accounted for by vegetation related independent variables. Vegetation-related variables contributed 0.33 to the R^2 value of the white spruce MAI and IS equations (0.86 vs. 0.53 and 0.91 vs. 0.58 respectively) and 0.22 to the R^2 value of the lodgepole pine site index equation (0.71 vs. 0.49).

Table 1 Coefficients of multiple linear regression equations for estimation of mean annual increment in total volume (MAI) and site index (SI) for lodgepole pine. Numbers in parentheses indicate the sequence for addition of the variable in the resepctive equations. Significance at probability levels:

* = .05, ** = .01

Independent Variables	With Vegetation MAI	Variables SI	Without Vegetation MAI	Variables SI
Constant	-14.3	252.5	76.0	343.3
Topographic				
Elevation (m)			-0.00424(3)	-81.6**(1)
Log elevation		-54.7**(1)		
Slope angle (%)				0.217(3)
Slope aspect	38.3*(8)		3.12(5)	
Edaphic				
Thickness Organic Horizon (cm)			-2.18(6)	
Thickness A Horiz. X%(Si+C)			-0.0125(2)	-0.0071(5)
Chroma A Horizon			3.90*(1)	1.55(2)
% Clay A Horizon				
% Clay B Horizon				5.44(7)
Consistence B Horizon	-7.29**(6)	-4.48**(8)		
Value B Horizon	-4.28*(9)	-0.332(9)		
Structure B Horizon			-3.65(4)	
Hue B Horizon				-0.519(4)
Depth to Mottles (cm)	-0.431**(5)			
Drainage class		-4.07**(7)		
Hydraulic Conductivity (cm hr^{-1})				-0.0138*(6)

Independent Variables	With Vegetation MAI	Variables SI	Without Vegetation MAI	Variables SI
Vegetational				
1/log litter cover (%)	-29.6**(1)	-11.9**(2)		
Canopy Cover (%)	0.429**(2)			
Deadfall Cover (%)	0.561**(3)			
Lichen Cover (%)	-1.12**(4)	-0.725**(3)		
Cornus canadensis (%)	0.687**(7)	0.385**(6)		
Rubus pubescens (%)		2.11*(4)		
Regeneration density (stems/ha)		.00406**(5)		
R^2	0.66	0.71	0.24	0.49

Table 2 Coefficients of multiple linear regression equations for estimation of mean annual increment in total volume (MAI) and site index (SI) for white spruce. Numbers in parentheses indicate the sequence for addition of the variable in the respective equations. Significance at probability level: * = .05, ** = .01.

Independent Variables	With Vegetation MAI	Variables SI	Without Vegetation MAI	Variables SI
Constant	2.67	21.1	3.81	15.70
Topographic				
Elevation(m)	-0.007**(4)	-0.004**(1)	-0.008**(2)	-0.004**(1)
Slope angle (%)			1.847*(4)	0.754*(5)
Slope aspect	12.88**(8)	0.918(4)		
Edaphic				
Log thickness organic horiz.			17.74(6)	
Hue B Horizon		0.584(9)	4.977**(3)	1.413(6)
Value B Horizon			9.491(5)	5.191(3)
Chroma - B Horizon				-1.785(7)
Drainage Class		2.320*(5)		
Log hydraulic conductivity (cm hr^{-1})	3.32(1)		12.43**(1)	-3.900*(4)
Stone volume (%)	0.362*(9)			
Vegetational				
1/log litter cover		9.673*(8)		
Canopy cover (%)	1.33**(2)			
Deadfall cover (%)		-1.110**(2)		

Independent Variables	With Vegetation MAI	Variables SI	Without Vegetation MAI	Variables SI
Ledum groenlandicum cover (%)	-5.43**(3)	-1.638**(3)		
Rosa acicularis cover (%)	-9.08**(5)	-1.972*(7)		
Calamagrostis canadensis cover (%)	-47.0**(6)			
Cornus canadensis cover (%)		0.769**(6)		
Regeneration density (stems/ha)	0.03**			
R^2	.86	.91	.53	.58

The Vegetation Variables

Most of the vegetation-related variables used in the regression were expressed as percent cover of individual plant species. Litter, forest canopy, deadfall, total lichen, total moss and total vascular plant cover values were also used. In addition, total tree regeneration was expressed as stems ha^{-1}. Many of the vegetation related variables are likely indicators of soil moisture regime and climate, but the factors controlling the occurrence and abundance of other vegetation related variables are less apparent. It appears that some plant species or other vegetation related variables are better indicators of conditions favorable to tree growth than the soil physical properties used. Of course, one should remember that understory plant distribution is a function of environmental factors in the same manner as is tree growth.

2. Classification of Forest Vegetation

Some relationships between forest vegetation type, productivity and soils are illustrated with the following and examples from Corns (1978). In this section, comments are made where applicable, pertaining to handling during reclamation of the soil material described. An integrated resource inventory, in addition to quantifying the soils and vegetation (and wildlife) resources, can also yield information valuable in determining forest soils relationships that may be very important to consider when reconstructing a forest soil after mining.

1. White spruce/Trailing dewberry - Two leaved Solomon's seal (Picea glauca/Rubus pubescens--Maianthemum canadense).

These white spruce forests occur at low to medium elevations (670 to 1220 m) on generally north-sloping (CSSC slope classes 1 to 6) sites. They are generally young (70 to 140 years) and have well developed shrub and herb understorys. Characteristic species are Lonicera involucrata, Rosa acicularis, Viburnum edule, Rubus pubescens, Maianthemum canadense, Mitella nuda, Cornus canadensis, Linnaea borealis and Petasites palmatus. Cornus stolonifera, Alnus crispa, Alnus tenuifolia and Aralia nudicaulis are often evident in this type, but are seldom seen on the other white spruce types. Hylocomium splendens is the predominant moss. This type can commonly be seen on depressional sites within aspen forest, suggesting that succession advances faster on these sites. The abundance of white and black spruce seedlings and fir seedlings in some stands of this type should ensure perpetuation of this type as well as increased abundance of black spruce and subalpine fir in some stands. Forestry productivity is good (CLI classes 3 and 4 with some examples of site class 2), but appears to be less in the older forests. It is distinguished from the wetter Picea glauca/Equisetum arvense/Hylocomium splendens type by the presence of Maianthemum canadense, lower Equisetum arvense cover, the absence of Carex capillaris, less moss cover and by generally better drained soils.

Soils are moderately well to imperfectly drained Orthic Gray Luvisols, Gleyed Gray Luvisols and Luvic Gleysols on alluvium over lacustro-till, Continental and Cordilleran till. Donnelly, Snipe and Edson are the predominant soil groups. The extensive gullying demonstrates the handling problems that occur with very fine textured materials like those of lacustrine deposits.

2. White spruce/Horsetail/Feathermoss (Picea glauca/Equisetum arvense/Hylocomium splendens).

The white spruce-horsetail forests occur at low to moderately high elevations (670 to 1450 m) on gentle (classes 1 to 4), generally northfacing slopes. The are young to moderately old (80 to 220 years). White spruce and subalpine fir regeneration is common in many of the stands. The understory is herb dominated and a dense Hylocomium splendens cover is present, with lesser amounts of Ptilium crista-castrensis and Pleurozium schreberi. Constant species include Rosa acicularis, Lonicera involucrata, Equisetum arvense, Petasites palmatus, Mertensia paniculata, Mitella nuda, Cornus canadensis, Linnaea borealis and Rubus pubescens. Carex capillaris, an indicator of the moist conditions of this type, is found in approximately one-half of the plots of this type. Forest productivity is variable (class 2 to 5) and appears to be less in the older forests.

Soils are poorly to imperfectly drained peaty Orthic Gleysols, peaty Luvic Gleysols and Orthic, Luvic and Rego Gleysols on Continental till, alluvial and lacustrotill parent materials. Snipe, Smoky and Gunderson are the predominant soil groups. Tree rooting is shallow on these soils, which are difficult to handle when wet.

3. Black spruce/Labrador tea/Cloud berry
(Picea mariana/Ledum groenlandicum/Rubus Chamaemorus)

This type represents the black spruce bog forest vegetation. The bogs occur at low to mid-elevations (915 to 1070 m) in depressions with impeded drainage on level sites, with hummocky microtopography. These open forests are often over 200 years old and can be considered climax. The well developed shrub layer is dominated by Ledum groenlandicum. The herb-dwarf shrub understory is dominated by Vaccinium vitis-idaea, Rubus chamaemorus and Oxycoccus microcarpus. Sphagnum spp. are abundant. Tree cover is sparse and productivity is very low (class 7) and can be considered non-merchantable.

Soils are poorly drained Typic Mesisols and Fibrisols on moss peat parent materials and trees are shallow rooted. Kenzie is the predominant soil unit. Slide 7 illustrates a poorly drained Fibrisol, an organic parent material derived from Sphagnum moss. This material could provide a valuable source of organic matter for reconstruction on mineral soils. Peat depth on these soils may range from less than 1 to over 10 meters.

4. Lodgepole pine/Black spruce/Labrador tea/Tall bilbery
(Pinus contorta/Picea mariana/Ledum groenlandicum/
Vaccinium membranaceum).

The lodgepole pine-black spruce-Labrador tea-Tall bilbery forest type is more extensive than any of the others in the 83L area, and occurs on gently sloping (classes 1 to 5) sites of variable aspect from low to relatively high elevations (840-1465 m). It is characterized by young to fairly old (65-190 years) lodgepole pine and black spruce stands of fire origin. Black spruce forms a tree understory layer of approximately the same age as the pine. Black spruce and subalpine fir regeneration is often abundant, indicating probably eventual succession to these species. Ledum often forms a dense low shrub understory, and herb cover is moderate. Constant species include Ledum groenlandicum, Vaccinium membranaceum, Vaccinium vitis-idaea, Cornus canadensis and Linnaea borealis. A dense feathermoss cover of Pleurozium schreberi and Hylocomium splendens is usual. At the upper limits of type 4, Rubus pedatus is common, and Menziesia glabella, Rhododendron albiflorum, Tiarella trifoliata, and Arnica latifolia are sporadic in occurrence. Forest productivity is moderate (class 5 with a few exceptions).

Soils are moderately well to imperfectly drained orthic Gray Luvisols, Brunisolic Gray Luvisols and "bleached" Gray Luvisols. Edson, Mayberne and Marlboro are the predominant soil units. A moderately well drained Othic Gray Luvisol on clay loam textured moderately calcareous continental till on rolling topography (Edson soil group), is very common in the Alberta lower foothills and would be very susceptible to compaction during soil reconstruction.

5. *Picea engelmannii-Abies lasiocarpa/Menziesia glabella*

The Englemann spruce-subalpine fir-false azalea forests form a climax type, which occurs on steep (classes 5 to 7) north-facing slopes, at high elevations (above 1670 m) in the south west corner of the Wapiti map area. *Menziesia* may form a fairly dense shrub understory, but herb and low shrub cover is generally sparse. Constant species include *Menziesia glabella*, *Phyllodoce empetriformis*, *Vaccinium membranacium*, *Rubus pedatus*, *Pedicularis bracteosa*, *Cornus canadensis*, *Lycopodium annotinum* and *Arnica latifolia*. Tree growth is slow (CLI classes 5 and 6) and stands are usually not suitable for commercial use. The type is species poor and would show a slow recovery after disturbance. Soils are moderately well to imperfectly drained Orthic Gray Luvisols on Cordilleran till. Robb and Copton are the predominant soil groups. Slide 11 illustrates a Brunisolic Gray Luvisol on loam textured non-calcareous Cordilleran till parent material, on rolling topography. This soil (Robb soil group) is very widespread in the Alberta foothills and would be expected to have more favorable handling characteristics than the Edson soil.

Summary

An integrated resource inventory is an effective, efficient means of quantifying soil and vegetation resources and can also provide relationships between (forest) vegetation and soils that may be useful in reconstructing a forest soil environment. A quantitative model of forest growth as a function of the factors that control it should be a useful tool for gaining an appreciation of forest-soils relationships. Such knowledge is prerequisite to a forest-soils reconstruction program.

RECONSTRUCTION OF FOREST SOILS IN RECLAMATION

Review

A. Banff-Jasper Project

Specific benefits of a resource inventory like Banff-Jasper are that it provides information on the kinds of soil and vegetation encountered and their distribution. It also provides an insight into the ecology of the area.

1. The wide range of surficial materials and soils combine with other widely varying environmental components such as climate, topography, aspect, elevation, etc. so that no single factor controls forest growth. Inter-relationships occur among: moisture regime, drainage, soil texure, pH, topography, aspect, elevation, temperature, soil compaction, geologic materials, climate, tree dominance, vegetation type and kind and intensity of use (e.g. grazing, recreation, fire control). The combined result of all of these inter-relationships is that other factors besides soil depth are important in controlling forest and other vegetation growth.

2. There is a problem of relating data to productivity and prediction; that is, what is the relevance of rooting depth to reconstructed soils?

b. Wapiti Sheet

1. Lodgepole pine and white spruce seem to prefer northerly aspects and moderate slopes, where favorable soil drainage is likely to occur.

2. Lodgepole pine and white spruce productivity is largely determined by climate and soil physical properties that determine favorable soil moisture regime and root penetrability.

3. Vegetation-related independent variables account for large amounts of the variability in lodgepole pine and white spruce mean annual increment and site index.

4. A quantitative model of forest growth is a useful tool to develop understanding of forest-soil relationships.

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ACTIVITIES OF THE SOIL QUALITY CRITERIA SUB-COMMITTEE

by

T.M. Macyk*

ABSTRACT

In 1975, the Alberta Soils Advisory Committee formed a sub-committee to develop a statement on soil quality for common agricultural soils. The report, which covered quality criteria only as related to the rooting zone of agricultural soils, or soils that have not been affected other than by normal cultivation practices, was completed and is now available. In 1978, another sub-committee was formed to consider quality criteria in relation to disturbance, reclamation and waste management. The terms of reference of this sub-committee were to develop guidelines relative to:

1) soil mapping and sampling for baseline and post-disturbance activity;
2) overburden sampling;
3) analytical requirements;
4) physical, chemical and biological criteria for evaluating the suitability of soil materials for revegetation;
5) utilization of soil as a medium for waste disposal, including materials such as sewage sludge, animal wastes and fly ash.

The sub-committee was also charged with the responsibility of preparing a glossary of soil terms relevant to the above subject matter, and development of recommendations for future action and research. The guidelines relative to mapping and sampling procedures and for evaluating soil and overburden materials will be presented for each of the Plains, Eastern Slopes and Northern Forest Regions of the province. The sub-committee has compiled information which may be useful to individuals within government and industry. The criteria and guidelines that will be contained in the report are put forth by soil scientists who are concerned about the soil resource of the province and are interested in providing ideas in regard to land use and conservation.

QUESTIONS - Macyk

J. Bondy: What was your criteria for choosing recommended soil depths? Was it based on observation or was it based on the fact that adequate depths depend on moisture regime, climate, soil temperature and even the genetic qualities of the tree itself?

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* Soil Scientist, Soils Department, Alberta Research Council, Edmonton, Alberta

T. Macyk: Basically, we relied on experience and a review of other pertinent work, tempered with a fair amount of practicality.

R. Johnson: I'm concerned that for some reason the weathered part of the geological overburden is considered to be sacred and, therefore, worth conservation above all else. I do not understand the scientific basis for believing that particular part of the overburden material is irreplaceable, and that seems to be the fundamental opinion which governs attempts to choose amounts of required soil or topsoiling. Can you clarify?

T. Macyk: You mean why save topsoil?

R. Johnson: Exactly.

T. Macyk: Topsoil contains those materials that will provide a reclaimable surface on an immediate basis, and probably if one wants to talk about sustained productivity, topsoil is most likely to provide you with the productivity that you want.

R. Johnson: Isn't the question--Are those the only materials?

T. Macyk: No they are not - again, if you go into an area - if you say, shall we pick something from our overburden that is 20 feet down. If you can demonstrate that is going to give you the results that you want, then that is between industry and the Provincial Government.

R. Johnson: How can that be decided between the industry and government if the recommendations are already out that you use a certain measure of topsoil? The doors to the government are closed.

J. Bondy: As part of the Development and Reclamation Review Committee, we will entertain any notion - if you come to us and say we feel that this, because of our mining practices, would be more suitable than the topsoil there, we will listen to you. The doors to the government are not closed.

P. King: The guidelines for the Eastern Slopes at least left that possibility open.

J. Bondy: Yes, it could be a possibility that in some areas, where soil was not available, we've recognized that overburden may be more suitable than topsoil and we've left it open, as approved by the Land Conservation and Reclamation Council.

T. Macyk: We may suggest a certain depth if you have it. If you don't have it, then we look at what you have, and that is overburden, weathered bedrock or whatever you call it, then we look at assessing the properties of those materials for use. What we are saying, is if you have topsoil, save it. Make the best of what you have available.

K. Armson: Are we talking about topsoil in the conventional agronomic sense or are we talking about the solum?

T. Macyk: We, for our purposes in this report, will talk about topsoil, and that is strictly Ah Horizon - organo - mineral material. We don't refer to it as a mixture of the solum.

G. Lesko: In north eastern Alberta, there is practically no Ah Horizon. It would be impractical to try to save it.

T. Macyk: In our report, we're only discussing selective Ah handling in agricultural areas.

G. Lesko: You have mentioned that if there is not suitable soil available from the disturbed site, then you would consider getting the material from other sites. I am not sure what you had in mind.

T. Macyk: I suggested that, for example, if you had steep slopes and 4 to 5 inches of Luvisolic soil within your disturbed area, you may choose not to salvage the soil there. However, you may have drainage course areas, where more of the till may have survived erosion, so in those area, instead of taking only the required depth, one might take off a little more to to make up the shortfall or average out soil depths across the reclamation site. I'm not saying you take the soil from outside disturbed areas.

In our report, we are making suggestions, not hard and fast rules. We would like to standardize the procedure and give everyone an idea of what is expected and how to go about doing it.

DEFINITION OF REQUIREMENTS OF RECONSTRUCTED SOILS IN NORTHEASTERN ALBERTA

by
R.L. Johnson*

ABSTRACT

The objective of this study was to define the properties of soils which would evolve to support mixed wood and jack pine vegetative communities in the oilsands area of Alberta. Furthermore, we were to identify a soil capable of supporting a self-maintaining, erosion controlling vegetation on dike slopes. Our approach is to define the functional aspects of soils in the environment of northeastern Alberta, to describe what factors operate so that soils can supply water and nutrients to the associated plant community.

This study does not include any original data from the author's work; it is a compilation and reinterpretation of previous studies relevant to this area.

The report is comprised of five components:

a) the oilsands environment
b) the plant communities and associated soils,
c) the properties of "starter" soils built with tailings sand,
d) the development of starter soils over time, and
e) the management requirements.

Each of these components are explained in more detail in the following paragraphs. Examples are given to illustrate how the functional analysis of a soil and its associated vegetation can be used to define the reclamation requirements.

INTRODUCTION

The Oilsands Environment

The climatic regime, as part of the oilsands environment, was divided into temperature and precipitation components so that a water balance could be established. Moisture is added to any ecosystem through precipitation (rainfall or snow melt) and lost by evaporation and transpiration. We have applied an evapotranspiration model (Thornthwaite and Mather, 1957) to show the effect that a water deficiency has on vegetation in the oilsands area. Figure 1 shows the relationship of the potential evapotranspiration to a widely fluctuating actual evapotranspiration rate. The changes in actual evapotranspiration correspond to three rooting depths and two levels of available moisture. The difference between the area under a line representing actual evapotranspiration and that of potential evapotranspiration is the amount of reduction in potential plant growth that can be expected under these moisture conditions.

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* Supervisory Soil Scientist, Monenco Consultants Ltd. 900 One Palliser Sq., 125 Ninth Avenue, S.W., Calgary, Alberta. T2G 0P6.

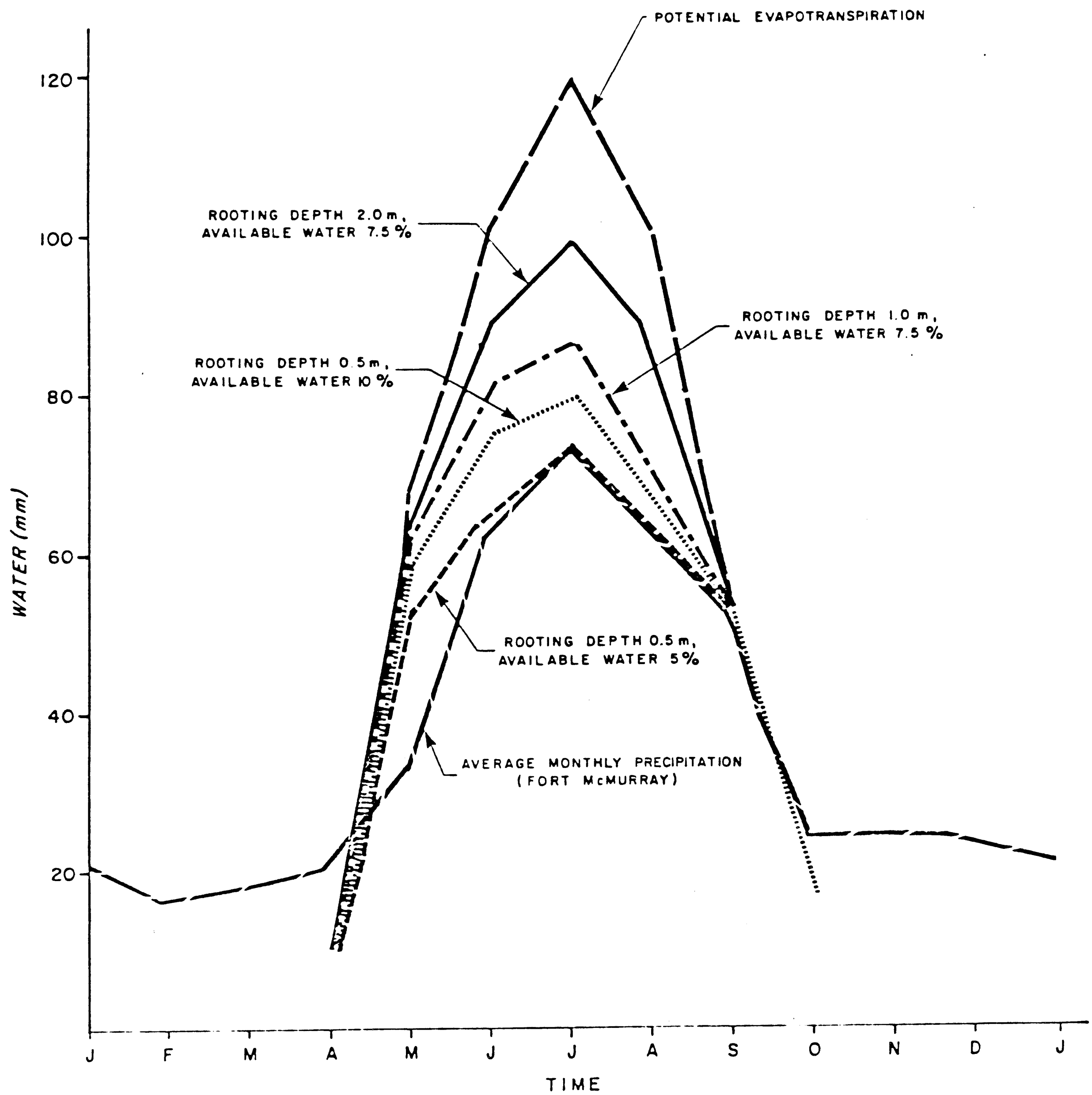

FIGURE 1
AVERAGE ANNUAL PRECIPITATION
POTENTIAL EVAPOTRANSPIRATION
AND ACTUAL EVAPOTRANSPIRATION
(FOR 4 ROOTING CONDITIONS) FOR
THE FORT McMURRAY AREA

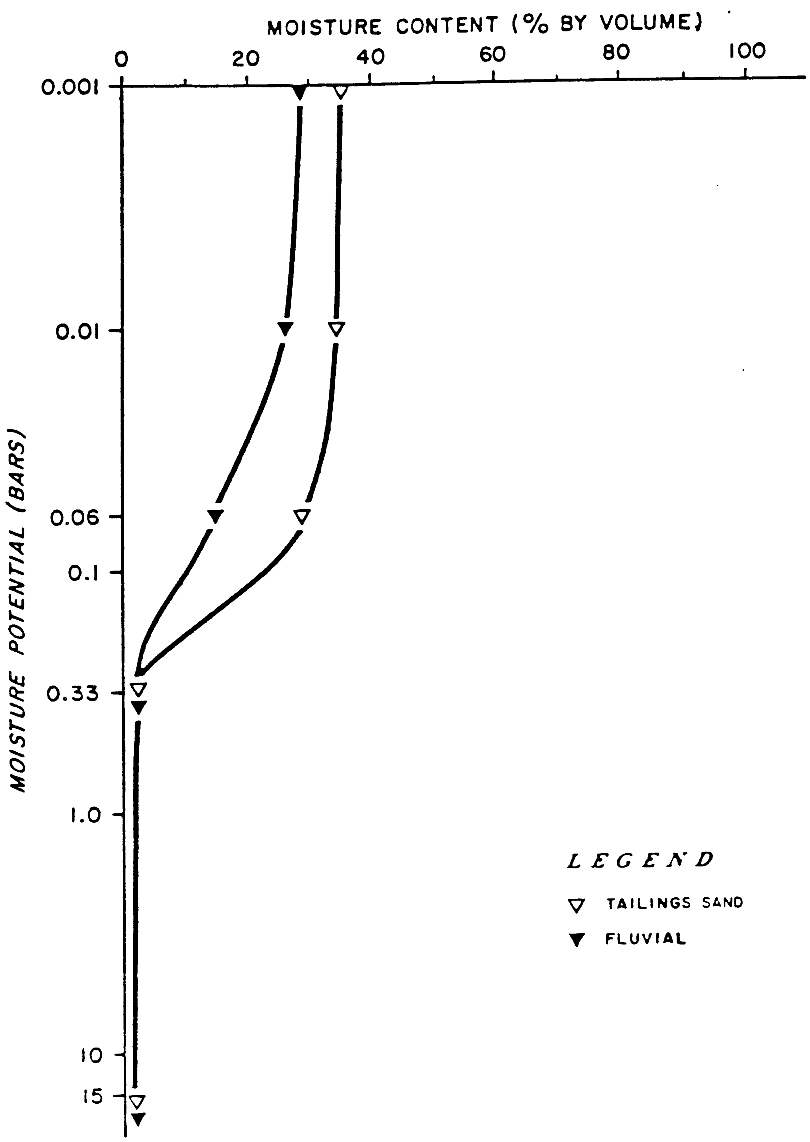

FIGURE 2
MOISTURE-RETENTION CURVES
FOR TAILINGS SAND AND FLUVIAL
SAND (LOGAN 1978)

Rooting depth and available water content of the soils are influential factors affecting the actual evapotranspiration and plant productivity. Figure 2 compares the moisture retention curves of fluvial and tailings sand (Logan, 1978). More importantly, it shows how an incorrect evaluation of soil materials might negatively affect the reclamation procedure. If available water content of sand is estimated as the difference in moisture content at 15 bars and 0.3 bars, these sands have less than one percent available water and are, therefore, completely inadequate as soil building materials. However, when field capacity is measured at 0.06 bars (Van Eck and Whiteside, 1958), these sands contain between 9 and 25 percent available moisture, and can easily supply the water requirements of vegetation in the oilsands area. We have chosen 7.5 percent available moisture as the basis of our calculations because it corresponds to a theoretical calculation and field experience (MacLean, 1980).

A description of the geo-materials which can be used during reclamation are included as a part of the oilsands environment and are represented by the tailings sand, localized peat or muskeg formations, and overburden or unweathered geological deposits occurring above the oilsands. Each of these has been characterized in terms of their physical, chemical and biological properties. Peat can contribute large amounts of organic carbon and nitrogen; overburden has relatively high contents of clay; and tailings sand, as the principle by-product of oil extraction, is an ideal material for situations where high rates of infiltration and hydraulic conductivity are necessary.

DISCUSSION

Plant Communities and Associated Soils

The vegetation and soils of the oilsands area have been included to obtain a baseline assessment of the characteristics needed to achieve an endpoint for a stable ecosystem. An extensive survey of literature written in reference to areas outside the oilsands is used to define the requirements of the various tree species and how the soil functions to provide for them.

Jack pine soils are most easily defined because jack pine itself is adapted to extremely poor conditions of water and nutrient supply. Jack pine has been found growing on a wide range of parent materials (aeolian sands to glacial till) and can tolerate "wet feet" or drought. It requires very little silt and clay in any horizon (<5 percent) and can survive in soils with available water contents as low as four percent. The total water requirement for jack pine in the oilsands over a growing season is estimated at 120 to 150 mm (MacLean, 1980).

The representative tree species of a mixed wood community in this study are narrowed down to white spruce (*Picea glacua*) and aspen (*Populus tremuloides*). These species require a totally different soil than that found under jack pine. The soil must have relatively high contents of silt and clay in the A and B horizons (12-30 percent) which, in turn, have important effects on water and nutrient contents. The available water contents of mixed wood soils are in the range of 10 percent, and total water requirements per season are estimated to be 300-350 mm. Cation exchange capacity and levels of available nutrients are higher for mixed wood than jack pine soils. The organic carbon and nitrogen contents are more variable, comparable to jack pine soils in the amounts.

Properties of Engineered Starter Soil

The definition of the initial requirements of engineered soils, as the third component in this study, has considered soil-water relationships, peat-organic matter transformations and erosion susceptibility as the basic assumptions affecting the reconstruction of all soils in the oilsands area. In other words, the selection of initial properties of an engineered soil is based on a predictive judgement of how they will interact to supply water and nutrients and control soil loss. This illustrates, in practice, the principle of the functional analysis as the basis of reclamation procedure.

Figure 3 shows how the moisture holding capacity of tailings sand can be modified by various peat amendments. When plants' requirements for available water are known, this data provides a quantitative method for selecting the mixture of materials to be used in soil reconstruction.

Figure 4 illustrates the same principle for predicting erosion control on dike slopes. Based on calculations from the Universal Soil Loss Equation (USLE), one can estimate the interacting effects of mulches vs. no mulch (P), soil erodibility (K), a cropping factor (C), slope gradient (S) and length (L), and rainfall events (R). In this case, a combination of grass establishment and peat application were the only treatments on dike slopes which theoretically reduced erosion to less than 37 tonnes of soil loss per hectare, an amount which represents serious environmental damage.

Soil Development

The fourth component of this study uses the published information on the genesis of natural soils to predict the soil development in the oilsands area. We have shown that bulk density and water storage potential are the most rapidly changing physical properties. Bulk density will decrease with root development and organic matter build-up. Water storage increases in relation to organic matter accumulation and structural development, but the effects have not been quantified. The chemical changes in the developing soil are primarily a result of organic matter stabilization (increase in cation exchange capacity and available nutrients) and losses of calcium carbonate (decrease in soil pH). The biological aspects of soil development are the most dynamic and consequential. The physical and chemical effects of organic matter accumulation have been mentioned, but its effects on nutrient distribution and supply are even more important. We show in this study that jack pine is associated with higher rates of nutrient cycling than a mixed wood stand although the latter community accumulates nearly twice the total amount of nutrients in the living biomass and litter

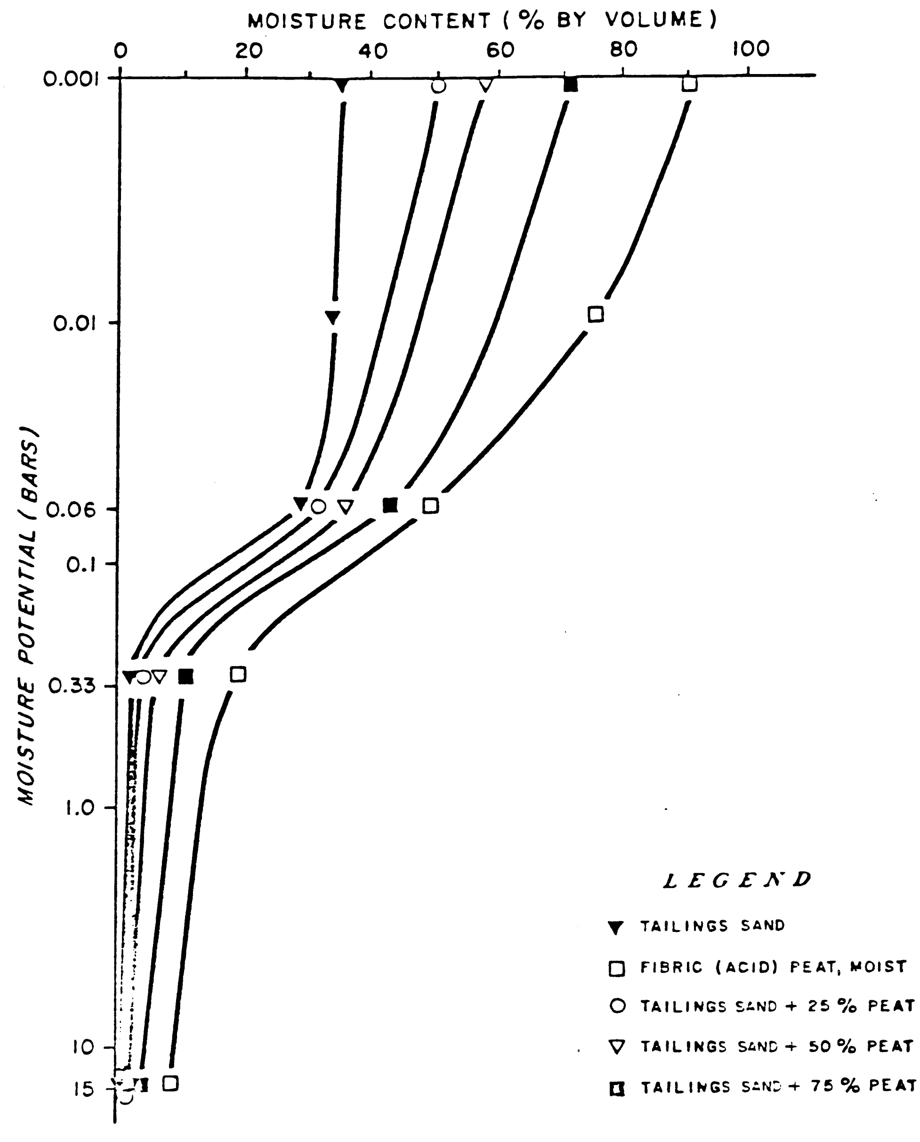

FIGURE 3

THE VARIATION OF MOISTURE CONTENT OF TAILINGS SAND AND TAILING SAND AND PEAT MIXTURES WITH DIFFERENT MOISTURE POTENTIALS (LOGAN 1978)

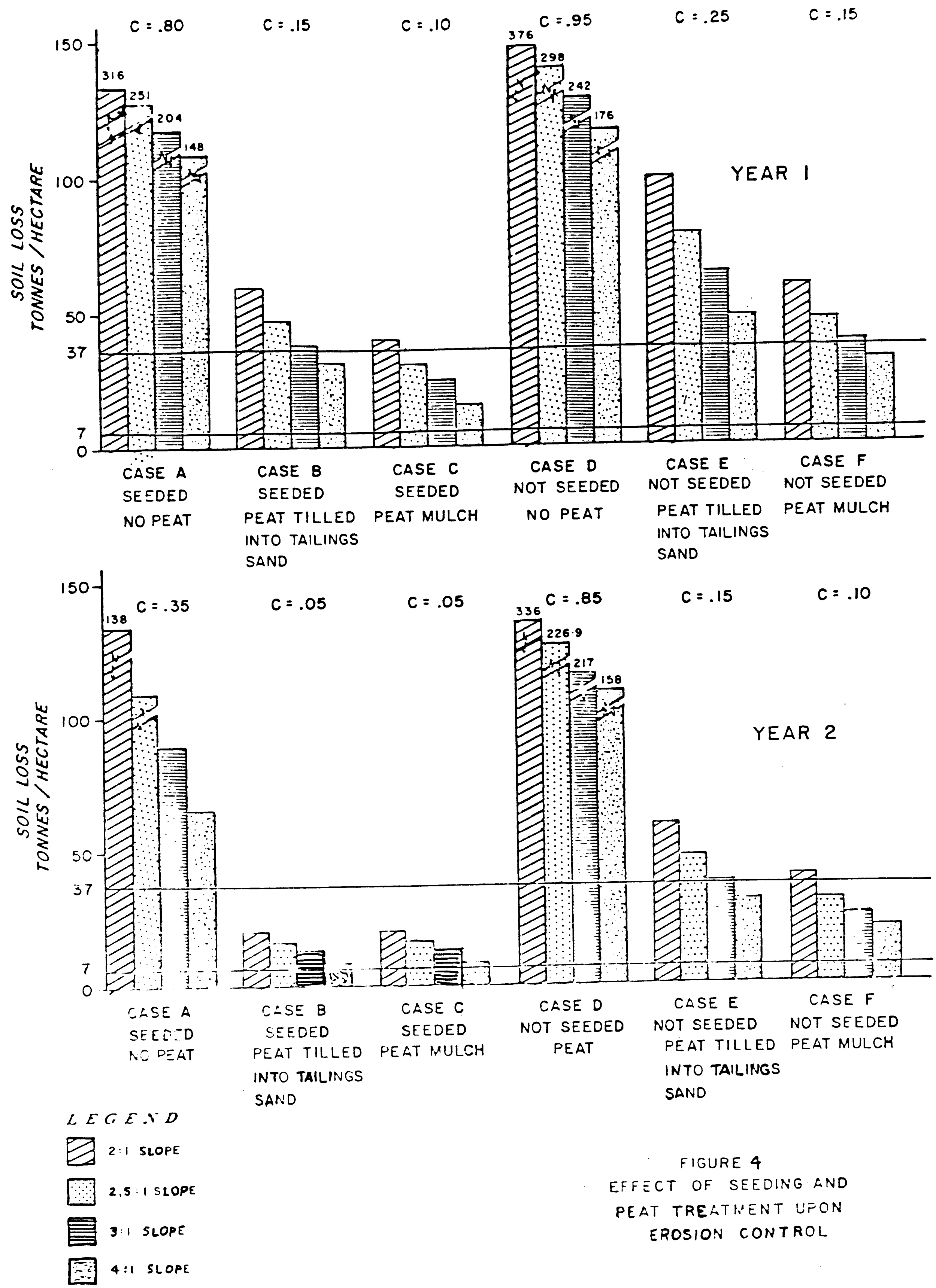

FIGURE 4
EFFECT OF SEEDING AND PEAT TREATMENT UPON EROSION CONTROL

layer. The characterization of nutrient turnover as a component of soil development is germane to a consideration of self-maintenance in the oilsands area where rates of nutrient movement will govern site productivity and vegetation survival under extreme conditions.

Management Requirements

Finally, this study examines the need for management inputs in light of the functional aspects of soil reconstruction discussed above. The most important considerations are nutrient levels, available water and erosion control. The strategic use of organic amendments (peat), fertilizers and plant species capable of nitrogen fixation can provide adequate soil fertility. The control of available water has been shown to be primarily a function of texture or, more specifically, the percentage of silt and clay. The control of erosion is based on the proper selection of materials used to reconstruct the soil, the reduction of slope angles and the use of peat with a fast- establishing plant cover.

In summary, this study has defined the soil properties needed to reclaim the oilsands area to jack pine and mixed wood species. The selection of minimal levels of soil properties is justified on the basis of a functional analysis of the interaction of vegetation, soil and climate. We have found that nutrient and water supply and erosion control are the limiting factors to successful reclamation; these can be provided for by mixing materials in proper proportions and providing soil amendments.

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WORKING GROUPS

On the second day of the workshop the participants split into four groups to discuss a list of specific questions. The questions centered on possible sources of inferrential data and the practicalities of topsoil removal and replacement. These discussions will help define reclamation research priorities and expand the information base available to Government and Industry reclamation groups.

Discussion Topics for Working Groups

The reclamation objective in Alberta is to return disturbed land to a level of equal or greater productivity.

Two major types of disturbances are under consideration here:

1. Oil sand mining and extraction in the northeast.
2. Coal mining in the mountains and foothills.

1) Soil Depth Requirements

   A. Is there a correlation between pre-mining tree rooting depth and post-mining rooting depth requirements?
   B. Is there a correlation between pre-mining soil depths and reconstructed soil depth requirements?

2) Is there a need for Selective Materials Handling?

   Are thin L, F, H, Ah horizons worth saving in light of:
   A. The realities of soil removal, stockpiling and replacement?
   B. Expected changes in organic matter and nutrient levels resulting from disturbance?
   C. Spoil physical and chemical characteristics. How does it compare with replaced soil?
   D. What kinds of materials are available besides soil? (Lacustrine, Aeolian, till, tertiary and cretaceous materials) what are their properties and occurrances?

3) What criteria should be used to distinguish suitable materials?

4) What can be said now about soil depth requirements?

5) What areas require further research?

Summaries of the four working group responses to these questions follow. The working group discussions are appended.

CONCLUSIONS

GROUP I

1. Soil depth requirements:

   Two main areas of existing knowledge were considered in light of providing approximations for reconstructed soil depth requirements. These are: pre-mining rooting depth and pre-mining soil depth. The group concluded that reconstructed soil depths, based on either pre-mining parameter, were unlikely to provide good correlations with tree performance after mining.

2. Is there a need for selective materials handling? Yes.

   The group felt that the quality of materials in the LFH, Ah horizons justified their separate handling. Terrain and equipment available for topsoil removal dictate the degree of selectivity attainable. In most situations, LFH and Ah horizons would be incorporated with most of the B horizon. The group felt this type of blend would be superior to either tills, lacustrine or other geologic deposits. Though most non-soil materials are innocuous, they are low in plant nutrients. Also, most tills, lacustrine and particularly some aeolian deposits are sufficiently rich in carbonates that some restriction to coniferous tree growth would be expected if these materialss were left on or near the surface.

   Insufficient evidence is available to say whether applied soil-building materials, particularly organic matter, will persist or whether their effects are only short-term.

   Selective materials handling is particularly critical where bentonitic formations form part of the overburden. Physical problems associated with weathering of these deposits severely restrict the growth of all plants.

3. What criteria should be used to distinguish suitable and unsuitable materials?

   Identification of appropriate materials was felt to be within our present capabilities and requires little, if any, further research.

   A. Nutrient status - as per known techniques.

   B. pH - The range of 5.5 to 6.0 is optimal. Conifers will persist at higher pH (7.0 to 7.5) but growth will be restricted by carbonates.

   C. Sodium absorption ration (SAR) indicates soil physical problems resulting from high sodium levels.

4. What can be said now about soil depth requirements?

   No evidence was presented to indicate how much soil-building material must be re-applied in order to attain a self-maintaining, productive vegetation cover.

5. What areas require further research?

   Two major areas were identified:

   1. Develop a better understanding of the processes involved in forest-soil development. What sort of "parent materials" are required to yield a given productivity?

   2. Long-term, controlled test plots with various soil mixes, monitoring of tree growth and soil development within the plots.

   3. The first approach would yield inferrential results in a relatively short time and the test plot approach would be long-term. Therefore, study of the natural situation would allow for interim recommendations on soil mixes, define target productivities and help in designing mixes for field trials. As the field trials are monitored, it should become apparent whether given soil mixes are moving in the direction of stable, productive natural stands or if regression will occur.

CONCLUSIONS

GROUP II

1. Soil Depth Requirements

   Soil depth requirements will have to be judged on an individual basis. There is likely to be no useful correlation between pre-mining soil or rooting depth and reconstructed soil depth requirements.

2. Is there a need for Selective Materials Handling?

   Yes, however, segregation of thin organic rich layers would be impossible. Topsoil would have to be removed and replaced as a mixture of LFH, A, B and possibly C horizons. This would constitute the first lift and would most likely be removed with scrapers.

   No significant changes are expected in organic matter or nutrient levels during the process of removal, stockpiling, reapplication and revegetation of reconstructed soils. Deficiencies in nutrients or organic matter levels can be easily remedied. Significant changes would probably occur in soil physical properties, however, geologic materials could possibly be used in situations where soil is unavailable, though their merits would have to be judged individually.

3. What criteria should be used to distinguish suitable materials?

   Any material which is non-toxic to plant growth could be suitable for reclamation. Obvious deficiencies relating to nutrient status, water relations of pH could be remedied with known techniques.

4. What can be said now about soil depth requirements?

   Recommendations must be made on a site-specific basis.

CONCULSIONS

GROUP III

1. Soil Depth Requirements

   Neither pre-mining rooting depth nor soil depth were felt to be good indications of what was needed in the reconstructed soil. Too many other factors related to tree growth and tree establishment were involved to permit isolation of depth as the key factor.

2. Is there a need for Selective Materials Handling?

   Thin LFH and Ah horizons cannot be realistically segregated and replaced. However, bulking of the upper soil horizons down to, but not including, the C horizon would be practical under most circumstances. And probably little loss in quality, organic matter and nutrient levels is expected upon application. We do not know whether organic material would break down any faster in a mixture than in an undisturbed soil horizon.

   It is not known whether peat addition will serve as a significant source of micorrhizal innoculum.

3. What criteria should be used to distinguish suitable materials?

   Physical criteria are the most significant properties of reconstructed soils. Chemical properties such as nutrient content and carbon content are not as important because they can be modified more easily.

   Possible toxic properties should be kept in mind, however.

   Calcium carbonate content in reconstructing soils is of concern in the foothills as a factor in moisture stress.

4. What can be said now about soil depth requirements?

   No conclusions can be made at this time.

5. Further Research:

   In the foothills, the number of variables involved in soil reconstruction suggests the establishment of a number of benchmark sites so that the important variables can be sorted out and a modelling exercise attempted to try to determine the effects of these parameters on tree growth, rooting depth, etc. Perhaps juvenile growth could be looked at on a reclaimed area and a natural area for 10 to 15 years. But we still need a full 100 years rotation before we know how a soil mix will produce commercial forest. So, some sort of modelling seems required.

   Other questions: When does a site become maintenance free? When can fertilization be stopped? Water relations? Nutrient requirements for forest growth? These areas all need further research.

CONCULSIONS

GROUP IV

A. NORTHEAST ALBERTA

1. Soil Depth Requirements

   There are too many factors influencing tree rooting depth to correlate premining root depth to postmining root depth requirements.

2. Need for Selective Materials Handling

   There is an implied need for selective materials handling, however, this seems an area for more research.

   The LFH and Ah horizons in forest soils are important and where possible, should be saved. Equipment may have to be developed to salvage these materials.

3. Criteria for suitable materials

   Whatever the criteria, materials should be characterized with respect to available as well as total constituents. By knowing the total status, one should be able to measure long-term losses or additions and thus better understand the genesis of a soil-plant system.

4. Present knowledge about soil depth requirements

   At least over a short term, tailings sand amended with 15 cm. of peat, fertilized, tilled to 20 cm and seeded to grass, will give erosion control on 2.5 to 1 slopes.

5. Research Needs

   It seems there is still much not known about oil sands reclamation. Some needs include:

   (1) What are the differences and importance of two major organic matter sources, that is, peat and LFH and Ah materials, with respect to nutrient cycling, microbial populations, seed sources, influence on soil structure, weathering, and so on.
   (2) Source and kinds of materials (fines) which will weather to provide a long-term supply of nutrients and amounts of such materials required.
   (3) Determinations of what constitutes a minimal level of reclamation. Establish various levels of reclamation.

A criticism against oil sands reclamation research is that much of the experimental work is not based on established theories pertaining to the genisis of soil-plant systems. It is suggested that the processes responsible for differing levels of productivity in natural systems be identified and measured. This knowledge should be experimentally tested and used to predict the requirements for reclamation.

B. MOUNTAINS AND FOOTHILLS

1. Soil Depth Requirements

Rooting depth is a product of many factors and would probably not reflect after-mining soil depth requirements. Important considerations would be the depth of the water table in the reconstructed materials and microclimate.

2. Need for Selective Materials Handling

There is a need for selective handling, however, the need and material availability are probably site specific.

Organic and organically enriched horizons are important in the natural state - beyond that, the importance of these materials is not well established.

3. Criteria for Suitable Materials

Criteria are generally not established, although is it recognized that material suitability differences occur. Again, criteria should measure total as well as available constituents and reflect properties which have genetic implications.

4. Present knowledge about Soil Depth Requirements

Present knowledge about soil depth requirements is limited. A limiting factor may often be availability of suitable materials.

5. Research Needs

Research needs are ill-defined, although they are probably similar to the needs outlined for oil sands research. Some additional concerns include:

(1) End land use. It seems mine companies are reluctant to make this decision and would like to be told what the end land use should be.
(2) Organic matter. Although important in an established forest, it is important in establishing a forest on barren mineral soil.
(3) Criteria for selecting suitable materials.

(4) How does one get from the initial stabilizing cover, usually grass, to the succeeding forest plant communities?
(5) What are the factors most limiting to reclamation? Climate and aspect have been implied.

Again, it is suggested that the natural systems should be used as templates on which to base research.

LIST OF PARTICIPANTS

G. Acott	- Cardinal River Coal
T. Adamson	- Union Oil
K. Armson	- Ontario Ministry of Forests
T. Ballard	- Univeristy of British Columbia
J. Bondy	- Alberta Energy & Natural Resources - Forest Service
B. Cary	- Suncor Inc.
G. Coen	- Agriculture Canada
I. Corns	- Canadian Forest Service
D. Dabbs	- Alsands Project Group
C. Dermott	- Alberta Energy & Natural Resources - Forest Service
A. Fedkenheuer	- Syncrude
B. Fessenden	- Syncrude
D. Graveland	- Alberta Environment - Technical Development Branch
W. Holland	- Canadian Forest Service
R. Johnson	- Montreal Engineering Co.
P. King	- Alberta Energy & Natural Resources - Forest Service
G. Krumlik	- Canadian Forest Service
G. Lesko	- Syncrude
B. Logan	- Luscar Ltd.
T. Macyk	- Alberta Research Council
R. Marvin	- Alberta Energy & Natural Resources - Lands Division
K. Natsukoshi	- Manalta Coal
B. Patterson	- Alberta Environment
D. Pluth	- University of Alberta
H. Regier	- Alberta Environment - Technical Development Branch
P. Sims	- Alberta Environment, Research Management Division
G. Singleton	- Hardy Assoc. Representing ESSO Resources
S. Takyi	- Alberta Energy & Natural Resources - Forest Service
H. Tomm	- Alberta Energy & Natural Resources - Forest Service
P. Ziemkiewicz	- Alberta Energy & Natural Resources - Scientific & Engineering Services

APPENDIX

Working Group Discussions

WORKING GROUP I

P.F. Ziemkiewicz	-	Alberta Energy & Natural Resources, Moderator
I.G. Corns	-	Canadian Forestry Service
G. Acott	-	Cardinal River Coals
A.W. Fedkenheuer	-	Syncrude Canada Ltd.
R.T. Marvin	-	Alberta Public Lands
C.A. Dermott	-	Alberta Forest Service

DISCUSSION

The Reclamation Objective in Alberta is to return disturbed land to a level of equal or greater capability.

Two major types of disturbance are under consideration here:

1. Oil Sand mining and extraction in northeast Alberta.
2. Coal Mining in the Mountains and Foothills.

Questions:

1. Soil depth requirements
   A. Is there a correlation between pre-mining rooting depth and post-mining soil depth requirement?

   B. Is there a correlation between pre-mining soil depth and post-mining soil depth requirement?

Corns: From yesterday's papers, it seems that soil depth requirements are, in large part, species dependent. I suspect that there is not a relationship between pre-mining rooting depth and the depth to which a reconstructed soil must be placed. The reconstructed soil may have a lighter bulk density than the original soil, so a given volume of soil may be more productive afterwards. If this is true, it may be advisable to spread the material thinner than it was originally.

Ziemkiewicz: Let's assume we're talking about commercial Forestry in this case. Should we take pains to ensure that we have the same volume of unrestricted rooting zone after mining as there was before?

Corns: Keep in mind that soil volume and rooting volume are not necessarily equal.

Ziemkiewicz: We are trying to identify the reconstructed soil depth requirement. In some cases in the foothills, where spoils have a high sodium absorption ratio, the depth of added soil will become the entire rooting zone. In other instances, where spoils are fairly innocuous, rooting will extend far below the reconstructed soil zone. So, if you have an innocuous spoil, it may only be necessary to add a thin, high quality material to provide nutrients and moisture-holding capacity. However, if the spoil is sodic, you'll probably have to look at re-creating a large portion of the original rooting zone, since sodic spoils tend to set up like cement.

In the absence of any empirical data, which pre-mining characteristic gives us the best indication of reconstructed soil depth requirements, soil depth or rooting depth? Area either of these valid indicators?

Corns: Profile development and rooting depth are very often synonymous, particularly in calcareous soils. Roots very rarely go beyond the Cca horizon in the foothills. In reclamation, you often have calcareous material at the surface. This inhibits tree growth.

Acott: Coal-mining companies in the foothills will often save the upper solum and place it on the surface to provide a better, less calcareous growth medium for trees. But we have no capability to segregate the different soil horizons. We usually take a mixture of LFH, Ae and B horizons.

Fedkenheuer: I'm not satisfied that we have a good feel for what "rooting depth" means. In many cases, the odd root will penetrate to as much as 10 m. Does that mean we need 10 m of reconstructed soil?

I don't think that pre-mining rooting depth correlates with a required post-mining soil depth. Certainly the talks given by Ken Armson, Wil Holland and George Krumlik indicated that forest productivity did not correlate with soil depth or rooting depth.

Corns: Sure, if sufficient moisture is available to a shallow-rooted tree, then you may get excellent productivity.

Ziemkiewicz: In the mountains I've noticed, on lightly disturbed sites, where you have perhaps 30 - 40 cm of unconsolidated material over bedrock, grass roots will form a shallow mass, then thin out until the bedrock, where they may form a nearly solid mat. I suspect they are there because the consolidated rock perched a small watertable which even grass roots could exploit.

In the mountains I rarely dug a soil pit more than a metre before encountering bedrock. Whatever effects the bedrock had in keeping moisture near the suface would be eliminated by mining. So, the plants could no longer rely on seepage water.

So, the correlation between pre-mining soils and post-mining requirements is weakened, since the site has usually shifted to a more xeric soil moisture regime.

Corns: Most species have characteristic zones of abundant rooting: White Spruce is generally more shallow-rooted, than pines.

Fedkenheuer: Sure, but we still do not know which root segments are most valuable to the tree.

Corns: The surface roots are certainly responsible for most of the nutrient uptake. But, I do not think anyone really knows what the deeper roots do. Obviously, they take in water, some minerals and help to anchor the tree, but their relative contribution is unknown.

Ziemkiewicz: I'm sure we've all seen poplar roots down 7 to 10 m in coal seams and bedrock. These roots may supply enough mosture to keep the tree alive during severe droughts.

Corns: When dealing with calcareous spoils, you could run into trouble if the calcareous material is left at the surface. If you can cover this with the previous solum, you'll have better luck growing trees.

Ziemkiewicz: This is a significant point, since most overburdens in the mountains have a pH between 7.5 and 8.0. Will coniferous trees grow at this pH?

Corns: Some of the tills, however, are not calcareous. Most trees grow very slowly on calcareous soil. There have been serious reforestation problems near Hinton because of the calcareous loess blown in from Jasper Park. Spruce trees 20 years old, in this material, may be no more than 15 cm tall. Even in mature forests, while they may appear normal, you'll find 250 year old trees only 15 cm DBH. Also, even where you have a mature soil profile, if carbonate is present in the C horizon, then you often get a continuous root mat right above the carbonate.

Marvin: Are we perhaps overly concerned with the idea of applying a uniform soil depth over large reclamation sites? Nature is heterogeneous. Shouldn't we take this into account?

Ziemkiewicz: I don't think we can get too picky in reclamation. We would do well to find a nice mean level of application and accept that some sites will be over-treated and some will be under-treated. Of course, it depends on scale. We're trying to prescribe soil mixes for three land uses in Richard Johnson's study. But we're talking about very large areas for each land use type.

Marvin: I would just like to ensure that we will not create homogeneous landscapes and vegetation types in reclamation.

Ziemkiewicz: I've gathered from yesterday's talks and today's discussion, that perhaps we just cannot set a recommended soil depth or even point to pre-mining soil depth or rooting as indicators of reconstructed soil depth requirements.

Acott: I agree, perhaps if a depth is to be recommended, one could be set with wide boundaries, say a range between 12" and 36", and let variations within that range be set by research or site-specific factors.

Ziemkiewicz: I have one more question on this topic. If we're looking for an unrestricted rooting zone, most mountain spoils would qualify in regards to grasses and legumes. Would calcareous spoils with a pH of 7.5 to 8.5 restrict tree root penetration? Or will we have to guarantee a root zone with a pH of 5.5 to 6.0 in order to grow trees?

Corns: If your surface material has a pH of 7.5 to 8.5, you'll have problems growing trees.

Ziemkiewicz: So, when you're talking about an unrestricted rooting zone for trees, you mean a pH of 5.5 to 6.0?

Corns: Yes.

Fedkenheuer: Would it be that narrow? On our site, we have shrubs and trees growing on pH 7.0 to 7.5.

Corns: You must be growing jack pine. A lot of shrubs will grow at that pH. But lodgepole pine and spruce won't do well at all at a pH of 7.5. I would still regard 5.5 to 6.0 as optimal for commercial trees.

Acott: Would sulphur addition to calcareous spoils help in tree growth?

Corns: I don't know, I suspect it would take a lot of sulphur to make a difference.

The group concluded that neither pre-mining rooting depth nor soil depth were good indicators of reconstructed soil depth requirements.

2. Is there a need for selective materials handling?

Ziemkiewicz: To generalize, it seems the common forest soil in Alberta has roughly a 5 to 15 cm LFH horizon, usually no Ah, 10 to 30 cm of Ae and quite lot of B horizon.

Corns: That's about right, though you'll find some Ah horizons on poorly drained areas supporting spruce. If you have Brunisols, as are common around Ft. McMurray, then a Bm horizon is common, but in the foothills, the common Gray Luvisols will have a Bt horizon.

Ziemkiewicz: Is the Bt a good reclamation material, or does the clay content cause crusting and compaction problems?

Corns: Bt horizon textures can vary from sandy loam to clay, so it is hard to generalize.

Fedkenheuer: If the LFH horizon is the only organic matter present, it should be saved, because it certainly can be significant nutritionally.

Ziemkiewicz: Considering the realities of removal, storage and replacement, can the LFH be handled separately, or would it be bulked with the rest of the solum?

Acott: I think it could only be blended down to the C horizon, since we strip our soil with a scraper or dozer. Scrapers tend to be a bit more selective.

Ziemkiewicz: So, to answer 2.A., yes. LFH is worth saving and (2.A.1.), you would have to accept mixing LFH, A & B horizons.

Dermott: On flat terrain, I've seen selective handling of LFH and A horizons.

Marvin: It depends alot on scale and topography. On smaller sites and flatter terrain, more selectivity can be applied.

Ziemkiewicz: This is perhaps the most important question we have to answer: What changes will occur in organic matter and nutrient levels resulting from disturbance?

For example, the soil nutrient and organic matter levels under a jack pine stand are quite low. But, if you look at the plant side of the site, you see lichens adding fixed atmospheric nitrogen and the shrubs and trees themselves constituting a very large cycling pool of nutrients. So, reconstructing a soil with the natural soil qualitites and quantities would miss an important point: soil under the forest is in steady state with the forest cover. Inputs roughly equal losses.

If you take off the trees and shrubs, you temporarily cut off new organic matter and nutrient inputs, while accelerating decomposition. As a result, you get a flush of mobilized nutrients and a loss of organic matter. This usually presents no great problem if root stocks and seeds survive in a cut over area and quickly re-establish a nutrient cycle. However, a quantity of organic matter placed on tailings sand, seeded with grass and fertilized, might undergo very rapid decomposition before a productive steady state is established. In fact, if decomposition continues to exceed organic matter replacement, you'll eventually be back to bare tailings sand.

Fedkenheuer: But in the oil sands area, you would not get such rapid decomposition as you would in the B.C. coast or in the Eastern U.S.A. The colder climate and lower precipitation in Northeastern Alberta would tend to retard decomposition.

Ziemkiewicz: Mike Rowell tested decomposition of pure cellulose strips on a peat/tailings sand mixture on the Suncor dyke and he reported, I think, about 65-75% decomposition over one year (in fact, the rate was more like 90% organic matter loss. ed. Note; see 1/) that is very rapid.

Acott: One would expect natural forest litter to decompose more slowly than pure cellulose.

Corns: There are big differences in forest floors too. Under pine you usually find a feathermoss cover, whereas, under spruce, you often get well-decomposed leaf litter as well as feather moss, as a result of usually moister conditions.

Ziemkiewicz: We have the potential for two types of problems here: too rapid decomposition, in which the added organic matter oxidizes off before soil development takes hold, and too slow decomposition, in which a nutrient bottleneck develops in the undecomposed organic matter.

If we are to make recommendations for soil reconstruction, we have to have a fair understanding of how that material is going to behave under field conditions. Soil reconstruction is not a simple, static process. In fact, it is highly dynamic. If we are not careful, we may wind up with bare ground in 20 years on the high decomposition sites (i.e. oil sands) and mossy thatch on low-decomposition sites (i.e. mountains).

1/ Rowell, M.J. 1979. Revegetation and Management of Tailings Sand Slopes from the tar sand extraction: 1978 Results, Syncrude Environmental Research Monography 1979-5. 131 pp.

Fedkenheuer: I don't think you'll get back to bare ground, I would think that litter buildup and grass root accumulation would prevent that. If anything, the imbalance in the C:N ratio tends to accelerate the accumulation of litter, at least with a grass cover.

Ziemkiewicz: Maintenance fertilization tends to produce alot of top growth which is transferred to the litter layer. If, when maintenance fertilization is discontinued, the litter fails to decompose quickly enough to supply the plants with nutrients, then the root systems begin to deteriorate and shoot pnroduction falls. If this goes on long enough, the root systems no longer are capable of holding the soil together and aerial cover drops to the point where erosion begins. Mind you, this is a "worst case" scenario, but it occurs frequently.

Conversely, I studied a low elevation site (1600 m) in my thesis down near the Crowsnest Pass, and after three years with no topsoil added, there was a nutrient stable plant community. When fertilization was cut off, nutrient levels in roots increased, plant masses increased and the site could stand on its own two feet. The high elevation site was a different matter.

Fedkenheuer: I suspect the difference was in part due to the poor adaptation of the commercial grasses at high elevation.

Ziemkiewicz: I'm sure that was a major factor. So for question 2.A.2., I gather that we just don't have any indications of the behavior of reconstructed soils. Certainly, we aren't in a position to say what will happen to the added organic matter and nutrients in a quantitative sense.

Acott: This would be an important area for study though. How long does it take to re-establish a productive nutrient cycle in a given environment?

Corns: What proportion of nutrients are lost during stockpiling?

Ziemkiewicz: Jim Fujikawa is studying that on a stockpile at Bow City. But that is chernozemic Ah material.

Fedkenheuer: Our muskeg is frozen to a large extent in stockpiles, I don't think too much would happen.

Ziemkiewicz: How do other geologic materials compare with soils as a growth medium (question 2.A.3)?

Ian, you indicated that there were acidic tills in the mountains.

Corns: The acid tills in Alberta are restricted to a zone right up against and within the mountains.

Ziemkiewicz: What formations do they derive from?

Corns: Quartizite, some acid shales.

Ziemkiewicz: The Fernie shales?

Corns: Yes.

Ziemkiewicz: Otherwise, everything else is pretty strongly basic isn't it?

Corns: Yes, most tills are derived from limestone, dolomite, quartite, sandstone and shale. Most of those are calcareous.

Ziemkiewicz: So, your average geologic material has a pH of 7.5 to 8.5?

Corns: 7.5 is closer to the average. Most do not get over 8.0. Some of the loess might get to 8.5, but that is pretty restricted.

Ziemkiewicz: So, even at 7.5 these materials would be an impediment to tree growth?

Corns: Yes, I'm sure coniferous trees can tolerate this pH, but they would do better at a lower pH.

Ziemkiewicz: There are places in Coal Valley where high sodium overburden shales pose a physical impediment to tree growth. Do any of the mountain and foothill soils present problems? For example, if you have a large volume of Ae material in your soil mix, will you have erosion problems and a poor nutrient status?

Corns: The platy structure typical of the Ae hoirzons would be lost in handling, so the erosion hazard wouldn't be so severe. Also, if fines from the B horizon are incorporated, I suspect the net result would be highly favorable.

Acott: There are places in Coal Valley mined 35 years ago where sodic spoils have prevented any plant life from establishing. Regarding soil mixes, I'm inclined to agree. I think any mix of LFH, Ae and B horizons would be better than, say, till.

Corns: We've found soils in Jasper National Park where Ae horizons were 90 cm thick, but this is very rare. They are usually only found in the upper Subalpine.

Ziemkiewicz: How would tills behave as soil building materials? What sorts of physical and chemical properties are common?

Corns: Most Boreal forest tills are clay loams, they tend to become coarser as you approach the mountains.

Ziemkiewicz: How do these tills handle? Do they present compaction problems?

Acott: Some of the clay loams compact when scraper applied. Generally, any rubber-tired vehicle presents greater compaction problems than tracked vehicles. But generally, the tills handle reasonably well.

Marvin: We are limited in our capacity to selectively handle materials. This is an area for equipment development.

Fedkenheuer: I am not satisfied with the available methods for soil incorporation. There may well be a better machine around for incorporation, but we aren't aware of it.

3. What criteria should be used to distinguish suitable materials?

4. What can be said now about soil depth requirements?

Ziemkiewicz: I think questions 3 and 4 have been dealt with adequately in the previous discussion. Let's move on to question 5.

5. What areas require further research?

Acott: So far, we've pointed out the need for work on re-establishing the organic matter cycle, equipment development, re-establishment of soil texture.

Ziemkiewicz: I'd like to see an inventory of available materials, then under controlled tests, mix or separately replace the various types of materials. For example: mixtures of soil horizons, tills, lacustrine deposits. In some cases, this would involve vegetation management to improve soil organic matter and nutrient levels. This would allow a cost benefit analysis of the efficiency of various techniques. What method of soil reconstruction yields the desired result at the least cost? These would have to be long-term, well-controlled tests. The emhpasis would focus on practical methods.

Corns: Also under further research, I think that further study is necessary on the relationships of soil, site, climate and how they affect tree growth on natural systems. It seems we have to understand these natural processes before we can successfully reconstruct a site.

Fedkenheuer: Should we not do something similar to what your group and George Krumlik presented yesterday: classify vegetation types and the kinds of soil properties associated with them?

Corns: It is important to look at a series of factors over many sites in order to find out what factors are controlling species distribution and productivity.

Ziemkiewicz: Can we do that, given the effects of historical events and subtle climatic changes on soil? The factors which swing a plant community in one direction or another are not well understood. It is easy to confuse correlation with cause and affect.

Corns: You usually never really know the history of disease, fire and climate.

Ziemkiewicz: So you're talking about describing end points for reclamation?

Fedkenheuer: Or guidelines.

Corns: I think you can look at the available materials for soil reconstruction and look at the natural situation where similar parent materials were available. This will perhaps help us to prescribe reclamation practice to meet more clearly defined goals.

Fedkenheuer: I wonder what the soil chemical and physical properties mean in terms of productivity or the rate at which a system reaches the desired productivity. I don't think a long-term test plot program will give us the answers in time to implement the practices in the near future.

Ziemkiewicz: You'll have a series of interim results. For example, after 5 years, you'll have a good idea when you can cut off maintenance fertilization for the various mixes. Given a developing soil-plant system, what kind of productivities and species will the various soil mixes give you? Data of this sort will come in over the next 10-20 years and ultimately, until a stable, mature vegetation type is established.

Fedkenheuer: But, inferences from natural forest sites can yield quick results, and we need this kind of information now. It would seem preferable to learn what we can from the natural situation, then proceed to the test plot stage. But we do not have time for that. Given our constraints, I would like to see both approaches taken simultaneously.

Ziemkiewicz: No problem there. Once we have defined our reclamation end points, and I think inferences from nature can help in this regard, then we have to define the rate at which reclamation treatment 'A' moves to end point 'B'. We can theorize about the end points and plan experiments accordingly, but until we have empirical evidence, we do not know if we will wind up with a desireable plant community or bare ground.

Fedkenheuer: I feel we also have a lot to learn about soil moisture relationships. This is a possible area for research.

Ziemkiewicz: That's an easy one to test. The question often comes up as to whether rodents or water stress are responsible for the failures of trees and shrubs plantings at the Suncor dyke. The studies done so far have confounded the two factors. But, by use of drip irrigation and protective cages, the effects could be isolated in a simple experiment.

WORKIGN GROUP II

S.K. Takyi	- Alberta Forest Service, Moderator
J.L. Bondy	- Alberta Forest Service
T.A. Adamson	- Union Oil Co. Ltd.
G.L. Lesko	- Syncrude Canada Ltd.
G.J. Krumlik	- Norwest Priva Labs Inc.
K.A. Armson	- Ontario Ministry of Forests
T.M. Macyk	- Alberta Research Council
T.M. Ballard	- University of British Columbia

DISCUSSION

Takyi: In our discussion, bear in mind the two areas of interest: namely; oil sands mining in northeast Alberta and coal mining in the mountains and foothills of Alberta. The first item on the adgenda is "Soil Depth Requirements". There are two parts to this item which I think simply need a "yes" or "no" answer. What are the soil depth requirements in reclaiming for a commercial forest or wildlife habitat?

Ballard: First of all I would like to pose a question. In the oil sands mining and extraction, as I gathered from yesterday's discussion, one of the major objectives is containment of slurry and stabilization of soil; this seems like a more difficult objective than merely returning disturbed land to the initial level of productivity. Now, is that a characteristic of oil sands reclamation in general, or is that just one component of it?

Lesko: We have more than one aim. Stabilizing the dikes is one aim and in those situations productivity is not important. We will have over 24,000 acres in the Syncrude development to be reclaimed in three major areas: tailings dyke, overburden (mining area) and other disturbed areas not necessarily mined. We will have about 3,000 acres of more or less level tailings sand at Syncrude. This land has to be regenerated to some productive capability and we have to put together a soil which has the potential productivity, on the average, similar to the situation before the disturbance.

Takyi: We still haven't touched on the question of soil depth requirements. Anyone?

Armson: Is there a correlation? The answer is no; if there is, it is totally coincidental.

Adamson: Depth is one of the factors that we are trying to get hold of in trying to define what the tree really needs. When we talk about depth, it seems we are not really concerned with depth, but the factors (chemical, physical and biological) which will support a tree population. We are trying to identify depth as one factor we can measure quite easily. It may be we should be considering something else. If we can identify this factor, then it may be we should get to that first.

Ballard: Perhaps the reason depth requirement looms large in this discussion, is the considerable expense of putting some kind of material, e.g. soil material, onto the land surface. The expense of adding fertilizer and/or whatever to improve the nutritional properties of material seems fairly small, relative to the cost of moving all that material. So, it seems that the economic view of what is at stake here has focused our attention on the soil depth requirement.

Adamson: I agree with what you are saying Dr. Ballard. Richard Johnson brought up the subject yesterday regarding available nutrients, regardless of depth. If you have just as much nutritional value, and tree requirements are satisfied at say half the original depth of soil, this improves your economics.

Ballard: The question we should be asking is why? What is it that we want from the soil? Are we putting it back to satisfy the rooting characteristics or are we putting it back for nutritional or moisture needs? The depth part of it is a concern, but is also a variable, depending on what you want to grow. The use of a blanket depth for everything is probably a place to start, but what we want from it is much more important.

Takyi: In your paper yesterday, referring specifically to the oil sands region, you (Krumlik) indicated two-foot soil depth as what we should be shooting for. Do you want to elaborate on this?

Krumlik: I think before any mining is done, there should be a thorough inventory of what is there, before talking of depth of soil. I know there are situations where there are sandy soils which are growing very poor jack pine forests. Obviously, if that is the situation before mining, it is very hard to justify that after mining the area should be put back into a very productive site. Depth is not really the most crucial factor. There may be a soil which is just a few centimeters thick in rooting depth, where white spruce will produce tremendous growth, very high volume, very high DBH and very good annual increment. There could be poor jack pine which is growing on soil as deep as 80-90 cm.

Lesko: I should like to remind you that the two-foot soil depth Krumlik was talking about will be the best possible for the area. In that case, the climate will be the limiting factor and not the soil material. It would not be the average productivity, but the very best the area can produce and would exceed the reclamation guidelines.

Bondy: I should remind you that within the regulation, there is a compensation factor. Because your (Syncrude) tailings pond will probably never be reclaimed that land is permanently taken out of production, we would, therefore, require greater productivity from lands that you have remaining. Your tailings pond alone will sterilize 11 square miles, multiply that by 10 or 20 oil sand plants, and we've lost a lot of forest land.

Lesko: Do you have the same requirements for other institutions? Like, for example, if Edmonton requires 200,000 acres for houses, would you expect the same compensation from Edmonton for agricultural land loss? Or the province builds a highway and takes up several thousand acres of land. Does the province invest more money to increase productivity of other agricultural lands to compensate for what was taken out of production? I think it would be very unfair to expect that of any industry.

Bondy: First of all, you are dealing with the provincial, not city government. The Land Surface Conservation & Reclamation Act applies within the green zone and covers the oil sands area. Within the Act, there is a compensation factor which relates to forest production as far as timber growth is concerned. Now Syncrude, because of its special lease, is somehow excluded. Other oil sands companies coming up, have to compensate Albertans for loss of timber growth on the remaining areas that they have left. That means that either they have to reclaim the tailings pond to productive forests, or they have to increase production on the rest of the areas. This means they have to go after the best soil materials to get that good growth.

Krumlik: Is this requirement reasonable? I don't know the figure in Alberta, but in British Columbia, all mining operations occupy about 0.013 percent of the provincial land. Many years ago, the Director of the UBC Research Forest, Jack Walters, made the suggestion that it may be better for forest industry to intensify management on the most productive land in British Columbia, which is about 15% of forest land in British Columbia. Economically, this would be more attractive. From my knowledge of Alberta, I would make the same suggestion to the Alberta Forest Service. Concentrate on your most productive land, because there are some very good tree growing areas in Alberta. There are lots of very good spruce and pine stands in northeast Alberta. Should we concentrate on these low-productivity sites?

Bondy: Yes we should, because the government's goal is to diversify the economy for that particular region. For example, at some future date, a small pulp mill could be lcoated in the Ft. McMurray area. We are finding now, that the proposed oil sands operations will make a tremendous impact on forest growth. Those areas, which are now in jack pine and muskeg will be some of your future producing areas for timber. We may find it economical in the future to drain some of those muskeg areas to enhance tree production. This is why we want very much to conserve the timber resource.

Going back to the comment you made (Ballard) for disturbances on the oil sands area, we are talking about dike areas, where we not only want erosion control measures, but we want a self-sustaining vegetative cover. We don't know exactly what soil depth will be required. But, the vegetation has to be self-sustaining, because once the oil sands companies leave, the government will be responsible for the next thousand years for any clean-up or maintenance. And, there is also the disturbance on the flat or tailings sand areas, where overburden or soil material will be placed on the surface. So, there are going to be two types of disturbance areas, and we will expect greater timber production from the levelled areas not the dike slopes.

Ballard: In tackling this problem of soil depth from the standpoint of tree growth and productivity, among the major areas for consideration are nutrition and water supply to the trees, and then stability against windthrow. If we can come up with some estimates of actual evapotranspiration and available water storage from climatic considerations, we can then make some estimates of what is required physically, in terms of soil depth for different kinds of materials. Since these materials will be disturbed during placement, it is probably easy to come up with reasonable estimates, because soil structure hardly enters the picture. From the nutritional standpoint, we may be able to apply fertilizers to bring fertility to appropriate levels. So, the residual question in my mind that I am not able to resolve is, given a soil with adequate water supply and adequate nutrient supply, what sort of minimum is there for stability of stands against windthrow? It may be Armson or Krumlik could answer this from their observations.

Bondy: Are there different soil depths for different cover types?

Macyk: There is some danger there. If you require returning the site to its pre-disturbed condition, will you make up for your shortfall if you require a metre of soil while before disturbance there were only six inches?

Krumlik: One has to carefully determine what was there before disturbance. Coming back to area, Lesko mentioned Syncrude would disturb 24,000 acres, which is 37.5 square miles. What percentage of the Ft. McMurray Forest is this? The Ft. McMurray administrative forest is few thousand square miles. I think the major objective is to prevent erosion and return vegetation to the area. I think any type of vegetation, like grasses or legumes will allow gradual native plant invasion and a forest will gradually invade the site.

Takyi: We are not only considering Syncrude's operation. We have to consider also, Suncor, Alsands and future oil sands operations. The areas these and other oil sand companies will disturb will, I am sure, be several hundred square miles, so this should be looked at on a regional scale. Why wait a century for natural regeneration, if you can at least get it started?

Armson: It seems to me, there is a pre-occupation with re-establishing what was there before disturbance. In some instances this is unreasonable i.e. in the case of a peat bog. It is really a question of vegetation management. If you wish to recreate a black spruce stand, we know how to do it. We also know the volume of soil. Using a reasonable linear parameter, depth, we can say it need only be "very shallow". The integrity of the stand will be maintained, if you maintain it against wind and so on. Once you start to open up that stand, watch out, because the trees are going to blow over in many instances. We have innumerable examples of this. On the other hand, if you want to create a wind firm stand that you can thin and produce a combination of pulpwood and sawn timber of various sizes, then you are going to have to go to a different kind of anchoring system, and your species will require a different kind of soil. You can stabilize most stands as far as wind is concerned, but there is not a "magic depth".

Lesko: We have different disturbed soils that we want to reclaim, some of it is just glacial till material disturbed on the surface. On these, you don't want to add any artificial soil layer. Just treat it, make a seedbed and seed it and the vegetation and climate will return it to the acceptable condition in a very short time. I don't think you have to wait for eight thousand years to know what the soils will do, because many studies all over Europe have come to the conclusion that, with the help of climate, most parent materials will evolve into the regional soil type in about four hundred years. Of course, if you have unconsolidated parent material and you get some help in the form of nutrition, preparation of a good seedbed and a good enough vegetation composition, it will be very much accelerated. From yesterday's presentation, it was very clear that there is no correlation between soil depth and productivity.

Bondy: Is there no correlation? So, you are saying that in Syncrude's case, ten inches of soil placed on tailings sand will support a self-sustaining forest?

Lesko: It depends on what material you put on. If you added 1 m of native sand, which is similar to tailings sand, it still would not improve the situation very much. But, if you put a mixture of heavy clay and good peat, in a much smaller quantity, it is going to improve the characteristics of the tailings sand tremendously. The trees don't need soil, the trees need water and nutrients. You could hang up trees in a chamber and spray nutrient solution on the roots, and they would grow very well. You have to have sufficient soil depth to keep the trees anchored. You have seen that tree roots penetrate into the tailings sand, so your rooting depth will not be equivalent to the amount of soil you put on. It will be mainly the storehouse of nutrients. Roots will go deeper and will use probably one and a half metres at least, in well-drained areas, to anchor themselves, which is more than sufficient. It is much better than the average situation in northern Alberta.

Krumlik: Based on my observations there is no correlation between soil depth and forest productivity in northeastern Alberta. Yesterday, I indicated that only two feet of soil were needed to grow first class or the best trees which I saw in northeastern Alberta. This was a slight over-simplification. It was one example of a certain stand of very good spruce, which had about two feet of soil available.

Now, regarding soil as an anchoring medium; the poor-growing jack pine is not usually blown over. Even on sandy soil (99% sand), roots were penetrating 60 to 80 cm. The pines were small and, if anything, were broken by the wind. Under very good growing conditions, white spruce, will grow about 25 to 26 m tall, with 500m^3/ha of standing timber volume. These stands are very susceptible to windthrow. The soil under the good white spruce stands is usually loam, with the root penetrating only to very shallow depths, since the white spruce is typically a shallow-rooted species.

Bondy: You are dealing with a different situation with oil sands companies. They will put back a uniform soil layer over all the areas (excluding the dike surfaces). What I want to know is; what uniform depth would be sufficient to allow a self-sustaining forest environment?

Lesko: We are going to get more than adequate productivity potential out of less depth. For example, when we put ten centimetres of heavy till and maybe 15 cm of muskeg or peat, and mix it to about 30 cm, it will be more than adequate to meet the minimum requirement.

Bondy: Even for a forest environment? Will there be enough soil moisture to support a forest stand, considering the underlying material will be very deep pure tailings sand?

Lesko: Yes. We are relying on soil moisture in the (amended) surface 30 cm and soil moisture in the underlying 50 cm (of the underlying tailings sand) to provide adequate moisture.

Bondy: Is that adequate for a forest stand? Has that been documented?

Lesko: Yes. You saw yesterday's presentations, that the available moisture (the difference in percent moisture between 0.1 bar and 15 bars) is more than ten percent even in the tailings sand. The reconstituted soil holds more moisture than is required - much more than a jack pine stand on sandy soils in the area. The reconstituted soil will have better productivity than the average productivity of the land which was disturbed on the Syncrude lease.

Ballard: What (Lesko) has suggested here, in terms of mixture of materials placed over a sandy base, has to be interpreted not only from water availability standpoint, but also in terms of the water retention capacity of that material in that particular stratigraphy. With relatively fine material introduced over coarse, the net effect is that this fine layer tends to retain more water, because the water doesn't break through into the underlying coarse material, so that the drainage and water retention will be different than if the material were uniform. A mixture of finer textured materials at the top is going to enhance the water regime more than could be predicted just by looking at that individual material.

Armson: I would like to turn this thing around. It seems we are tackling the question from the standpoint of what are the desirable attributes or depths. The materials involved cover a wide range of conditions. Why don't we turn around and say if by legislation you require that a forest or some other type of vegetation be re-established in relation to a particular location. Then, you say to company A, B or C, operating in the Ft. McMurray area to submit its strategies or plans, showing how it will reconstitute a particular forest desirable for the area of its operation. Company D, who may be working in the subalpine area with different vegetation, will perceive different necessary background information and attributes. You look at that and take it on its merits - whatever information is known for that situation. That is just a perspective and may really mean that the questions here (before us) are non-answerable.

Ballard: I certainly agree that there is no way that some soil depth requirements could be specified unless we specify the materials. Unless we are willing to specify the materials, which can only be done by looking at the areas in question, we cannot come up with a satisfactory number.

Takyi: I have to cut off the discussion on this item so that we may have time to discuss others. We now have to summarize our discussion of this item. Very briefly, I gathered that we cannot pick a blanket soil depth applicable to all mines; a mine or other kind of operation should be considered individually.

Takyi: (Lesko) What minimum depth would be required to guard against windthrow?

Lesko: If you have no impeding layer to hinder root penetration and if you put almost nothing on top of the tailings sand, it will be very firm, because your trees won't grow too big, and you will have deep enough roots to keep them firmly in the soil. You will have trouble with windthrow only if you have an impeding layer, either by poor aeration or high water table or compaction.

Takyi: Let us now answer the two parts of the question, which appear to me to require either a "yes" or "no" answer. (Is there a correlation between pre-mining tree rooting depth and post-mining rooting depth requirements, or between pre-mining soil depth and reconstructed soil depth requirements?)

Ballard: Unless you are willing to restrict the population that you're dealing with for purposes of making such a correlation, I would say there is no correlation. Only if you stratify the population so that you are dealing with a restricted group of materials and a restricted range of climatic variation and other stratificataions, can you expect to find any sort of correlation.

Bondy: Would you say there is a correlation between depth of material over the tailings sand and tree growth? Do you say six inches or ten inches would be sufficient so long as the material is of good quality?

Ballard: This business of rooting depth, I would think, requires some very specific definition. Is it the maximum at which you find any roots, is it the depth you find a lot of roots, or roots of a certain size class? For example, in the pre-mining situation, there may be a substantial organic layer and there may be a lot of fine roots there, but relatively little rooting in the deeper layers. In the reconstructed soil you don't have the same type of stratification with organic layers over mineral. You may well require quite different rooting depths to get a similar level of productivity. So, I don't think there is necessarily any correlation at all, because you are dealing with quite different soils. I just don't see how the depth relationship can be established in any sort of statistical correlation that is going to be useful.

Takyi: In the pre-mining state, you may have 2 feet of soil. Would we require the same soil depth when reclaiming the site? Will more be required?

Lesko: When you return say 25 cm and mix it to 30 cm depth, that does not represent the rooting depth. The ultimate soil will be much deeper than that.

Bondy: Is the tailings sand a good growth medium, or do you need a deep reconstructed soil over it? I wonder why established trees are dying on Suncor's tailings sand dike?

Lesko: This may happen because of insufficient addition of amendments or competition problems. We have seen some of the information presented by Al Fedkenheuer, where although the reconstructed soil was only 25 cm, root penetration was as deep as 50 cm. The (underlying) material was not toxic or poorly aerated. There was no zone to impede root penetration, there was adequate moisture and percolating nutrients.

Takyi: Selective Materials Handling: For this you need a grading system for your materials. Are they good or bad?

Armson: I propose that they are neither good nor bad. They have attributes which fit your purpose, or don't fit your purpose. If they fit, you select them if they don't fit you dump them.

Ballard: Looking at this second question and making an assumption; let's assume that for a particular species and for a particular level of productivity and considering your management options, you conclude that it is desirable to have some organic matter to incorporate in the reconstructed soil. Whether, as the question asks, thin LFH, Ah horizons are worth saving, may well depend on what the options are. For example, if there is muskeg, if there happens to be an area with deep peat deposits that could be used, the efforts involved in saving thin LFH and Ah materials would be ridiculous alongside the possibility of mining peat. But, where one does not have that kind of option, this may well be something of an economic advantage.

Macyk: If we are talking about the forested area, which includes the oil sands, foothills and mountains, I don't think under any situation, whether we have peat or not, that it is reasonable to suggest that anyone saves these organic layers. One could save what we refer to as the upper lift, which may be the upper 30 cm. This is important not only from the nutritional point of view, but it has been documented that it may be a good source of native plant materials in regeneration. I don't think the amounts of nutrients in these thin layers have strong influence on the nutritional requirements of the planted trees. Note that these layers are not lost; they are only "diluted".

Lesko: I do not think we really have to consider the nutritional problem here, because this could be readily corrected.

Takyi: Is it the general agreement that if the LFH and Ah are thin they could be stripped along with the underlying material to say the 15 to 30 cm depth?

Macyk: With the size of equipment you area dealing with, I don't think you should consider anything less than 30 cm. With the type of operation I know of in the foothills, to strip 15 cm off with available equipment is difficult or even impossible. Perhaps the word "thin" in the question should have been qualified.

Takyi: It appears that the overriding question would be the ability of your equipment to strip these layers separately.

Macyk: It is inherent in forested areas in the province that these layers are generally thin.

Lesko: There are two questions under item two. First, "is there a need for selective materials handling?" I would say it depends on the circumstances, sometimes there is the need for it and we can improve our reclamation quality by selective materials handling. In our (Syncrude) operations, we selectively handle peat and other good quality materials to improve the quality of our reconstructed soil, rather than using the random overburden. The same, I would think, should be applicable in the foothills. The answer to question (a) "Are thin LFH and Ah layers worth saving?" is no.

Bondy: Normally, we would not expect a company to selectively handle those thin layers. We normally deal with blended material. The question is, how much of the blended materials do we need? What would be the quality of underlying material in the reconstructed soil?

Macyk: I think selective handling is done to gain some of the physical properties of the material, rather than nutrients and organic matter. In the foothills I don't think it is reasonable to expect more than the removal of one lift of the material because in a lot of cases that's all you get above the consolidated bedrock.

Bondy: After the land has been logged or cleaned in readiness for mining, is it worthwhile to salvage logging slash not yet decomposed along with the surface material, or should it be handled separately?

Ballard: Economics may not justify it being handled separately. However, if there is concern that stripping LFH and Ah is uneconomic, I would, consider handling the logging slash separately.

Bondy: It is handled separately anyway. They bulldoze it and burn it. Is this a good practice in the foothills area?

Armson: I would say yes. If you are going to take your slash and chip it - we have done that in the east - and put it down as mulch or incorporate it, you are asking for problems, root nematodes love those situations in our climatic conditions. Generally, you should be hesitant to move into mulching unless you are very clear about why you are doing it. If you go into heavy fertilization, then you have a different situation.

Bondy: Chipping would be expensive.

Armson: If you are going to have a general distribution of unchipped debris, you will usually have beneficial effects.

Ballard: I doubt if you will get an adequate distribution when you bring it back to get the benefits to make it worthwhile if you are concerned with erosion control.

Armson: I agree. What is the time interval between clearing the site and returning the debris in readiness for revegetation?

Bondy: From one to five years.

Lesko: I could see some benefits in erosion control in this, and also the creation of some microsites at the seedling stage. I cannot comment on the cost benefits. Proper redistribution may be very expensive.

Takyi: Let us get on to items 2A.2 and 2A.3. What are the expected changes in organic matter and nutrient levels resulting from disturbance and how do replaced soil chemical and physical properties compare with the original soil?

Macyk: There are drastic changes in structure and all things related to bulk density, compaction, etc. Many people have, in the past, assumed that areas that have been mined have high infiltration rates, high permeability, and water moves through very quickly, resulting in rapid fertilizer losses. From some literature I reviewed recently and from my own work, I have found that infiltration rates can be very highly reduced, some by ten fold on reclaimed surface having a vegetation cover established for three years, in comparison with an undisturbed adjacent site. The reason for this is that you are putting back a mixture of A, B and C horizons, which are generally high in silt in the foothills and that material seals up quickly with equipment moving over it and with rainfall. So, the physical properties which have bearing on water retention, are changed rather drastically. Our experience has been that these reconstructed soils will not accept large amounts of rainfall at one time, so erosion problems arise. Several years after the vegetation has established, the situation improves as the vegetation cover opens up "cracks" in the soil.

Adamson: I have done some work on the Highvale mine and found it difficult to measure organic matter, when you have a lot of coal incorporated with your material. There is always the attitude that coal is a source of organic material. What the exact relationship it had with ordinary organic matter we just did not know.

Ballard: I imagine this problem of coal versus other organic matter is similar to the problem we have had in forest soil that has been burned. Often, we would like to exclude the charcoal. We often find that analytically, it is nice to do something like a Walkley-Black wet oxidation, which leaves a lot of that unattacked and gets the organic matter that is likely to be biologically somewhat more active.

Bondy: In the foothills area, are we dealing with enough organic matter to make any difference? The situation is different in the oil sands area, where lots of muskeg is available.

Macyk: I will take an extreme case. If you have a 15 cm profile and in that you have an LH, Ae, Bm and whatever, the proportion of organic matter is low. Scrape it, mix it and use it. I have to add that, to a certain extent, it will have a bearing on the tilth of your material. Certainly anything will help. In this case, it does not hurt to have it, but do not give it any special treatment.

Takyi: I would like to direct this question to Lesko. In Syncrude's and Suncor's operation in Fort McMurray, peat has been stockpiled for several years. What change has stockpiling had on peat?

Lesko: It is almost impossible to get a complete separation of the peat from mineral soil when stripping. In stripping say 1 metre of peat, you have to go down deep enough, say another metre, to get to the material with enough bearing strength to hold the equipment on the surface. The peat, therefore, is stored, mixed with considerable amounts of mineral soil. I don't have much evidence, but the temperature in storage would be low, and there would be little aeration. I don't expect significant decompositon for quite a few years.

Takyi: Are you saying that when the peat is stockpiled for say five years, there are hardly any chemical and physical changes when you go to use it for reclamation?

Lesko: I do not expect significant changes.

Krumlik: I think with the pH of peat between 3.5 and 4, it would be well preserved.

Takyi: Some of these peats are near neutral in reaction.

Bondy: In the foothills area, the organic matter levels are so low that they may be considered unimportant in most instances. Is that fair enough to say?

Ballard: In the foothills, if you can demonstrate the need for organic matter, you may best opt to build your own organic base from vegetation. In reclamation there, you may find it impossible to go immediately to forest. You may be concerned with immediate stabilization and cover establishment early successional vegetation and use to hang on to nutrients. The subsequent stage is to go on to some kind of long-term plant cover, i.e. forest cover.

Armson: There are some examples of large scale commercial peat operations, in relation to forest tree nurseries, where they stockpile for 2, 3, 4 or 5 years and there has been no indication that the peat has deteriorated so that it is less useful.

Macyk: There are bogs in the foothills and certainly these materials could be used as amendments, if they are within the mine leases.

Takyi: Question 3. "What criteria should be used to distinguish suitable materials?" for reconstructing soil in reclamation.

Let's assume here that we want to grow shrubs and trees in the forested regions. Let's generalize. The emphasis of the question is on the "criteria".

Krumlik: From data I presented yesterday, if you have 99 percent sand and one percent clay, that would be suitable for jack pine.

Bondy: Good jack pine? Or just barely surviving?

Krumlik: What do you consider good jack pine?

Bondy: A stand that might be harvested someday.

Krumlik: In the whole summer of 1978, I don't think I saw a stand of jack pine that would be economical to harvest.

Bondy: How about for a cover to control erosion on reconstructed soil?

Krumlik: Fire is a very important factor in northeastern Alberta. We saw a lot of stands which were burned 15 to 23 years ago. The LFH layer is completely destroyed, but after 23 years, it was covered sufficiently that there was no big erosion problem.

Takyi: That was not a reconstructed soil.

Bondy: There are certainly poor stands of jack pine, say on the Syncrude lease, but there are also areas of good stands for white spruce growing on better soils; these areas should be reforested. The unsuitable materials, which will not support tree growth, should not be used during afforestation of a particular site.

Macyk: In considering this question we have to generalize a bit. We don't have to specify jack pine or spruce. I think we should consider a mixed forest type stand. We have to look at the soil - what are its important properties? What are the pH ranges, textural ranges of the soil, etc.? Would loam be satisfactory to jack pine, white spruce or lodgepole pine, or whatever? I think we have to consider a compromise. I don't think anyone would like to put back ninety percent sand here, because you are aiming at growing jack pine and some other species somewhere else.

Armson: The type of sand, whether coarse, medium or fine sand, is absolutely critical in terms of the moisture relationship.

Macyk: In a nutshell, it relates to what you have, and the quality of what you have. From here, you rate your materials good, fair, poor or unsuitable, then you establish your depth requirement, depending on your set priorities in your end land use.

Bondy: Will each site have to be considered individually? How about if a company comes up and says that it only has 5 cm of suitable material?

Takyi: In that situation, I believe there will be no licence issued for mining in the first place, if reclamation will not be possible. I think that will be the situation at the present time.

Item 5: "What areas require further research?"

Ballard: We have some idea of what the problems are and what factors need to be considered. It will be useful in future research first, to examine areas with the kinds of materials reclamation people have to cope with, to examine areas where past severe disturbances have taken place, whether natural or because of human intervention and see how these areas have (naturally) rehabilitated. This may give the "jump" on some research. In other words, look at soil-vegetation chronosequences on disturbed sands which are similar to the sands you may be encountering. A second aspect is to use available information to establish new trials which have sufficient scope to enable interpolation of treatment levels giving the target level of productivity after reclamation. This will help in planning areas like materials handling procedures, etc.

Armson: One further addition, I think the monitoring of growth in the operational treatments already in existence is very important. This will give you the background information - not just "cause and effects" all the time, but it will tell you what is happening.

Takyi: Any more opinions in the areas of future research needs? There may be a situation where it is not a question of returning a site to species X. It becomes a question whereby one has to find the right type of species or plant communities to suit a given material. What types of research would be needed?

Krumlik: We need further research in the area of silvics of forest tree species in northeastern Alberta. From the work I did in the province, (I found) there is an absolute minimum information on tree productivity in northern Alberta, and I think we need to understand better what parameters are required for optimum tree growth and the seral sequences of the different forest types.

Adamson: There has been concern about saving LFH and Ah, because of the organic matter content. The role of coal as a possible subsitute for organic matter in the foothills could be further studied - especially in the establishment of trees.

Bondy: Presently, it is required that the waste coal should be buried four feet deep, because it may heat up the surface. I understand coal could be detrimental to plant growth when left on the surface.

Adamson: I was considering incorporating it with other materials, so that it is no more than one to three ratio of the growth medium.

Ballard: I wonder about the necessity of putting the coal below the surface for the main reason of avoiding high surface temperatures. The reason I raise the question is, because if the coal bearing material has a large mineral fraction, then the thermal properties will resemble more those of a mineral soil and will probably result only in slight changes in the net radiation at the surface during the time vegetation is establishing. I would like to see some hard experimental evidence to support this.

Bondy: I do not see any organic value in the coal; considering there are other properties of the materials. Are there in fact calcareous materials which are contemplated for use in rehabilitation?

Macyk: Some of the materials in the foothills are high in calcium carbonates.

Ballard: So it would seem to me that may well be a problem, given the rainfall situation.

Macyk: There are some species which can tolerate that.

Armson: Jack pine will grow through free carbonate soils. We have many examples of that in the boreal in northern Ontario.

Ballard: With the free carbonate right up to the surface?

Armson: We have rehabilitated old railways cuts in southern Ontario, cut deep into the free-carbonate materials with jack pine. The only problem is you have to put organic matter on the surface, otherwise they grow very slowly. They will root freely through carbonates.

Ballard: Yes, they will root through it, but will they tolerate it right up to the surface?

Armson: Yes, right up to the surface.

Krumlik: It is the same situation with lodgepole pine in northern Alberta. The soils were around pH 8 or 8.5 and extremely effervescent. The pines were not the best, but were growing.

WORKING GROUP III

H.P. Sims	- Alberta Environment, Moderator
K. Natsukoshi	- Manalta Coal Ltd.
W.L. Cary	- Suncor Ltd.
G.M. Coen	- Agriculture Canada
D. Pluth	- University of Alberta
P. King	- Alberta Forest Service
W.D. Holland	- Canadian Forestry Service
R. Johnson	- Montreal Engineering Co.

DISCUSSION

Introductory Comments (P. Sims)

We've all heard people throw out figures for rooting depths, or talk about putting back a given rooting depth after mining. Some of the presentations yesterday showed that it may be more complex than we had imagined.

Coen: Is there a correlation between topsoiling and rooting depth? I would say there is no correlation unless you indicate what it is that you want to grow and why. What kind of productivity is wanted? Then you could start to talk about the depth requirement.

Cary: For the Oil Sands, I'd have to agree. You've created a completely different environment after you've mined, and there's absolutely no correlation between the muskeg bog that there was prior to mining and the tailings sand that you have after mining.

Sims: If we have to add some amendment to tailings sand to get jack pine or grass to grow on it, what would be their normal rooting depth requirements? We're not concerned with the fact that the area previously had muskeg and tamarack, black spruce and sedge.

King: As Dr. Coen said, given that for your end land use, you've decided on some particular crop, there is a definite rooting requirement. That land use decision has to be made before any further discussion on rooting depth is possible.

Coen: It is also possible that if you have an important site and you're short of soil materials, you might substitute water and nutrients for materials. Provide a shallow rooting depth and provide water and nutrients from external sources. This is providing that you have enough anchorage for the tree. However, I would imagine the cheapest way to provide enough water and nutrients would be to provide rooting volume.

King: I think you also have to consider the fact that reclamation legislation defines satisfactory reclamation to be that which is self-maintaining. This would mean that a reclaimed area requires no artificial inputs in the long term, such as irrigation or fertilization.

Coen: The system may be engineered so that water is channelled onto a reclaimed area or you might engineer it by using peat moss to provide nitrogen and phosphorus through decomposition and still end up with the same amount of water or nutrients.

Sims: This is what the project of Richard Johnson from Montreal Engineering Company is trying to do. The project is trying to define forest community requirements in terms of water, nutrients and other soil factors. This would give us some idea of what the plant-soil system is capable of doing and help define the depth of soil which must be put back.

As Wil (Holland) indicated yesterday, it is difficult to say where the roots are going to go anyway. If some material has good aeration, no compaction, etc., the roots will occupy whatever is available. Wil, what information is available pertinent to soil depth requirements in the Eastern Slopes?

Holland: Little in quantitative terms. It is possible to root trees to 6 or more feet, but I think we could grow a reasonable tree crop on 4 feet or 3 feet or 2. Does this mean that you only have to put back 2 feet? Other variables come in. There's no way I can talk about soil depth in isolation. Our observation is that you need a loose, friable soil. Something with a bulk density of 0.93 or something like that, will give you more root volume. But, if it's high elevation and cold, it's not going to matter if you have 6 feet because the trees won't be able to use it anyhow. I don't know how to deal with the question.

Sims: It would be difficult to say how much material is required. I think we'd be looking for the minimum, not necessarily that for maximum growth. What's the minimum that must be put back to restore the productivity prior to mining? Is there any way you can get at that?

Holland: I hate to come back to these variables all the time. What are you going to do about topography? Are you going to restore to the same contour, or are you going to flatten it out from the original contour? As soon as you flatten it out, it makes a difference. If you leave it at the same contour, you're going to have erosion before you get started, and it will be far more difficult because much of your water is going to run off.

Coen: We're trying to deal with the system as a rooting volume. I have difficulty dealing with it in the absence of different layers. If you are mixing the organic horizons and the non-calcareous material with the calcareous material below, you're dealing with a different situation than if you were just to use the calcareous material. In terms of supporting growth, the amount of available water needed in the calcareous-rich material is considerably more because the moisture stress is affected by the salt.

If you're going to destroy natural horizons, I think you'll need more rooting depth. If you're going to set a guideline, you'll have to set it for the worst possible situation.

King: It is unrealistic to expect that a reconstructed soil will restore an area to high productivity immediately. Even if little rooting volume is available for a reconstructed site, a fair level of productivity could be restored by vegetation management. This would allow some flexibility in establishing rooting depths, but unfortunately, it's a longer term proposition.

Sims: The question comes back to what to you need. I doubt that we have any good data that would indicate whether a site with 110 cm of soil having good productivity would suffer decreased productivity if we had 50 or 60 cm of rooting depth.

Holland: If you take a site and disturb it to 180 ft., I doubt very much you're going to pack it nearly as dense as the ice did. So, right off the bat, you should have an increase in productivity.

This was brought out by one of the Toogood (Dr. J.A.) studies on pipelines, where farmers were complaining that they weren't getting enough compensation for the disturbance, and they found that the productivity was higher over the pipeline than in their undisturbed fields.

Johnson: Is bulk density an accurate enough description of the rooting environment? Can you use that as a single parameter in terms of improvement?

Sims: Bill, on the dike slopes, have you got any measurements of bulk density?

Cary: Yes we have, but I don't remember them.

Sims: As I recall, some of them are pretty high. I know there was some concern as to whether or not there was a blockage of root penetration at the interface between the part that was tilled and the bottom, because some of the bulk densities were high in the sand.

Cary: We have to compact the dike sand to maintain the stability of the dike. I think they're talking in terms of 1.2.

Coen: Yesterday, a bulk density of 1.3 in sand was said to inhibit root penetration.

Cary: Tailing sand is unique in that it is very uniform in size, and has a high void volume.

Holland: There is some information in the literature which would indicate that some tree species will tolerate higher bulk densities than others. Between spruce and pine, I would suspect that pine requires a somewhat lower one than spruce.

Johnson: Mr. Armson pointed out yesterday that white spruce could penetrate much higher bulk densities than pine could, simply because of the size of the roots. So you're right, there is a difference between species.

Sims: Making inferrences from natural stands on tree requirements is confounded by fire history. I've seen good pine that grows on a heavy till with a shallow watertable. It's about 130 years old now and it's starting to fall apart. Spruce is starting to come in.

Johnson: However, is the reverse true? Is it also true that where you have only jack pine, the soil texture, bulk density, moisture content, nutrient content, etc., may preclude invasion by white spruce? I suspect there's a cut off limit for white spruce. There are areas that are amenable to reforestation or afforestation by jack pine that are not amenable to afforestation by white spruce. Yet the reverse is not true. Every place that white spruce can grow, jack pine can probably grow.

Sims: If it could get started there.

Johnson: It seems to me that you have a vegetative definition of these characteristics of soils which represent minimal properties of adaptability.

I don't see how we can talk about depth without talking about bulk density, without talking about water, without talking about a lot of other things.

Cary: If there is a minimum of water, is it generally better to have deeper soil?

Johnson: Yes. As Mr. Armson pointed out to me in a private conversation yesterday, the root "sees" the soil by the volume it can exploit. If water is the critical element which it is missing, it would seem that productivity would be limited by the volume of soil water the root could exploit.

Sims: I would agree. For fifty years a stand might do well on a shallow soil, but maybe one year in fifty a drought may be critical. I've seen this on jack pine sites, where there is a hard pan. Most years they do fine, but in a dry year they have limited volume from which to draw moisture. In those years, the stand gets knocked out or you get drought damage. In other areas which are just as dry but don't have that hard pan, you don't get the same damage. Those areas where you have that hard pan also seem to be more susceptible to insects, disease and other things.

Johnson: From what you are saying, I get the impression that water is the determining factor in the stability of jack pine site, excluding fire.

Sims: They do exist on very impoverished soils.

Johnson: In that case, if we can eliminate some of the complex problems, nutrient cycling for one, and concentrate on water, then the problem is of a different nature.

Sims: I think for any species in the boreal, the critical factor is moisture. However, if you give them maximum nutrients and maximum water, you'd increase the productivity of all of those species.

Johnson: I've seen evidence in the literature that makes me question that. It is the relationship of alder to plant succession. Alder seems to play an important role in a lot of areas in the boreal forest. I think that this must be due to its nitrogen-fixing ability and the quality of the litter it lays down. Nutrient relations are changed greatly under alder. That's the reason why I wonder if water is the limiting factor.

Sims: To confound matters, alder is usually present only on moist sites. I don't think that on alder sites anyone has sorted out whether the productivity is due to water, nutrients or some combination of the two.

Pine sites having a large alder component are quite productive, but in a lot of cases, the alder is very scattered. I'm sure there's not enough there to make any significant contribution to the nitrogen content of the soil. But if moisture is high, and even on sites where there is no alder, the productivity is high.

Johnson: After deglaciation in Alaska, the curves of soil nitrogen after alder succeeds another plant community there's an enormous jump in organic nitrogen.

Sims: At the beginning, there may be alder on a site that will give pine a little jump.

Johnson: I'd like to ask Wil (Holland) a question. As you did your soil profiles, did you find that water was the primary determinant of not just productivity, but also of minimal soil standards for tree establishment and growth? And I stress the word minimal.

Holland: I wouldn't isolate it as the only controlling factor. It is one of the major factors that controls productivity. We know that many of our forest stands on the Eastern Slopes go down to the wilting point every year.

King: At the risk of over-generalizing, I think you could say that the situation on the Eastern Slopes is somewhat more complicated than elsewhere. There are so many confounding factors: elevation, slope, aspect, topography, parent materials.

Sims: How about things like windthrow?

Coen: Some of the worst windthrow areas we've got, in terms of disturbance, are white spruce on west facing slopes where the soils have been churned up to a depth of 2 or 3 feet. However, I don't think it's so much soil-related as it is exposure and tree size. Where we've got shallow, silty materials over dense tills and lodgepole pine, you don't see much evidence of windthrow in the soil.

King: During our discussion we have seen that factors such as moisture, nutrients, topography, soil density, soil texture and nutrients are tied into required soil depth. Wouldn't a modelling approach work in giving us some predictive capability given certain critical factors?

Johnson: I think that's the only way to go. The situation is so complex. You may get it down to two or three factors, but you can't get it down to one. We can start with a simple model and refine the model as reclamation experience proceeds.

Sims: Is there a need for selective materials handling? Are thin L, F, H, Ah horizons worth saving in light of the realities of soil removal and placement, changes in organic matter and nutrient levels resulting from disturbance? What kinds of materials are available besides soil?

First of all, how thin a horizon can be practically removed?

Cary: Two feet probably. You may get down to one foot with the proper machines.

Natsukoshi: We've salvaged down to 15 cm. In the Plains area it may be different, but in the Plains you can save less than that.

Cary: Are you using scrapers?

Natsukoshi: Scrapers and bulldozers.

Sims: How about the importance of saving L, F, H and Ah as sources of microbial innoculum?

Holland: Jim Dangerfield has done some work on that in B.C.

Sims: When Dennis Parkinson got started on his work in Calgary, I talked to Jim Dangerfield. He said that just sorting out the identification of some of the mycorrhizal fungi and dealing with some of the very specific relationships between plant and mycorrhizal species would almost be a lifetime's work.

Johnson: I don't think there's any question about the variability of mycorrizae. And I don't think you can forget all of the other endophytes. Nitrogen fixing shrubs need a specific innoculum. Micro-organisms probably don't have to be cultivated under laboratory conditions, but provision has to be made for their reinstatement into the growing media.

Sims: In the Eastern Slopes, what kind of materials handling are we looking at to save material?

Coen: It seems that the conclusion we came to for the last question also applies here. Once you decide what is required, you can decide on a means to provide it. If the cheapest way to provide mycorrhizae is to save the L-F-H, that's the way you're going to do it. If you aren't going to save L-F-H because it's too difficult, you'll have to culture the organisms. You'll then have to supply the organic matter as well as the innoculum.

Sims: So, you can't save a couple centimetres of LFH material, but you can take off the first 30 cm and incorporate that material. Would you be destroying the microbial productivity of that soil?

Johnson: I don't think so. I can't help but think that you're providing the optimum medium for these micro-organisms. The question that I have is, should we only be talking about microbial populations? What are you going to do about the other biological attributes of soil? Organic nitrogen, total carbon, organic carbon? Aren't those major considerations in plant establishment and productivity? And if they are, do they have to be simulated in a reconstructed soil?

Coen: I don't think so. That happens to be a nice way to provide structure, nutrients and water, but it may not in itself be all that essential. If you can supply the nutrients, water and the microbial populations without providing it in that organic form, then I say more power to you.

Sims: If you take thin organic horizons along with some mineral soil, mix that up and put it back, you change moisture and temperature relations. Does it break down more quickly? Are you in danger of losing the organic matter?

Cary: I don't have the experience to answer that question. I really don't know.

Johnson: I'm a little bit worried about the use of peat as an addition. Oil Sands work has shown that when peat is applied to tailings sand with the right nutrient and water mixtures, its gone.

Cary: What's gone?

Johnson: The organic matter. It has broken down, evolved as carbon dioxide. The micro-organisms use carbon as an energy source, it's gone. If you can use peat to soil replace organic matter, I think they have the solution, the perfect solution. But, I think it's necessary to say how close those two things are related. Do they perform the same function, in the same way?

If they don't, by just using some extra peat, can you make up for it? It's an important question for Oil Sands Reclamation.

Cary: After nine or ten years, I would say the answer is "yes". On plots that are now ten years old, the peat that was put there originally is still there, and hasn't wasted away.

Johnson: Mike Rowell, in one of his reports, suggests that peat is being decomposed and replaced by root material.

Cary: I don't recall.

Coen: Do you mean that when you dig a pit, you can pull out and examine the peat, you can see the cellular, intact structure of the Peat?

Cary: Yes.

Coen: The reason that I asked that, is because if you're using total carbon or organic carbon, your total may not have changed very much, and yet you could have had all of your peat cycled into some other system.

Cary: But you can actually define peat and see it there.

Coen: The moisture content throughout the year and the nutrient supply in those systems is adequate that you'd expect decomposition.

Cary: I couldn't say about that, but it's growing good grass.

Johnson: Yes it is. It's not optimum. Tailings sand probably would never be an optimum soil for any kind of growth. But yes, they do get good grass growth and they have even ceased fertilization in some cases for the last 4-5 years. Some of that information is absolutely vital to what we've been discussing for the last two days, but hasn't been published. It would give a good lead in as to what the real problems are going to be.

King: Richard (Johnson), has anybody ever examined the carbon cycle in this situation?

Johnson: Mike Rowell and McGill (W.B.) have done about the only studies I've found on defining the biological relationship of tailings sand reclamation. Oddly enough, he (McGill) stresses the need to get a handle on nitrogen. He wants to use the heavy isotope of nitrogen N_{15} to find out what is happening in terms of the nitrogen cycle. I personally think that it would be much more important to use a radioactive sample of C_{14} and find out what happens to the carbon rather than the nitrogen. One's related to the other. You could not only predict the nitrogen, but also other things if you knew what is happening to the carbon. The answer to that is no, in terms of knowing what's happening to organic carbon.

Coen: Part of his rationale might be that nitrogen N_{15} is so much easier to work with than other isotopes.

Sims: There's a lot of work now with carbon, nitrogen and sulphur isotopes for tracing processes. It's now common and not too difficult to do with any of them.

I'd like to get back to this question of breakdown of organic matter in the soil, and to why one would expect six inches of peat incorporated into tailings sand to break down any faster than an organic horizon in a natural environment. Richard, do we have any information on turnover times in the boreal forest?

Johnson: Foster and Morrison are doing the work in jack pine and are looking at turnover of all nutrients and their distribution in tree canopies and the root systems. Anybody interested in oil sands reclamation should take a look at their papers.

Sims: Do you agree with all of the figures they have in their compartments? Some of them seem rather strange to me.

Johnson: Mr. Armson told me last night, that when Ian Foster publishes a figure, you can put your life on it. I think, in fact, that Foster did his masters degree under Ken Armson.

Pluth: What type of peat are we dealing with?

Sims: We were discussing whether L, F, H, Ah horizons can be saved. I don't think we have a good handle on the kinds of peat that are available in the oil sands, and I'm not sure that they can be easily segregated.

Cary: First, I don't think that for Suncor, it would be feasible to salvage L-F-H horizons, because they are very thin. We have plenty of organics in these muskeg peats. There's too much of that and we can pick and choose what we want. As for the types, I know that Don Klym has looked at the types and tried to decide whether it's feasible to segregate them and he had given up. He doesn't segregate types.

Sims: Are there vertical changes in peat type?

Cary: There are.

Sims: In a bog area, would you expect there to be much vertical change? I'd think that with succession, you'd get changes in peat types.

Johnson: In peat bogs, the whole process of humification would have an effect. As you move down in the bog, there'd be more mature peat types.

Pluth: There's the bog and the fen. The bog dominates the upper part of the profile with sphagnum sources of material. In the fen, it ranges from materials from sedges to shrubs and trees. The differentiation of types does exist vertically.

Johnson: Could I ask a question of Bill, who probably has the most practical experience in the area. Are you sure that peat is required to replace organic carbon? I've never really seen anything that would say to me that you have to have peat to replace organic carbon.

Cary: I think that what has happened, is that it has been assumed that we must use peat because we have to meet legislative requirements. Peat is the easiest available material to do that.

Sims: I think in the oil sands, that there were initially some assumptions and guesses made and they have hung on. One of the reasons we got Montreal Engineering Company to do this study, was that there was really nothing conclusive out of the original research up there. Hopefully, the information that we get out of Richard's report will confirm whether some of the practices were valid.

Coen: Even if the only purpose that peat serves is to control erosion until a grass cover can be established, it would seem that that is reason enough to use it.

Johnson: I agree, peat is absolutely necessary for erosion control on the dyke slopes. But now the question is, how much is necessary? So far, about 15 cm has been used, but for erosion control, maybe all that's needed is 7.5 cm or 5 cm.

Sims: I don't think that peat was originally used for erosion control. It was something necessary to get an erosion controlling cover.

Maybe we can get off oil sands for a minute. I don't really know what we can say about saving L-F-H in the mountains and foothills.

Johnson: What are we going to do about permeability of soils in the foothills area?

Holland: It's exactly the problem in that road slide that I showed you yesterday.

Johnson: Exactly! That strikes me as being one of the major practical problems of reclamation in the foothills. Reclaimed soils seem to be very impermeable, and an organic addition would increase the permeability.

Sims: Sometimes permeability is a problem, sometimes it isn't.

Johnson: I'm talking about situations where you bring up shales or other fine textured materials.

Sims: That material seems to break down.

King: It also depends a lot on the spoil handling technique that you're using. A company which uses a wrap around dump method, gets a gravitational sorting of spoil and minimizes the amount of compaction due to equipment traffic on the spoil piles. A mine which handles most of their spoil by cat or grader could create some permeability problems.

Johnson: I would think that compaction and also sodium contents would be critical in affecting permeability. You may get some very crusty surfaces.

King: From my experience, some mines have had localized salt problems, but that is usually due to a lack of selective materials handling.

Sims: I don't know of any area on the Eastern Slopes where there's a major sodium problem, even when there are shales exposed.

Johnson: But there are some solonetzic soils in the lower foothills area.

Coen: I think that any place where you have till materials or some of the easily weatherable shales, there will be compaction problems. They do pack down quite nicely. They do have the right silt and clay contents to create a real permeability problem.

Johnson: Have there been any good erosion studies done in the foothills?

Sims: John Harrison of GSC has done some work.

King: Some work was done by, I believe it was called, the Eastern Slopes Conservation Board.

Coen: Dr. N.W. Rutter (U of A) has done quite a good study.

Sims: Bayrock and Reimchen did an erosion potential study for the Eastern Slopes, but I don't know that it was well accepted. That fourth point in the questions, what materials other than soil are available? What overburden materials would be useable for soil building?

Holland: By overburden I assume you're talking about aeolian and lacustrine deposits.

King: In coal mining, overburden is defined as being any material overlying the coal seam. It could include till, bedrock and weathered material. In some areas of the Eastern Slopes, there may be little choice but to use overburden in top-dressing.

Coen: If we can create a favourable growing medium by using non-soil material, go ahead.

Sims: Question three, what criteria can we use to distinguish suitable material (organic matter content, particle size, texture and nutrient content)?

Johnson: On question three, Percy, I've got a lot of doubt about whether organic carbon, organic matter and nutrient content should be included to distinguish materials.

Sims: Why do you say that?

Johnson: Because I suspect that with proper management practices, you can encourage their development. That it's not actually the nitrogen, phosporous and potassium content of the soil that's worrysome. It's the chemical and physical properties that will allow proper moisture regimes and non-toxic conditions to plant growth.

King: If you're evaluating in situ materials before handling, how reliable would some of the properties be? For example, bulk densities prior to mining may bear no resemblance to those after mining.

Johnson: That would certainly be a factor to be considered.

Coen: I can't help but feel that when you're talking about operations, that fertilizer is a fairly cheap way of substituting for some of the other things.

Cary: Fertilizer is still very cheap compared to moving materials. I'm talking about one hundred times more expensive to give the results you want, compared to fertilizer.

Johnson: For how long?

Sims: That's the question. How long does it take for it to be self-maintaining?

King: On a coal mine in south eastern B.C., I did a comparative cost studdy of topsoiling and fertilization. The break-even point came after about fifty years of fertilization. At that time, there was still no guarantee of self-maintenance on the high-elevation reclaimed sites.

Johnson: On the oil sands, the real question, from what I heard yesterday and last night, is not self-maintenance. There's no real worry about that, it's erosion control. That's the real worry. So it would have to be productive enough to control erosion.

Sims: In the mountains and foothills and on the dyke slopes perhaps, but on a large area of the oil sands, erosion control isn't any problem. On the mine area, they start with a uniform topography and there's no problem there.

There's been a large number of publications from the States, in which a large number of criteria have been laid down for rating materials for reclamation. Many of them are physical properties, and the main chemical properties are things like SAR, ESP and electrical conductivity. However, those are Plains soils where these things are of concern. So, are we looking at mainly physical properties then?

Cary: I would say so.

Pluth: And, upon weathering, that input creates imbalances. For example, the oxidation of pyritic tills.

Coen: I would consider that to be toxicity, but I suppose it wouldn't show up unless you were looking for it. Any source of sulphur could be a problem.

Holland: We haven't mentioned lime.

Johnson: You find that a problem? High calcium carbonate equivalents?

Holland: We've had everything from 0 to 65%. I think even up to 84%.

Coen: I think that in our montane areas, it strongly affects moisture regime.

Holland: It would certainly affect nutrients.

Coen: In the mountains and foothills, calcium carbonate can certainly have an effect on regeneration. Lodgepole pine ordinarily grows in a calcium carbonate rich environment. However, if you grow it and plant it into such an environemnt, it won't grow. It will usually die before its roots get large enough to supply moisture.

Sims: I think we'd better move onto the next question. I don't think we have any more to say about soil depth requirements. Five, what areas require further research?

Pluth: We need the concept of a benchmark. A few benchmark sites to try to answer some of the questions, which are more long term.

Holland: What kind of benchmarks?

Pluth: I think that, in the reconstructed soil, work is needed.

Johnson: Isn't the Forestburg project the type of thing that you're talking about?

Sims: The Plains area is a little different question, and the research effort there is an entirely different thing.

Johnson: But I'm saying that wouldn't it be logical to have the equivalent of the Forestburg project in the Foothills and in the Oil sands?

Coen: Would you need some benchmark treatments as well, that haven't been included so far?

Cary: How about the modelling approach?

Holland: We need some kind of modelling to handle all of these variables.

Johnson: We certainly need some work on water relations.

Sims: Where?

Johnson: In the foothills area and in the oil sands. I can't help but feel that you need some idea of nutrient requirements and forest growth on reclaimed soils.

Pluth: I think that moisture factors are the key. Nutrients are secondary.

Johnson: Is there a question about when you can cease fertilizer application?

Pluth: That's an open question.

Coen: But, if you're going to set up a benchmark site, it would seem reasonable that you would include enough information in it that you can make some predictions of when you would be able to withdraw nutrient applications. That should be included as one of the things that you should look at in designing it.

Sims: What do you mean by benchmark sites?

Pluth: Benchmark, in the sense that you establish a concentrated research effort, and it is holistic. And it's long term. And secondly, that question of being representative to what site conditions will be expected and from which you can extrapolate.

Sims: The problem in studying trees as opposed to agricultural crops and soil depth, for instance, is the period of time required. Do you have thirty years to wait? How do you get a handle on that other than studying natural sites? And, if you study natural sites, how do you interpret that when you turn everything upside down?

Holland: It may be enough to just compare juvenile growth rates on the two sites.

Sims: That may not be valid.

Johnson: As Mr. Armson said yesterday, about root growth, it drops off at 30 years while foliar growth goes on until 80 or something like that. Very interesting graph.

WORKING GROUP IV

H. Regier	- Alberta Environment, Moderator
H. Tomm	- Alberta Forest Service
R.J. Logan	- Luscar Ltd.
R.J. Fessenden	- Syncrude Canada Ltd.
D.N. Graveland	- Alberta Environment
D.B. Patterson	- Alberta Environment
G. Singleton	- Hardy Assoc. Ltd. (Representing Esso Minerals Ltd.)

DISCUSSION

Regier: So, starting with oil sands soil depth requirements, is there a correlation between pre-mining tree root depth and post-mining rooting depth requirement?

Fessenden: I think the answer was demonstrated yesterday: There is no strong correlation. There may be a very general relationship. There are too many other factors involved. The concept of supply and demand was mentioned yesterday by a number of the speakers. Depth is simply one aspect of supply.

Singleton: It is possible that the pre-mining tree rooting depth could be a template for establishing an objective requirement for a post-mining rooting depth?

Fessenden: Maybe we should define just what rooting depth means. Armson showed some pictures of jack pine where the majority of the roots were in the top 20 cm, and there was one root that went down for 20 m. Was the "rooting depth" 20 m?

Singleton: The natural soils in the area could be a very good template to define what constitutes an adequate rooting depth for a particular environment. Also, it would define the kinds of productivity that we should have as an objective for reclamation.

Fessenden: I think that for different species, the rooting depth is not important. I just don't think that it is productive to key-off with a perception of pre-disturbance rooting depth, whatever that is.

Regier: Maybe we should let this develop into Part B. Is there a correlation between pre-mining soil depths and reconstructed soil depth requirements? If a stand of trees has a metre of good material, that is fairly well rooted, is that something that we should be aiming for?

Logan: Another point to consider is your land use objective. You may have an existing area that is covered with trees, but afterwards, you may want to break it up a little bit so your depth of materials may vary.

Fessenden: Yes, when you design a soil, you have to do so in terms of your objective and in terms of desired vegetative cover, because the requirements for jack pine, would be quite different from black spruce.

Singleton: Even within a stand of black spruce, you have to define a desired level of productivity. We must first agree on a target productivity for a given vegetation type, then estimate what kind of soil system is necessary to support that level of productivity. The best way to do this is to venture out into the surrounding areas and find out what kind of soil characteristics generate that level of productivity.

Fessenden: The statement of productivity or the target of productivity is essentially a political decision. It is not a technical thing and the Government will have to set a target for the industry to meet. Presumably, it should bear some relationship to what is possible. You should take into account not just the technicial capability, but also the long range plans for a particular area and the economics of developing productive forest land in the northeast.

Singleton: I feel reclamation objectives are very site specific. Suncor is likely to be much different from Syncrude in terms of the materials that they have to work with in reclamation. So, the objective possible for Syncrude may be much different in terms of productivity than could be possible with the materials at Suncor's site.

Fessenden: I am happy in terms of the productivity criteria, and I think the requirement for re-restablishment productivity means average productivity on the lease area. This should be equal to or better than the average productivity prior to disturbance.

Patterson: When you design your reclamation plan, you don't design for the average, but higher to allow for leeway and redo work. Like the engineers you build in a safety factor.

Fessenden: Right, but nobody knows what "safe" is.

Graveland: You may have a desert after 30 years.

Fessenden: I don't believe that. We're a little more optimistic than that. I think it's possible to make quite a productive area. But nobody knows.

Graveland: Do you know the pre-disturbance productivity of the area now?

Fessenden: Yes, although most of the tailings pond and mine areas are cleared off. There were some pre-disturbance vegetation surveys, so we looked at the average productivity for the kinds of vegetation, weighted productivity of the various areas and worked out an average productivity, which I think is about $10ft^3/ac/yr$. So

that's what we're targeting at as an average lease productivity. But that doesn't mean that we're not going to try to go higher on some areas and lower on others. But, I would say, that it's within the perrogative of the company to decide where on the lease area it's going to have various productivities, as long as the average comes out.

Regier: Let's move on to Section 2. Selective Materials Handling. LFH: Terry Macyk said he wouldn't suggest a broom and a dustpan for litter recovery, and yet I remember a couple of speakers pointing out the importance of the LFH in the forest soils. What are the realities of soil removal, stockpiling and replacement?

Patterson: The biggest constraint, seasonal limitations, dictates when you can and when you can't recover soil.

Regier: Bob, in your operations, how much LFH do you usually have?

Fessenden: From a couple of centimetres up to maybe 10 cm.- that is in well-drained soils. But then so much of the oil sands area is covered with peat.

Regier: So, it isn't practical for you to remove the LFH?

Fessenden: No, not in our particular operation. I suppose there are some oil sands lease areas which don't have any muskeg or peat, in which case, LFH recovery may be required.

Regier: You have two sources of organic material, but does peat have the same capability of recycling and making nutrients available to plants as would 5 or 20 centimetres of LFH?

Singleton: At the U.S. Soil Conservation Service Symposium last March in Billings, I understand people there are finding that they're having to pull back their horns a bit in terms of discounting litter layers and surface layers of native soils. It seems the surface soil is valuable in terms of microbial composition, something that may not be easily obtained from peat. Also, surface material can contain a source for native vascular plants. Where it's possible and easily done, I think that a litter layer should be conserved. The other problem is with storage of these materials. If you put them in a big stockpile and leave them for a couple of years before you use them, you virtually eliminate most benefits of microbial content and seed source.

Regier: Regarding seed viability, the sooner you get it back in place, the better.

Regier: In forest areas, since the trees are knocked down first, is there much of a chance to recover the litter layer?

Fessenden: No, because you run into problems with stumps and rocks. Maybe if you try to put a scraper in and take it, but it's nearly impossible to get it off. You know, if you're talking about 20 centimetres, 15, 10 centimetres, it's nearly impossible. And again, we ask the question, it is necessary? Nobody really knows.

Regier: Getting away from the organic materials, how about the mineral soils, or even consolidated materials.

First, let's talk about the B horizon and unconsolidated materials below that. Are these materials worth retrieving and what characteristics should be outlined for selecting them?

Logan: As far as looking at soil characteristics, I think you've got to look at the site and the region and kinds of limiting properties that are going to be important. I'm not totally familiar with the materials in the oil sands, but I don't think we should be getting hung up on soil content.

Regier: I think organic materials, at least peat materials, are at least partially being recovered now, right? So, I think probably what we're addressing here are inorganic materials - fines, specifically.

Logan: I think tailing sands need something to help them along. But again, there would be mechanical problems, such as mixing in the clays. I like the concept of engineering a soil - looking at the different properties and trying to build it up so it has better moisture retention properties.

Regier: Glen, what do you think about collecting and incorporating fines?

Singleton: Well, I think it's a good idea, where it's possible and where it's feasible. The tailing sands and oil sands are quartz rich, 98%, say, in most cases. There are very few weatherable minerals, and although most of the forests in the area are highly efficient nutrient cycling systems, they're not 100% efficient. So they may run down over time, and I think you have to have a storehouse of nutrients and that would be in a form of weatherable inorganic materials (they can also come from organic materials). I see placing organic materials in well-drained positions as being a short-term measure. I see very few instances, in natural sandy soils, where there are large organic matter accumulations. In fact, most organic matter in well-drained positions is fairly unstable and can be broken down fairly rapidly. Peat is very good as a short-term measure, such as for erosion control. I feel mineral materials are necessary for a supply of nutrients over the long-term. I don't know that there are too many ways around that.

Regier: You've expressed my bias. However, is this feasible?

Fessenden: I don't think anyone argues against putting some fines in for the reasons that Glen expressed. Primarily, you need a long-term supply of things like potassium, magnesium, calcium specifically, as well as a source of trace elements. Some of those are going to come in with peat addition, but some of them should come in with mineral addition as well. I disagree with some of the things you said about organic matter. Basically, what you're going to be looking at over time is a transfer of the organic matter built into the Ap, if you want to call it that, and it's going to eventually end up on top as an LFH as the stand develops. But, although we're trying to achieve acceptable reclamation, we also want to do it most cost-effectively. And so, the question we always ask is, how little is necessary to get acceptable reclamation? That's not to imply that we don't want to be acceptable, it just means that you don't want to haul any more than you have to. I think it's being responsible to the company and also to society at large, because costs in reclamation eventually get transferred back to society.

Regier: Number 3. Physical and Chemical Characteristics. My experience with some of the surficial materials in the oil sands area is that, generally, they are of good quality for replacement and one need not try to differentiate, say tills from lacustrine materials. I think once you get into bedrock materials, you might want to be a little more careful. Is there a need for physical and chemical selection criteria? I would anticipate, for example, salt problems from some of the Clearwater Formation shales in the oil sands area. The glacial materials are fine.

Singleton: I have one concern here. I think a lot of the chemical properties of oil sand materials are too often evaluated on available nutrients as opposed to totals. If you're monitoring additions or losses of various elements to soil/plant systems, you should perform total elemental analyses as opposed to available. A lot of times available analyses are thrown around as being indicative of how these systems are behaving, and in fact they are often misleading.

If you want to look at the changes in systems over time, in terms of the gain or loss of organic matter, nitrogen, phosphorus, sulphur, then we should not continue to look at only available nutrients. It's preferable to have both, but if you have total, at least you can see whether, in the long-term, there's a trend towards an increase or decrease.

Logan: How far can you take that approach? You could take a rock, crush it and analyze for total composition, but this doesn't necessarily indicate the rate of weathering.

Singleton: If you have the total elemental composition, then you have a pretty good idea of what you're going to end up with.

By total elemental composition, I don't necessarily mean a great number of different elements. But, if you know the total amount of selected elements in the materials that you're working with, then you have some basis on which to watch it's genesis or its changes over time.

Fessenden: If you want to walk away from the system and be assured that it's going to look after itself in perpetuity, as so-called natural stands do, for the most part, then I think that you want to be assured that there are enough nutrients in the soil to support a jack pine or black spruce forest in perpetuity. I don't think those quantities are big.

Regier: How do these reconstructed soils compare to the natural soil systems? (And does it matter if they are slightly different if you are confident that through genesis they will become similar to the old system?)

Fessenden: In a reconstructed soil, a number of criteria have to be fulfilled. First of all, it must support an erosion-controlling cover. Then, it must evolve with that vegetation over time, to support a mature plant community. We must approach short and long-term goals: to build up erosion control and then meet some kind of productivity guideline. What that means is diffucult to say until better data is available. There are so many unknowns, that you're not going to know much until it is empirically demonstrated.

Singleton: I disagree with that because I think you do know what constitutes a stable system. All you have to do is go out and find a stable system in the natural setting, and that defines what your system is likely to become.

Fessenden: Yes, except that there is no parallel for what we're trying to do.

Singleton: No, but at least it establishes the necessary components, and you know if you don't have those things to start with and if you're not adding them somewhere in between, that you're not likely to get that end point. For example, if you require 10% fines to generate the level of productivity that you find in the natural situation and you don't have those 10% fines to start with, then you may not achieve your objective.

Fessenden: I would argue. You see, what's the function of the 10% fines? What are they really doing for you? It's not 10% fines, per se, but the things that they're contributing.

Singleton: That's right, so you have to study that whole system to find out what that contribution of the fines is. Maybe it's the watertable that's affecting productivity, maybe it's not the fines at all. But, you have to study that system very carefully to define what components are necessary for that end point to create the desired level of productivity. Then you can come back and ask: with these materials, are we likely to end up with that same kind of system.

Fessenden: Oh, I guess I'm skeptical enough about man's ingenuity that he could totally study the system. I think we could make a good effort. And, we can theorize and hypothesize, but until these things are demonstrated, we won't know for sure.

Singleton: What's the demonstration time period, though?

Fessenden: (Facetiously ed. note) Several thousand years.

Patterson: So, we're back to the original baseline and defining what you want for the alternate vegetation community. We still have to define the soil requirements which are associated with that vegetation community.

Fessenden: Well, if I can take a harder line, from an industry point view, I would say this: the government should define a target for us, because that's essentially a political decision, and then leave it to industry to achieve that target. I think the regulatory bodies should demand a statement of how one intends to achieve that, and be satisfied if they think it's possible.

But, I would hate to see guidelines or regulations come down to say you have to save this, you have to save that, you have to mix it a certain way. Don't tell us how to do it, leave it up to us. I think there should be check points along the way; checks against what the industry implementors say they will achieve.

Patterson: We talked about saving thin LFH's and Ah's, and sometimes there's no way you can do it. But if you have baseline surveys, if you've got available materials in depth so that you can reasonably salvage at any reasonable cost, then it should be done.

Fessenden: Again, my point of view, I think, is very simple and that is, if it's necessary, if one has to do it, then one does it. But you recognize the costs ahead of time and what the implications are. If you don't have to do it, then you don't do it. But you achieve the target as cost-effectively as you can. That's why I think the guideline, the regulation, should never tell you how. It should just tell you what you're trying to do.

Patterson: Well, I don't think it ever will tell you that.

Graveland: We did some analyses on tailings sand, and if I remember right, my impression at that time was that, excluding the biological components, the tailing sands had probably better physical characteristics, and similar chemical characteristics to native sandy subsoils.

Singleton: Well, it depends what you mean by chemical characteristics.

Graveland: I'm talking about inorganic.

Singleton: If you're talking about available nutrients, I'm sure that is the case. Now, if you talk about total, I think that is a different case, because natural sands in the area are of fluvial or aeolian genesis, and come from a variety of different source areas. They have quite a variable minerology.

Their nutrient status is low, but they do have a variety of other minerals as well, and I think that's the thing that's overlooked a lot of times when you look at strictly available nutrients. Minerology is definitely important.

Fessenden: Yes, there is some feldspar and mica in the fluvial sands. It's not high, but it's there.

Patterson: I looked at a number of soil pits on the Alsands lease, and as you say, there are a number of combinations. In fact, there are a number of holes where there appear to be combinations of materials. You may start with a fluvial base, then a fire, and next you have aeolian deposits stacked on top of each other, I think there are a lot of benefits from that sort of stratification.

Regier: I think in answer to what criteria we use to distinguish suitable materials, we have to first study this system and determine the limiting criteria, then apply these to soil reconstruction requirements.

Singleton: I think that can be most generally agreed on from the whole discussion yesterday, except there is not just one criterion that can be used. Maybe it could be used as an index, but I don't think it's decisive. I think the objective that we should be striving for is very similar to what George Krumlik presented. He showed a number of different sandy soil materials with different levels of productivity. We need to define the characteristics of these soils in terms of their buffering capacities, nutrient regimes, total elemental compositions and the influence of the litter over the mineral material. Once we understand how the productivity is arrived at on these natural sandy soils, then we will have a better basis for stipulating what level of productivity we should require for reclamation in the case where we have only sandy materials to work with. If we have other materials to work with, then we can maybe expect a little higher level of productivity. At least we have a natural template so we can expect a soil with certain characteristics to have a certain level of productivity.

Regier: Realizing there are a lot of interactions going on.

Singleton: Yes, but we're talking about a lot of parameters. We're talking about waterholding capacity, talking about buffering capacities, and so on.

Graveland: And combinations and permutations thereof. Regarding depth of topsoil, you look at hydroponics or a greenhouse, you don't need much soil. There'll be a good crop on glass beads, providing you add enough nutrients. I guess Glenn's suggestion is the only way to go. But I wouldn't anticipate nice equations and models that you can plug into to determine final productivity levels.

Singleton: Well, I think it can be narrowed down fairly rapidly. I think the complications that we saw yesterday in forest soils examples in the slides, were mainly on the basis of slope positions and moisture regimes. But, if we confined our examination to well-drained sites, which in most cases, reclaimed surfaces will have, I think that would be greatly simplified. I think George Krumlik had a number of slides on well-drained positions. The soils looked similar, but had different amounts of organic matter or different amounts of fines.

Patterson: Suitable material is really anything that satisfies your requirements for that specific operation. That brings us back to the initial definition of what you have to have.

Graveland: Except in the tailing dyke, you've got a little different situation than you'd ever have in nature. Natural slopes don't have to hold back 10 square miles of sludge. It's just not the same as any natural situation.

Regier: Isn't it the objective now to pump the sludge back into the pit areas, and eventually you no longer have a very serious problem with very steep slopes? In fact, those areas could be levelled if they are not going to impound sludge.

Is that still a problem?

Fessenden: As far as I'm aware, the concept is still to maintain a good-sized sludge pond.

I would say that most people's impression of what a tailing's pond and dyke slopes look like, is derived from the Suncor situation. And, I daresay, there'll never be another Suncor-like tailings pond. Both in terms of location and slopes. In our case, I think there are only a couple of very short areas on the first lift that will have 2 to 1 slopes. I think the majority of the slopes will be 4 and 5 to 1. I think they will be really quite gentle slopes. So again, one shouldn't necessarily go on the one existing tailings pond as the model for the others.

Graveland: I'll believe that when I see it. At any rate, the slopes will be greater than what you find in a pre-mining situation.

Fessenden: I don't think anybody knows what's going to happen to some of those slopes. We've demonstrated that you can establish a good erosion-controlling grass cover so long as you add fertilizer. There are dyke areas that have not been fertilized for 6 years, and they don't look that bad. The root mass is maintaining itself. Whether those areas, if abandoned for 100 years, would maintain erosion control, nobody knows.

Regier: What can you say now about topsoil requirements? Or depth of soil requirements? Is 30 cm enough? Bob Logan, you worked on tailings sand for your thesis. What did you find?

Logan: I mainly looked at mulching versus mixing of peat into sand, and an initial attempt at looking at the moisture-holding capacity of mixes how much peat do you need to reduce moisture stress to a certain degree.

Regier: Bob Fessenden, you suggested yesterday a peat mix to 30 cm was enough.

Fessenden: No, no, no.

Regier: Are you getting success with 30 cm?

Fessenden: In terms of short-term soil erosion control, I think 20 cm is plenty and you can probably even get away with less than that. In terms of long-term erosion control and soil stability following discontinuation of management inputs, nobody knows. I don't think anybody can tell you about long-term productivity, either, we can make some guesses. So it's important that you look at all the objectives or all the aspects of what acceptable reclamation is.

Regier: From a genetic point of view, Glenn, what would be desirable?

Singleton: Oh, as Bob suggests, once you tell the mine people what you want in terms of productivity, they will know what is going to be required. For above-ground boimass requirements we could calculate how much nutrients are required to provide a given above- ground boimass. That amount of amendment, at least, has to be added.

Regier: So, we're looking at a minimum of 15 or 20 cm for erosion control, at least on a short-term. Bob, that's what you say, and you're probably saying too, Glenn, that basically, this is the minimum that we would also want for productivity too.

Fessenden: It's been demonstrated that tillage to 20 cm with 15 cm of applied peat with no mineral fines, and with a fertilizer schedule is sufficient to achieve erosion-control on 2 1/2 to 1 slopes.

Singleton: You can grow erosion-controlling vegetation on gravel if you fertilize and water it. As far as I'm concerned, evaluation of these things while they're under fertilization doesn't give you a good concept of how successful they are, nor how valuable the amendment is. To me, you should be scheduling a whole series of amendments without fertilization just to see what is optimum. As far as I'm concerned, when you fertilize, that completely negates the effect of the material. So, I don't think it has been demonstrated yet how much peat or soil is needed.

Fessenden: We talk glibly about 6 inches of peat, but peat changes it's volume on handling. Are you talking about 6 inches in-situ equivalent, 6 inches as a haul equivalent, 6 inches as a spread equivalent, what are you talking about? Peat can change 50% in volume. Or, should we be talking about the absolute weight of carbon that you put on. This is why it gets to be a real tricky question. From our point of view, it's easier if we look at the quality of the final product as opposed to being hung up on how much you add, and then we can vary what we add relative to the quality of the material. I admit there's still some question about what the quality of the end product should be for a defined vegetation.

Regier: Let me summarize and say that we don't really know all that much about reclamation of mined oil sand areas. And that puts us into Number 5: What don't we know and what might we be giving research priority?

Patterson: First of all, establish baseline data. Establish the vegetation communities, the soils and the parameters which are critical to measuring the systems. Let's get the background information first.

Fessenden: Don't we already have some of that?

Patterson: I don't think we do.

Singleton: I think it was pointed out that there was very little.

Patterson: I think we've got to go into these areas and define the plant-soil systems and determine their functions.

Patterson: From this, project the kind of soils and plants you need for reclamation. I think we're throwing down 3 or maybe 4 species, and saying, this is it. Maybe we're missing one of the key plant species which could be carrying the whole thing within the sequence. We don't know, so let's establish how the total plant community works.

Fessenden: In the AOSERP program, you know, there was some work done on baseline vegetation and soils and that advanced, I guess, our understanding of the oil sands vegetation to a certain point. A number of different plant classifications have been advanced, but what's missing is the productivity.

Patterson: This would all be part of the baseline data collection.

Singleton: That information was collected as an inventory. It was never collected on the basis of reclamation with that as an objective. So, I think you have to get in that information as a specific objective.

Graveland: So we look at what's there now, and relate that to productivity, but I wonder what good that will do, because if you tell me the minerology and the stuff that's there now is different than what you're going to end up with in the tailing sands, then you've changed the rules of the game. And now you're saying you can modify and amend tailings sands? You've changed everything controlling their ability to supply nutrients. What good does it do you to find out what's there now? What does that mean for reclamation?

Singleton: You have to know what the minimum requirement is to provide that level of productivity. Now, if you start with tailing sands that don't have any of those attributes, then you have to do something with it if you hope to achieve that productivity. You can't go with tailing sand alone. I'm giving that as an example. It may be that the tailing sand alone will give you that level of productivity, but, in all probability, the mineralogy is not adequate, which means that you have to add something to it. How much do you have to add to it? What's the minimum you can get away with to arrive at that kind of productivity?

Richard Johnson's study tries to take existing theories and the little available data to derive some quantitative conclusions. There's just not that much information available. There's no buffering capacity data on the soil as such. There's hardly any data on total elemental compositions or mineralogy. There are a lot of analyses floating around, but they are not specific to the problem.

Regier: Glenn, you suggested looking at, say less productive sites. Finding out what really makes that system work could be a good starting point.

Fessenden: Well, from our point of view, in terms of trying to achieve a target productivity, we've got to know what things are necessary to do that, and there are a number of ways to arrive at that kind of information. One is to look at the natural system and draw from it what inferences you can. The next is to advance a theory by an approximation or experimentation. I guess that is no different from the agricultural system, literally. Start off with working models, conceptualize the problem and then try to relate reality to your theories, advancing by approximation. Is that not fair?

Regier: Could we not achieve the same results without studying these systems if we already now what we want?

Graveland: As Bob said, you could take an empirical approach. I'm sure that approach will put us much further ahead.

Regier: If we know that we need weatherable fines, if we know that the water regime is a problem - if we know we need these things, why go back to the natural system. Why not just incorporate those things which will ameliorate known defficiencies?

Singleton: By adding various amounts of silt, clay or peat, you can change the buffering capacity. Now, what does that mean in terms of the natural sandy soils? How does that influence productivity in the natural situation? What level of buffering capacity is necessary to create the level of productivity that we're interested in generating? We don't know that. There's no buffering capacity information available on the soils in the oil sands area to tell us the required level.

Regier: Some general research needs have been outlined. It's suggested that we try to identify mechanisms in the soil plant systems which are now functioning in relatively low producing areas, find out what the limitations to these systems are, and incorporate those findings in designing a fail-proof constructed soil.

Fessenden: I think as Dave Graveland has pointed out, you can get too hung up on looking at the natural system. Looking at the natural system may serve a couple of functions. First, it may tell you something about the kinds of targets you should be shooting at, and secondly, it allows you to look at or draw some inferences about what might be important in terms of affecting the productivity of jack pine, aspen and spruce. But, we have to keep sight of the engineering systems of reclamation, and the minimum of properties required for acceptable reclamation.

Regier: But could we not identify the minimum by studying systems in the natural state?

Singleton: Yes. There are two schools of thought here - one empirical and the other process/theory. Dave is suggesting we're getting hung up on natural systems. I suggest combining information obtainable from the natural system with our soil genesis theories, which are well-developed This approach would narrow down the research topics that need be looked at in an empirical way. If we just go empirical, we end up again on very many tangents. There are very many combinations of things that can be looked at. In fact, AOSERP was a classic example of that; where everything under the sun was looked at. I'm suggesting we study the natural system to find out what things need to be addressed more thoroughly from an empirical point of view. That will provide a template from which we can see the things most important in the natural system. Then empirically test them in field plots or whatever, but using our theories of genesis and our powers to predict what's likely to occur.

Graveland: Except they won't work.

Singleton: Oh no, that hasn't been demonstrated at all.

Fessenden: I'd like to think that what you're talking about is already in process. We (OSESG and RRTAC) asked Monenco to set down the baseline theories, to use the existing information and theories in literature to develop a statement, our best statement to date, recognizing the imperfections and theories in literature about what in fact is needed in that original soil. That's our first approximation. It's like baking a cake: if you have a cake to look at, a model, you can analyze that thing until you're blue in the face, but that doesn't necessarily tell you how to achieve it. You can draw some inferences, but until you start empirically to mix the ingredients, and bake it for different lenghts of time, you don't know how it's going to be.

Patterson: Let's touch base on another problem, and that is the development of specialized equipment for mixing soil materials. We're trying to plan reclamation to the equipment we now have, and I think it has short-comings. We need special equipment.

Fessenden: Perhaps we don't yet know what's necessary in terms of an engineered soil to achieve adequate productivity and long-term stability. There's no reason to believe that what we're currently doing is inadequate. Maybe 30 cm is perfectly adequate. Why deeper? Are you concerend about lack of root growth below the 30 cm tilled zone? I don't think that's a concern. We're getting root penetration to 50 cm after 2 or 3 years.

Patterson: Even so, a lot of the equipment we've got leaves a bit to be desired. This is supported in the equipment tests as well.

Fessenden: My feeling again, maybe yes, maybe no. Until you can show that we have to get to 50 cm, I won't be willing to admit that you have to develop a machine that will get to 50 cm. We're still at the point of trying to define what the minimum properties are for an engineered soil that will give acceptable productivity and stability. I don't think you can demonstrate that what we're currently doing is not going to result in long-term acceptability. In fact, we may already be doing too much.

Patterson: That's one thing, but there are other things as well. I've seen demonstrations where it appears that some of the available equipment, say some of the tree planters, just aren't going to work on reclaimed surfaces. That's an example, but I'm talking about engineering equipment in general. We're going to have to find some specialized mining equipment that can work on a large scale.

Regier: Moving to the mountains and foothills is there a correlation between pre-mining and tree-rooting depth and post-mining rooting depth requirements?

Graveland: It depends on what you call rooting depth.

Patterson: Look at some of Will Holland's pictures. There's no correlation at all in some of those.

Graveland: There's a lot of things that go along with rooting depth.

Singleton: I don't think you want to be too confused by the variations in rooting depth. I think they're all very logically explained by the combination of factors at that particular site.

Logan: The same applies to soil reconstruction depths. The other thing that's got to be looked at besides what was there before, is what materials you're putting it on. In any one operation you get different types of materials and a spoil material can end up being a pretty effective soil in one case and not another, depending on the quality of the material below it.

Patterson: Quality is more important than depth, especially in the mountains. The material below the root zone is a lot more inconsistent in the mountains.

Graveland: All I got out of those talks yesterday was that watertables are probably fairly important. How can you construct or forcast where the watertable is going to be? It's easy to say in the undisturbed state, that 30 cm of soil is fine, but where is the watertable at the reconstructed site?

Singleton: You could define water relations and rooting depths for jack pine on a well-drained site on sand to very general specifications. You could then define jack pine rooting depth on a loam textured material on a well-drained site. Now, if you had a number of instances where you could define these things under different combinations, then rooting depth becomes a meaningful term. But it has to be qualified.

Tomm: From the initial research that we've got in the mountains and foothills, rooting depth has no correlation to plant establishment. The primary factors are microclimatic.

Graveland: You said plant establishment?

Tomm: Yes, there may be a correlation later on in development of a successional community, but we don't know that.

Patterson: You've got to take aspect and elevations into consideration.

Singleton: It goes back to the soil forming factors - vegetation plus soil, in other words, the total community is a function of climate, parent material, relief, organisms and time. Rooting depth is one factor of this whole scheme. We can't use rooting depth alone.

Regier: Can we move on now to Selective Materials Handling? Again, if you can save the LFH horizons it's good, but in the mountains, you might not even have any to save.

Patterson: The problem here, is that you get a lot of pockets in the landscape. If you have a good shovel operator and a good salvage scheme you can go into those pockets pick, them out and haul them to away where you want them. Those are worth saving, but a lot of thin duff layers are diffcult if not impossible to save.

Regier: I don't think we understand the realities of soil removal, stockpiling and replacement in mountain areas. The problems are going to be very site specific. I think too, that we don't know very much about nutrient levels, or and nutrient cycling.

Patterson: The big problem is getting the plants established. It'll be intersting to see how the native species perform in alpine conditions. Right now, the alpine is pretty well closed to mining development under the coal policy.

Regier: Moving on to spoil physical and chemical properties, Bob, what is your experience from the work you're doing now around Hinton? Are there materials there that are inferior as rooting materials?

Logan: I'm working more south of Hinton. In the work that I'm familiar with we haven't looked at that too much. We've looked at materials that we've been taking off for topsoil and subsoil. We try to do some materials handling and blending, but when you're in the field, you actually have great problems identifying what is what. Chemical analysis, standard routine things, get messed up. If you are looking at organic matter, which should be obvious, there are problems in that there's coal mixed in and it is present on the surface, at outcrops. This messes up some of the methods of differentiating between materials. There are also differences in bedrock which make reclamation planning difficult. I question the salvage of topsoil, loosely using that as the litter layer in the mountains areas. A couple of examples that I'm looking at compare some reclaimed areas to a forest clearcut. Standard practices there involve removing enough of the LFH layer to get a mixing of LFH and B horizon to get, I think, at least 40% of the mineral soil exposed. Isn't that producing something similar to the land we're getting in mine areas when we don't save the litter layer?

Regier: When scarifying, the duff layer is worked in not removed or buried, right?

Logan: It depends on the site - in some it's taken off, in others it's mixed in. The recommendation is to take it off to expose mineral soils if you're starting with pine.

Patterson: You can compare that to an area that's had a forest fire. The duff layer has burned off, which is the ideal situation for establishment of lodgepole pine.

Logan: Yes, I think the burn would be part way between complete removal. But you've still got ash there, creating a flush of nutrients.

Patterson: I think the high level of nutrient availability holds for a 3 year period and then tails off, but then by that time, the germination period has taken place. I think that's the way the cycle goes.

Fessenden: Yes, it varies with fire intensity and the texture of the materials.

Logan: There were some charts shown yesterday on nutrient cycles and the pool of organic matter in forest soil, but the data primarily concerned mature stands. When you put small trees in, how much of a demand do they put on the soil at that point? Do they need litter or is there enough just from the mineral soil and the rain?

Fessenden: It depends. If you're dealing with a very coarse sandy acidic material, then the amount of potassium in the organic fraction can be incredibly important. If you take that off, you are basically removing the reservoir of immediately available potassium.

I really worry about removing the organic horizon. Turning it over and turning it in, incorporating it, are somewhat different than taking it right off.

Logan: It's not totally off the site, but it's certainly away from the roots for the few first years.

Fessenden: That strikes me as being a foolhardy practice.

Patterson: There are many kinds of materials available on a mine site in the eastern slopes of the mountains. This material variability should be used to advantage in reclamation.

Regier: Are the tertiary or cretaceous materials in the mountains generally suitable or unsuitable for plants, or is this again very site specific? You said you had some bentonitic material, Bob.

Logan: I'm not certain what, where and why. I'm not too familiar with the geology.

Graveland: The E.I.A's showed some highly sodic material.

Patterson: There are pockets where S.A.R.'s are high.

Singleton: I think the focus really comes into the material selection. It's been demonstrated near Judy Creek, that the overburden materials are sometimes more productive than the soils, regarding reclamation potential for initial establishment of grass and seedlings. We've shown that in greenhouse and field tests it then becomes a question of selecting that material which is beneficial and mixing it with whatever you have the most of. I feel the same applies in the mountianous area. Selection of materilas with optimum characteristics is paramount, and a lot of times, it will involve empirical work to establish which is the optimum material.

Regier: What would be a good place to start, from a general point of view, for research?

Logan: Before we do all this, the final land use must be defined.

Tomm: That sounds like a long way to go. We are finding that getting initial plant cover establishment is the major concern. You've got to get something on there to get the cycle rolling. We're not even worried about the end product right now.

Regier: And again, to get something going, would it be helpful if we took a systems-level approach?

Singleton: The benefits of having a litter layer with its associated microbial activity has been well documented. The benefit is substantial to the establishment of tree seedlings. Whether it is beneficial after stockpiling needs to be addressed.

Patterson: Yes, we've had a couple of sites where they placed mixed LFH on the surface.

Fessenden: The organic material must be re-applied directly after removal.

Regier: I don't think we are identifying concrete research needs.

Fessenden: In terms of making some of the economic decisions, what's missing is the biological information. What is the effect of including LFH horizons? Until you have the biological side of the equation, the benefit side, you can't decide whether it's worthwhile in economic terms. I'd say the same thing about the Northeast. To achieve acceptable reclamation most cost-effectively, what is the minimum requirement for organic carbon, or for silt plus clay or any factor for that matter? What is enough?

Patterson: We usually do not have trouble establishing erosion-controlling cover, but we have trouble establishing trees and shrubs in that cover. This is critical where the objective is to move to either commercial forestry or to an eventual native vegetation cover.

Singleton: Yes, I think the empirical approach is important, but at the same time, we're dealing in long-term reclamation, almost in terms of geologic time. We have to study the systems and with our theory, try to predict the end product.

Fessenden: Yet, the system and theory should be the guide for the empirical appraoch.

Patterson: That's one reason why we ask each company to carry on continuing research programs and demonstration programs when they're on site, specific to that site. They should keep modifying and updating, applying their results to their own reclamation operation. This is written into almost all the approvals now, and reported in annual or at least in the most-annual reports.