MINESOIL RECONSTRUCTION FOR FORESTRY - SOME CONSIDERATIONS[1]

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Abstract.--In planning for reclamation of minesoil with trees, the reclamationists should consider macro and microclimate, soil temperature, topography, rooting medium, soil water, soil microflora and fauna, plant nutrients and any adverse characteristics. Guidelines for important effective properties for growing lodgepole pine, white spruce and, to a lesser extent, Douglas fir, are discussed in this paper.

INTRODUCTION

This paper is oriented toward the task of establishing woody plants on areas disturbed by mining. An attempt has been made to highlight important things to consider when conducting reclamation with the end objective of having a stand of woody plants, especially lodgepole pine (*Pinus contorta* Laudon) and white spruce (*Picea glauca* (Moench) Voss) and to a lesser extent Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco).

Some important specific site variables are: supply of mineral nutrient elements, soil reaction, temperature, moisture supply, radiant energy, soil structure, composition of soil air, biotic factors and the absence of growth-restricting substances. Good plant growth is dependent on a favorable interaction of these variables and if one is out of balance with the rest it can prevent or reduce plant growth. As many variables are not uniform or continuous in their interactions or their effects on growth from landscape to landscape, it is difficult to evaluate a site by individual soil physical and chemical properties.

The technique of focussing on fewer "effective properties" which reflect the net effect of combinations of several individual properties as proposed by Stone (1984) has merit. With this technique the management program must be examined regarding its impact on the soil effective properties rather than depending on measuring changes in individual characteristics. This is not to state or imply that this "holistic" approach is easy, as it is not. It requires a more ecologically oriented knowledge of a number of interactions, but we believe this will return the greatest benefit and provide the basis for more successful site reclamation.

CONSIDERATIONS

Climate. This factor is particularly important in a mountains-foothills area where rapid changes in elevation, aspect, slope and wind patterns occur over short horizontal distances. In this area, the effects of climate are often more important than soil variables. Powell (1981) showed that temperature demonstrates a dominant control over tree growth near altitudinal timberline while available moisture is a dominant factor at lower elevations in the valleys. Where moisture is sufficient, tree productivity appears to be most affected by photosynthetically active radiation and temperature. Increased heat results in large productivity increases at low radiation while at higher radiation levels increased moisture improves productivity.

Microclimate is also important on disturbed sites. Root (1973) compared the microclimate on a subalpine coal mine in Alberta with that of an adjacent undisturbed area and found: 1) the air, surface and soil temperatures on the mine site averaged 1 to 3C higher than on the undisturbed area: 2) precipitation was similar among sites; 3) wind speeds were significantly higher on the mine site; 4) evapotranspiration was consistently higher on the mine site because of higher wind speeds; 5) soil moisture deficiencies were more pronounced and longer lasting on the mine site; and 6) natural revegetation of the mine site was limited by removal of seed by wind, the abrasion of vegetation on the mine site by wind-borne rock and snow particles and a moisture deficiency created by high permeability of spoil materials.

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[1]Paper presented at the combined Fourth Biennial Billings Symposium on Mining and Reclamation in the West and The National Meeting of the American Society for Surface Mining and Reclamation. March 17-19, 1986. Billings, MT.

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Proceedings America Society of Mining and Reclamation, 1987 pp 223-230
DOI: 10.21000/JASMR87010223

https://doi.org/10.21000/JASMR87010223

Soil Temperature. This site factor becomes limiting in land reclamation as elevation increases and temperature decreases. Seventeen diverse native plant populations along an elevational gradient between 10 m and 3170 m were evaluated by Anderson and McNaughton (1973). They found that plants from low elevations could not maintain leaf water contents at a low soil temperature of 3C.

Soil temperature also affects nutrient uptake and photosynthetic rates. Chapin and Chapin (1981) studied Carex spp. along a latitudinal gradient and found phosphorus uptake and growth at low soil temperatures was highest for arctic species. They also reported that "cold-soil" adapted species had the largest root to shoot ratios and the smallest tiller mass. Havranek (1972) reported that Norway spruce and European larch exhibited reduced transpiration rates of up to 50 percent and a reduction of photosynthetic rates of 30 percent at a soil temperature of 2C versus 15C and a constant air temperature of 25C. Soil micro-organism colonization and biochemical processes such as organic matter metabolism are also faster at higher soil temperatures.

Modification of soil temperatures can be accomplished by changing soil surface roughness and soil moisture content; or by using mulches. Surface treatments such as contour furrows, dozer basins, pits and gouges concentrate rainfall which increase soil moisture and subsequently contribute to maximizing soil temperatures. Mulches which possess a higher heat capacity than the soil, e.g. rocks and gravel, will also assist in increasing soil temperatures as they absorb and transfer heat into the soil. Revegetation procedures which maintain a rocky, rough soil surface will help to maintain soil temperatures.

Evapotranspiration. Evapotranspiration is the net upward (outward) transport of water vapor from plant community and soil surfaces. If the necessary soils and climate data are available, the method of Thornthwaite and Mather (1957) can be used to calculate components of the water balance on mine sites and show general trends in moisture deficiency. The procedure can be used to calculate the potential evapotranspiration (PE), which is the evapotranspiration that would occur if moisture was not limiting, the actual evapotranspiration (AE), the moisture deficit (PE minus AE), and the moisture surplus (P minus PE in months with average temperatures greater than minus 1C) for selected climatic stations. Reclamation procedures and species selection can then be modified to alter or work with the existing site evapotranspiration status.

Topography. Specific post-mine topographic requirements must be determined on a site and end land use basis. It is important to note that topography exerts a considerable influence on climate at meso and micro scales, natural vegetation patterns and forest productivity, soil development, water movement, water erosion, land use,and wildlife habitat values. Recognition of the importance of topography in controlling erosion potential, moisture regime, soil characteristics and plant productivity goes a long way toward successful reclamation with trees and other vegetation. Recognition of the effects of slope gradient, length, shape and aspect assist in planning for various plant communites.

Commercial forests can be (and are) produced and harvested on steep slopes, however, more level terrain assists in implementation of stand management practices and makes for more efficient and economic harvesting. Uniformity of landscape characteristics encourages uniform, single species stands of even age and size, but greater productivity may occur on rougher terrain (Dumanski et al. 1973).

The impact of slope aspect was emphasized by Harrison (1977). He found a 25C difference in surface temperatures at the 1135 m elevation level at 1445 h MDT for a south and north facing slope with a slope angle of 26°. The lower temperature was on the north facing slope. Temperatures for southeast and southwest facing slopes were about the same. He attributed the greater presence of trees on southeast slopes to be due to more wind protection. It is likely that there is more snow accumulation on southeast slopes from wind scouring on the exposed windward slopes with snow accumulation on the protected lee slopes which results in higher moisture levels.

Rooting Medium. Important parameters involved in the rooting medium are organic matter, soil porosity, texture, bulk density, coarse fragment content and thickness of surface soil horizon.

As stated by Wilde (1958) organic matter has a positive impact on soil structure, porosity, permeability and aeration. It also increases the water holding capability of soil, although this doesn't always mean more available water for plants as some organic materials, especially peat, hold water so tightly it may not be available to plants.

With respect to levels required for growing tree seedlings there are some discrepancies among researchers. Wilde et al. (1965) reported that trees can grow quite well on a raw geological mix (e.g. a gravel pit) if the tree seedlings have been inoculated with mycorrhizal fungi and there is sufficient water and nutrient bearing minerals available. Lodgepole pine is one of the pioneer plant species which can grow on soils with little or no organic matter. Wilde (1958) recommended a level of 0.7 percent organic matter for lodgepole pine and Wilde et al. (1965) suggest a minimum organic matter content of 3.5 percent for white spruce.

Salvaging organic matter prior to mining is not the only way to re-establish it in minesoils. It can be built up to "acceptable" limits using biological systems. There is little quantitative information about root sloughings and exudates in natural ecosystems, however, grasses develop a fibrous root mat and their roots periodically die and are replaced with new ones and grasses could be used to build up organic matter levels prior to planting tree seedlings.

Root form was similar for approximately 10 year old lodgepole pine and white spruce on reconstructed and natural soils in Alberta's Smokey River Coalfield (Macyk 1984). Roots were concentrated in the upper 30 cm of soil with only minor amounts of rooting below 50 cm for both species.

The amount of soil water available for plant growth is related to the amount received at a site, the amount that infiltrates into the soil, the amount that is stored and the amount that is available for plant growth. Also, landscape characteristics exert strong control over the amount of water that infiltrates or runs off and causes erosion with lower slopes and depressions receiving more water than upper slopes.

Rogowski and Weinrich (1981) reported the infiltration and redistribution of water in mine-soils is often not a slow, uniform downward movement because of coarse fragments, boulders, old root channels and varying compaction. Flows may be along cracks or may be held up by discontinuities of pore-size with the end result that some of the profile may remain dry. Pore-size discontinuities can be used to the reclamationist's advantage by perching water tables above them if desired. A coarse layer or compacted layer of finer textured materials will artificially perch water tables above them. Russell (1980) stated that 6 percent available water capacity in the 0 to 20 cm soil layer was correlated with reasonable vegetation growth on spoils at Alberta's Mountain Park mine in the subalpine zone.

Soil Microflora and Fauna. The importance of soil microflora in mineland reclamation has been recognized by many researchers. Soil microflora are important in nutrient availability and uptake through mineral weathering or organic matter decomposition as well as possibly influencing plant root morphology and root to shoot ratios.

The symbiotic association of nitrogen-fixing organisms and higher plants offers good potential for the biological addition of nitrogen to minesoils. Fessenden (1979) indicated that at least 49 actinorhizal plant species either had or were being evaluated for use in North American land reclamation efforts because of their pioneer plant properties and low maintenance requirements.

Mycorrhizal development is very important for tree growth and many other plant species on spoils and natural soils as these relationships increase nutrient cycling, water absorption, feeder root health and longevity as well as tolerance to drought, high soil temperatures, soil toxins and extremes of soil pH. A study by Vogel (1980) found that mycorrhizae accounted for 50 percent of the annual throughput of biomass and 43 percent of the nitrogen released annually in a Douglas fir ecosystem in Oregon. Mycorrhizal nutrient transfers were five times larger than the release from litterfall or litter decomposition. Harvey et al. (1976) evaluated the top 38 cm of a western Montana soil and found that 66 percent of the active mycorrhizal fungi were in the 23 percent of the soil layer which was humus. Only 5 percent of the fungi occurred in the 60 percent portion of the soil which was mineral and 21 percent of the fungi were in decayed wood.

Plant Nutrients. Plant nutrients have been the subject of a large amount of research. To present it in this paper is impossible, however, it is important to understand that the dynamics of forest soils are not necessarily the same as those of agricultural soils. As pointed out by Wilde (1958), in forest soils nutrients enter the plant through the root system in water and also, mycorrhizae may make nutrients directly available to plant roots. Result of agricultural soil analysis techniques are not always easily interpreted for a forest soil. Also, the long term nature of a tree crop makes it difficult to assess its needs compared to a much shorter term agricultural crop.

In reclamation it is also important to consider the value of weathering of disturbed soils, regolith and overburden material. A knowledge of weathering rate differences and an understanding of their causes is essential to relate data on rock weathering and water and soil chemistry to nutrient gains in forest ecosystems. Some nutrients which may be released are phosphorus, potassium, calcium, magnesium, sulfur, iron, molybdenum, boron, copper, manganese and zinc.

In Table 1 some reported levels of soil chemical parameters are provided for selected trees. Some of the levels are considered to be desirable, others are suggested as minimal and still others are field values reported in the literature. Generally forest species have considerable ecological amplitude, i.e. they can do well on a wide variety of sites.

Adverse Characteristics. Adverse characteristics may result from edaphic or climatic conditions. Almost any element can be deficient or toxic, although normally micro-nutrients are considered in toxicity problems. Elemental deficiencies can usually be corrected over the short term with fertilizers. Toxicities may require burial during minesoil construction.

Adverse climatic-site conditions occur on hot, dry southwest facing slopes and windy exposed ridgetops. These are difficult sites because of moisture stress and because of sandblasting from moving soil particles and extreme winter temperatures without the benefit of snow cover.

PROPOSED DESIGN GUIDELINES

One of the early requirements for designing minesoils is a premining inventory. The value of rating surface soils and deeper overburden materials as to quality for use as rootzone material in minesoils has been recognized for many years as a part of reclamation planning. The purpose of this procedure is to identify the quantity and quality of materials suitable for minesoil construction, or conversely, detrimental to plant growth.

The distribution of pore size is a changing soil property and root growth, surface traffic, overburden weight, tillage, soil fauna, wetting and drying and freezing and thawing continually re-arrange soil pores. The development of adequate roots requires an open network of pores to promote the drainage and aeration needed to restore aerobic conditions after heavy rains. With low oxygen concentrations, soil microorganisms produce ethylene which restricts root growth and makes soil nitrogen unavailable to plants through the process of denitrification.

Soil porosity under undisturbed forest has been reported to range between 30 and 60 percent (Wilde 1958). In agricultural soils an air filled porosity of 10 percent at field capacity is normally used as a minimum for proper aeration. The 10 percent is also suggested by Wilde (1958) as a requirement for satisfactory tree growth.

Soil texture influences moisture retention, the higher the fines content the greater the water retention, however, too many fines can create aeration problems. Texture also influences nutrient content because the fine particles serve as a major nutrient source.

Wilde (1958) recommends 5 percent as the minimum silt plus clay for lodgepole pine. Wilde et al. (1965) reported that white spruce stands in Wisconsin had average silt plus clay percentages of 12, 37 and 44 percent for low, medium and good sites, respectively. They found that for 22 stands of medium site quality white spruce the silt plus clay contents ranged from 10 to 59 percent.

Soil texture also influences soil compaction and bulk density. The negative impact of compaction on plant growth is because of impacts on soil moisture, soil aeration, soil temperature and impedance to root elongation and shoot emergence. Bulk density is important as an indicator of soil compaction and it is also useful in converting nutrient analyses to a more meaningful weight per volume basis. As pointed out by Wilde (1958); "In spite of its importance in soil management ..., bulk density is the factor that is most sadly neglected in analysis of forest soils."

Minore et al. (1969) reported that lodgepole pine, Douglas fir and red alder seedling roots grew all the way through sandy loam soil cores with a bulk density of 1.45 gm/cm^3, however, Sitka spruce, Western red cedar and Western hemlock seedlings did not. All of these species grew through cores with a bulk density of 1.32 g/cm^3. Armson (1980) recommended a maximum bulk density of 1.2 gm/cm^3 in the surface soil layer to encourage tree seedling root growth. In four Minnesota jack pine stands, Fedkenheuer (1975) reported bulk densities of 1.44 to 1.52 g/cm^3 in the profile where root abundance changed to "few".

The content of coarse fragments can affect agricultural soil capability ratings, however, that is not normally the case for land to be returned to forestry. Dumanski et al. (1973) concluded that excessive amounts of stones had no signi[illegible] impact on lodgepole pine productivity. [illegible] (1984) reported a high degree of associa[illegible] stony soils and successful tree growth [illegible] that mine soils with high coarse fragmen[illegible] may possess a productivity equal to or [illegible] pre-mine soils with lower content of co[illegible] fragments. This was most likely due to [illegible] crop life, conservative nutrient econo[illegible] coarse root systems and the close associ[illegible] mycorrhizal fungi which trees have.

In some cases the presence of coars[illegible] can enhance soil moisture conditions by [illegible] runoff and evaporation loss. Smith et a[illegible] stated that soil productivity was not se[illegible] reduced by up to 75 percent coarse frag[illegible] weight in minesoil top and subsoil horiz[illegible] addition, these soils were only slightly [illegible] while non-stony topsoil was considerably [illegible] erodible.

Sufficient soil volume must be avai[illegible] root growth and mechanical support and [illegible] the question of soil depth and how much [illegible] original soil (if any) must be salvaged [illegible] over mine spoil in order to grow trees. [illegible] combined result of inter-relationships [illegible] many controlling variables is that other[illegible] besides soil depth are important in con[illegible] forest growth. This is supported by Du[illegible] (1973) who found little relationship be[illegible] lodgepole pine productivity and availab[illegible] depth and reported some very high growth [illegible] shallow soils. Krumlik (1980) also note[illegible] rooting depth was related to soil moistu[illegible] soil aeration, soil temperature, availab[illegible] plant nutrients and species characterist[illegible] form in addition to soil depth.

It is important to note the density [illegible] and their function and to not just look [illegible] depths at which roots are found. Klock [illegible] reported the upper 3 cm of surface miner[illegible] a marked effect on the potential site pr[illegible] of Douglas fir and a lesser impact on lo[illegible] pine. He attributed the latter to lodgep[illegible] pioneer status and its ability to suppor[illegible] under lower nutrient regimes. Wilde (19[illegible] out that the surface 15 cm is the most i[illegible] part of a forest soil. Strong and La Ro[illegible] found that the root systems of most bore[illegible] trees are dominated by horizontally spre[illegible] lateral roots which absorb moisture and [illegible] within 3 to 15 cm of the soil surface.

A study by Eis (1970) of 5 to 15 year [illegible] spruce, alpine fir and lodgepole pine showed that [illegible] percent of the white spruce had all their roots in the top 22 cm of soil. The average root penetration for alpine fir with a well developed tapro[illegible] 26 cm and for lodgepole pine it was 36 cm. [illegible] reported that lateral roots became more [illegible] with increasing stand age. Hamburg (198[illegible] tree stands shifted the zone of intensive [illegible] from the mineral soil to the detritus wit[illegible] increasing stand age, which followed a s[illegible] in location of the nitrogen supply.

Table 1. Some reported levels of soil chemical characteristics in surface horizons for nutrition of selected vegetation.

Revegetation Type	pH	O.M. (wt. %)	C:N	Total N (wt. %)	CEC (me/100g)	Exchangeable K	Ca (me/100g)	Mg	Avail.P. (ppm)	Reference
Desirable Levels										
Conifer Seedlings	4.8-5.5	3-5	<20	0.2-0.25	—	0.2-0.3	3-8	0.4-2.0	100-150	Vanden Driessche, 1979
Minimal Levels										
Jackpine	4.5-6.0	2.5		0.3	5.0	0.2	0.5	0.25	30	Monenco Consultants, 1983
Reported Field Levels (0-15 cm)										
Lodgepole pine	3.9-7.5	—	—	—	—	0.25	0.6	—	3-300	Dempster & Higginbotham, 1985
Lodgepole pine	5.5-7.5	0.7	—	—	—	—	—	—	—	Wilde, 1958
Jack pine	5.0-7.0	1.0	—	0.04	2.5	0.06	0.5	0.15	6	Wilde, 1966
Jack pine	5.1-5.7	2.6	—	—	—	0.11	1.16	0.52	26	Fedkenheuer, 1975
White spruce	4.7-6.5	3.5	—	0.12	12	0.17	3.0	0.7	40	Wilde, 1966

In an attempt to make guidelines for soil material quality evaluations generally applicable, quality classes have often been developed with class limits which appear to reflect agricultural soils and requirements of agricultural crops. Application of these guidelines in forested areas may result in many forest soils being classified in a lower class than they should be. A given volume of wood may be produced in the same amount of time with, e.g. white spruce or lodgepole pine on very different soils.

Knapik (1984) proposed using three quality classes, Favorable, Tolerable and Poor, and 10 soil properties with class limits when evaluating soil materials for growth of conifers. As with any system, the rating of individual soil properties must consider interactions between soil properties and site variables. It is important to note that in his classes there is a considerable range in pH (4.8 - 6.5) for a Favorable rating. This also holds for texture, rock fragments (up to 50 percent) and organic carbon (down to 0.5%).

We endorse the concept of using guidelines to rate any of the overburden materials for use as "coversoil". This is similar to the approach described by Schafer (1980) which suggests any suitable overburden material could be used as the surface layer of a minesoil, especially if more suitable materials are not available. The guidelines proposed by Schafer (1980) include assessment of the hardness and stability of bedrock materials and place less emphasis on derived surface soil properties.

Minesoil quality is highly sensitive to topographic factors and to construction and management practices. As a result, growth performance of plant communities on reclaimed land does not necessarily correlate to the quality of materials used for minesoil construction. Many soil properties may change as a result of mixing of surface soil horizons, long term storage, compaction, loss of structure by puddling, enhancement of structure by plant growth, rapid weathering, oxidation of soil from anaerobic sites, changes in acid-base buffering systems and changes in mycorrhizal relationships. These changes can result in effective soil properties that control rooting, moisture supply and nutrient uptake that are quite different from pre-mine soils.

Consideration of the material presented earlier in this paper, as well as many other references, led to the development of Table 2. The material presented represents what we feel are the important "effective properties" required for a Favorable site quality rating for growing trees - especially white spruce, lodgepole pine and to a lesser extent Douglas fir, in the northern Rocky Mountains and Foothills. We stress that many of the limits presented have not been tested and they will need to be adjusted to compensate for interacting factors at individual sites. The table is intended as a general guideline and not to be used as regulations for specific site reclamation.

The surface 10 to 20 cm is the most important layer for most forest soils. Most root activity in forest stands is within this depth which corresponds with the zone of maximum biological activity, water supply and nutrient uptake. Deeper rooting provides anchorage and unknown amounts of water and nutrient uptake. A soil of 20 cm of rootzone of Favorable quality (Table 2) and a subsoil layer with no restrictions to rooting or water movement to a depth of 50 cm from the surface is expected to provide a suitable rooting environment for trees.

Soil texture is used to indicate available water storage capacity; and along with bulk density and porosity it is used to estimate water movement and aeration. Generally plant nutrients are not expected to be a serious problem and if a deficiency is perceived it can be rectified with commercial fertilizer applications.

Table 2. Proposed key minesoil requirements and limits needed to provide a Favorable* site quality.

SOIL REQUIREMENTS FOR FAVORABLE ROOTING AND WATER SUPPLY IN THE:	
Rootzone Layer	Limits
1. Thickness:	>20 cm
2. Textural Class:	all classes except Clay, Silty Clay, and Sand
3. Coarse (>2 mm) Fragment Volume	<50%
4. Bulk Density	<1.5 g/cm^3
5. Porosity:	
(a) Distribution	uniform with depth
(b) Macro	>10%
(c) Total	high
Subsoil Layer	
6. Family Particle Size:	finer than Fragmental (i.e., voids are filled)
7. Permeability:	absence of restriction causing ponding for ecological moisture regimes drier than subhygric
SOIL REQUIREMENTS FOR FAVORABLE NUTRIENT SUPPLY IN THE:	
Rootzone Layer	
8. Microbiological Requirements:	generally met by above rooting requirements
9. Organic C:	0.5 to 1% (by wt.)
10. pH:	
forest	4.8 to 6.5

*Favorable quality (versus Tolerable or Poor) is expected to provide acceptable or better soil performance for growth of vegetation suited to the site and soil conditions.

ACKNOWLEDGEMENT

The authors express appreciation to The Mountain-Foothills Reclamation Research Program of Alberta Energy and Natural Resources and The Coal Association of Canada for providing funding to prepare a more comprehensive report entitled "Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills" which provided a basis for much of this paper. Recommendations presented are those of the authors and are not necessarily endorsed by these organizations.

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