

ASSESSMENT OF THE SOIL RESOURCE IN THE RECLAMATION OF
DISTURBED MOUNTAINOUS AREAS

by

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INTRODUCTION

When choosing soil assessment methods for land reclamation we must go beyond traditional soil testing concepts. Soil characteristics as they are now and changes in soil properties with time concern us equally.

To clarify this, it is useful to draw a distinction between soil testing and soil analysis.

Soil testing methods have been developed primarily for farmers with the purpose of studying the current status of the soil/ particularly its fertility, and to recommend the addition of nutrients and amendments to maximize crop production. Interpretation of data is often highly dependent upon research experience which is used to calibrate the testing methods for particular crops and soils within a limited geographical area. Fertility testing methods are generally used for annual crops. Tests are made in the fall or early spring from bare soil and are hoped to indicate nutrient levels prior to seeding. Application of these methods to perennial agricultural crops or to forest production has met with more limited success.

True soil analysis is a more precise science and requires a more comprehensive understanding of the soil both vertically and horizontally. The objectives are more diverse and take into account longer term aspects of soil quality and the relationship of the soil to the landscape.

In land reclamation problems, we study a variety of soil materials ranging from surface soils, rock fragments, mineral overburdens, tailings to subsoils. The legislation we are constrained by contains phrases such as "self-sustaining vegetation" and "soil productivity to be as good as or better than prior to disturbance." The correct choice of analytical techniques is most critical to meet our various objectives. Little has been offered to date to explain what constitutes soil quality under particular defined conditions. For instance, it is generally assumed that cultivation of prairie soils has resulted in a decline in their quality (Alberta Soils Workshop, 1980). This obviously has something to do with deterioration in organic matter contents, soil

erosion, salinization and so forth, but we are unable to agree on critical levels or management solutions. How much organic matter is enough? How do we measure the quality of organic matter?

In this paper, I have not attempted to comprehensively discuss soil assessment in terms of type of analyses required or the preferred methodology. Neither have I discussed the organization of the reclamation element as it fits into the commercial development of a new resource. I have tried to look in a general way at the type of soil characteristics which are important, point out the usefulness of the information obtained, and in some instances discuss the potential problems in analysis and interpretation. Since the theme of these meetings is high altitude reclamation, I have also tried to place most emphasis on assessments of soil in mountainous areas.

MOUNTAINOUS AND HIGH ALTITUDE TERRAIN

Most problems encountered in the reclamation of disturbed areas at high altitude or in mountainous terrain are not specific to just those situations. However, the effects of steep slopes and low temperatures result in more severe problems than are normally encountered at lower elevations. Therefore, reclamation programs have to be conceptually well thought out and executed at a higher level of initial effort and subsequent management than elsewhere.

Management of the physical state of disturbed soils in mountainous areas is most critical due to the potentially erodible nature of the land surface. Steep terrain at high altitude is subject to extreme climatic conditions of high winds, intense storms, avalanches and flooding in exposed areas. Stabilization of slopes with vegetation is difficult to achieve due to naturally infertile and potentially droughty soils, and to meagre plant growth during the short cool growing seasons.

Mountain soils are typically weakly developed, of variable depth and generally contain thin accumulations of organic matter. Lack of organic matter and low soil temperatures result in poor recycling of nutrients, particularly nitrogen. Low moisture holding and water interception characteristics often result in a poor moisture status within the rooting zone during much of the growing season.

Topsoil salvage would in practical terms involve removal of the A, B and probably part of the C horizon.

Plants growing in mountainous areas at high altitude are predominantly perennial (Eamon 1974). The annual pioneer types common in disturbed low altitude sites are infrequent since they are unable to complete their life cycles and compete effectively.

Low temperature produces slow growth, poor nutrient uptake, and results in low annual biomass production. Native species seem better adapted physiologically than agronomic species though are infrequently used in reclamation due to poor availability of seed.

Windthrow and frost heaving often hinder the establishment of grass or tree cover and are both related to soil characteristics.

Due to the poor nutrient status of most sites, the initial establishment of growth is dependent upon the addition of fertilizer, particularly nitrogen. Nutrients taken up by the plants are only slowly recycled in available forms. The poor response of commercial legumes, especially above the tree-line, puts further strain on the nitrogen economy of reclaimed sites at high altitude.

Therefore, to avoid erosion and successfully revegetate mountainous areas, careful consideration should be made of the physical and chemical characteristics of all potential soil materials on hand.

TYPES OF SAMPLES

Soil samples presented to the laboratory may be generated from many different sources and for many different reasons. However, in terms of land reclamation, the following categories may be identified:

1. Soil survey of undisturbed surface terrain prior to disturbance.
2. Inventory of surficial deposits.
3. Deep coring programs as part of exploratory phase.
4. Rock, overburden, tailings and other wastes generated during mining and processing of coals, ores, etc.
5. Samples from monitoring of partially reclaimed areas.

Soil samples from inventory and soil survey work are most frequently those that will be used to plan future reclamation of disturbed areas. The data obtained is generally of most use if presented in the form of a map either using the classical soil surveying descriptions or for more site specific use to show topsoil depths, textural distribution, erodibility, etc. With recent advances in data handling using computer linked printer-plotters, the direct transfer of soil data onto base maps will become more common.

The particular types of analyses carried out will depend upon the nature of the sample and the purpose of its collection. There must be a good reason for each analysis and the information gathered should help meet some practical objective. Despite this obvious statement of common sense, it is evident that sometimes we are guilty of over-analyzing rather than under-analyzing soils.

PHYSICAL CHARACTERISTICS

Physical characteristics of the soil are probably more important than chemical or biological properties in the reclamation of disturbed mountainous areas. While admittedly vegetative cover is an integral part of soil stabilization, the correct management of physical characteristics of the disturbed surface will largely make or break the success of reclamation.

Physical measurements are concerned with the evaluation of erodibility, moisture storage, compaction, aeration and the behaviour of soil under load at different moisture conditions on variable slopes. Certain measurements involving structural, textural and permeability characteristics may be made in the field while others can be made with more precision under laboratory conditions.

Physical measurements may include particle size distribution, bulk density, particle density, porosity, water storage capacity, consistence and surface resistance. The close relationships between many of these characteristics mean all the analyses need not be measured on all samples.

PARTICLE SIZE DISTRIBUTION

For agricultural purposes, texture and particle size distribution are described in terms of the distribution of coarse fragments (>2 mm

diameter) and of particles less than 2 mm in diameter, the latter being sand (0.05 mm to 2.00 mm diameter), silt (0.002 mm to 0.05 mm diameter) and clay (<0.002 mm diameter). Sands and silts may be further subdivided.

In mountainous areas, the coarse fragment content may often exceed the volume of the smaller particles so that some adjustment of the normal agricultural interpretations is needed. A high coarse fragment content increases permeability and aeration of dense soils. However, the favourable effects on plant growth are said to be outweighed beyond about 20% by volume coarse fragment content (Lutz and Chandler 1946). At greater coarse fragment contents, the moisture holding capacity of the soil is reduced and the amount of mineral soil available to root growth becomes proportionately too small.

Some inaccuracies in methodology are likely when particle size distributions of mine spoils are measured (Ames 1980). Most procedures are based upon sedimentation rate calculations in water and assume spherical particles with a mean density of 2.65 g/cm³. Many mine spoils may have particle densities well over 3 g/cm³ (e.g. Como et al 1978) which will result in slight overestimations in sand and possibly silt fractions unless the Stokes Law constants are modified. In addition, further problems may be encountered from poorly wettable materials, predominance of linear particles, particles with densities less than water and poor dispersion with very saline spoils. All require modification of the standard procedures to obtain reliable results.

The relative distribution of the finer particles affects many soil characteristics. The relative effect on surface phenomenon may be appreciated if one realizes that the surface area per cubic meter increases from about 7 ha in sand to about 140 ha for silt and 1400 ha for clays. Most chemical and biological reactions in soils occur in the film of water around soil particles.

The total pore space and the relative pore size distribution is largely determined by the particle size distribution though it is modified by aggregation of primarily particles and the presence of organic materials. Sandy soils have large pores which do not restrict infiltration and percolation of water. Clay soils have a large total pore space but have predominantly very fine pores which result in poor infiltration and aeration. Loamy soils with a balanced distribution of sand, silt and

clay sized particles (see Figure 1) have a wider distribution of pore sizes which allows for adequate permeability and aeration.

It may be appreciated that information on texture and particle size distributions may be used to estimate moisture storage, infiltration, erodibility, frost and windthrow hazards, nutrient holding characteristics, buffering capacity and many other characteristics of a soil.

BULK DENSITY

The bulk density, or oven dry mass per unit volume, of an undisturbed field soil is important in several respects. The volume that a soil occupies includes the volumes of soil particles, and air or water filled pore space. Therefore, by determining the mean particle density and bulk density, we may also determine porosity since:

$$\text{Porosity, } P = 1 - \frac{D_B}{D_p}$$

where D_B = bulk density and D_p = particle density.

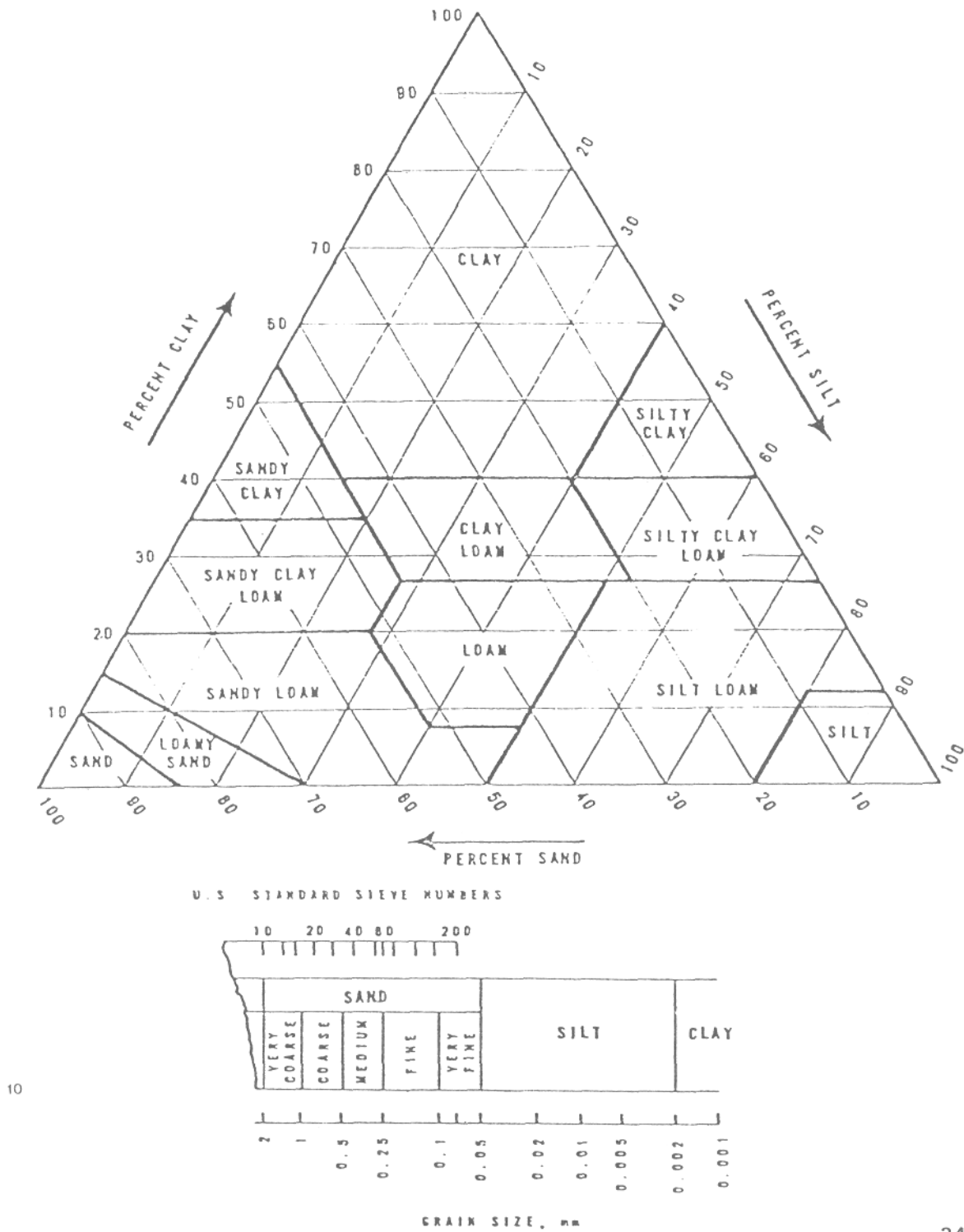
Since soil densities may vary widely (see Table 1), it is essential that field bulk densities are determined to convert mass based data in units of ppm, %, etc., into data of an area nature, e.g., Kg-N/ha, cm water stored/ha, etc.

TABLE 1: APPROXIMATE BULK DENSITY RANGES FOR DIFFERENT SOILS AND RELATED MATERIALS

MATERIAL	BULK DENSITY (g/cm ³)
Moss cover (Sphagnum)	0.04
Undecomposed peat	0.10
Organic duff layers	0.20
Tilled mineral soil	0.80
Surface mineral horizons	1.1 - 1.4
Compacted subsoils	1.6 - 1.9

FIGURE 1

SOIL TEXTURAL DESCRIPTIONS BASED ON
 DISTRIBUTION OF SAND, SILT AND CLAY FRACTIONS



Bulk densities of 1.6 g/cm^3 to 1.7 g/cm^3 and above are commonly considered so dense as to impede penetration and enlargement of roots.

MOISTURE STORAGE

Moisture storage in the surface 1 m to 1.5 m of the soil is most critical to plant survival.

Water in unsaturated soil is prevented from draining by forces that result from surface tension and cohesion of water molecules/ the adhesions of water molecules to soil surfaces and from electrostatic forces at the inter-molecular level. The amount of water available for plant growth will depend upon the total water content of the soil and absorptive properties related to particle size distribution, organic matter content, and the structural stability of the soil.

To determine the moisture retaining characteristics of the soil, the amount of water held at different suctions is measured. Suction is commonly expressed in terms of bars ($10^6 \text{ dynes.cm}^{-1}$), approximately equivalent to atmospheres. The characteristic shape of the curve produced is largely related to the particle size distribution of the mineral fraction of soil. The upper and lower limits of moisture availability to plants are usually arbitrarily set at 0.3 bar (field capacity) and 15 bar (permanent wilting point). Field capacity is the point at which the rate of removal of water from a saturated soil due to drainage begins to be reduced. Availability of water to the plant at lower suctions can be thought to be unrelated to the soil but dependent upon root interception of water in a hydroponic situation. The permanent wilting point is the moisture content at which plants can no longer obtain sufficient water from a dry soil and begin to irreversibly wilt. It is not surprising that considerable variability exists between plant species in terms of the wilting point though 15 bar is a practically oriented mean value for most agricultural crops. At the lower end, field capacity is better set at about 0.10 to 0.15 bar for sandy soils and at 0.5 bar for heavy textured clay soils.

The favourable pore size distribution of soils textured as loams, silty loams and silty clay loams give them superior moisture storage and release characteristics in comparison to clay-rich or sandy textured soils. Christie (1980) in this meeting last year presented a useful figure relating moisture storage to texture and coarse fragment

content. It is also important to note that sandy soils do not just have poor moisture storage but also have little "moisture loss buffering" and they reach wilting point very rapidly under drying conditions in the field.

CONSISTENCE AND SURFACE RESISTANCE

Atterberg's limits are indexes of consistency or workability and firmness of soils at different water contents. They have agricultural and engineering application in showing us the ease of working soils in terms of machinery power requirements, the likelihood of destroying soil structure and the possibility of slope failures.

The plastic limit is the lowest moisture content at which the soil can be deformed without cracking. The liquid limit marks the moisture content where the soil becomes semi-fluid in consistence. The difference between these upper and lower plastic limits, called the plastic index, gives an indication of clayiness or plasticity of a heavy textured soil.

Surface resistance, which is also related to soil texture, can be studied by penetrometer measurements in the field or by determining the modulus of rupture in the laboratory. The latter, which is a measurement of the cohesion and strength of dry soil may provide useful information on surface crusting of soils (Richards 1953).

WATER PERMEABILITY

Infiltration rate, permeability and drainage are all related terms used to assess water movement through soil and predict groundwater flow patterns.

Permeability is often equated with hydraulic conductivity, as the rate at which water is transmitted through saturated soil, a condition infrequently encountered in the field. Infiltration rate refers to the entry of water under unsaturated conditions. Drainage is a term used more with the plant component included and describes the ease of water loss from the rooting zone.

Water movement depends upon texture, structure, the presence of impermeable layers, the ionic constituents of the soil solution, the nature of

the vegetative cover and its rooting characteristics. Consequently, the accurate measurement of water movement through soils is a field measurement. Hydraulic conductivity and infiltration are often measured using double ring infiltrometers (Bertrand 1965).

It may be appreciated that physical measurements can be used to study many features of practical importance in reclamation planning. By example, I will briefly discuss erodibility predictions since they are important in disturbed mountainous terrain.

EROSION HAZARD PREDICTION

Landscape erosion produced by the action of wind and water is governed by the interrelationships of climate, vegetation, topography and soils. We have little control over climate but are able to manipulate the remaining three within fairly wide boundaries constrained only by the materials at hand, the compatibility of the vegetation and, as always, cost. With some foresight, we should be able to devise soil survey and analytical programs to provide information needed to predict erodibility under several different mining alternatives. Basic soil data needed will relate to moisture holding capacity, infiltration/permeability and soil consistence.

Resistance to erosion is largely related to the stability of soil particles and aggregates, and the way water infiltrates or runs over the soil surface. Soils high in very fine sand or silt are especially susceptible to erosion. Sandy soils which do not have the necessary fine material or organic matter to bind particles together are unstable to both wind and water. Soils with moderate amounts of clay and organic matter develop secondary aggregates which resist detachment from the soil surface.

Vegetative cover affects physical deterioration of soil through interception and absorption of rainfall and shielding surface from the direct impact of wind. The effectiveness of the vegetation depends upon coverage of the ground, thickness of the vegetative layer and the stabilizing effect of rooting.

Water infiltration into soil is dependent upon permeability and drainage characteristics. High surface infiltration reduces runoff but will be destructive if soil drainage is poor due to bedrock, non-wettable

layers, hardpans or compacted layers, etc. near the surface. There have been various attempts to relate steepness and slope length to erodibility. A practical statement seems to be that where the vegetative cover, including litter, is less than 50%, the erosion rate doubles for each 10% (5°) increase in slope (Meeuwig 1971). Generally, slopes in the 60% to 70% (30° to 35°) range and greater are considered to be internally unstable as well as difficult to revegetate. Doubling the length of slope seems to increase erosion by a factor of 1.5 to 3 times (Rothwell 1971, Wischmeier and Smith 1978).

The assessment of erosion hazard shown in Table 2 is provided as an example. It was developed for potential use in commercial forestry for designing logging management and roadway construction and so contains elements not so relevant to reclamation. However, similar schemes could be developed for site specific use by modifying the characteristics used and providing a numerically weighting scoring system rather than the "very low" to "very high" rating.

TABLE 2. ASSESSMENT OF EROSION HAZARD

	VERY LOW	LOW	MODERATE	HIGH	VERY HIGH
Texture	Gravel	LS, cSL	C, SiC, SiCL, fSL, SCL, CL, L	SiL	Si, fs
Slope	0-15%	16-30%	31-45%	45-70%	70% +
Erosional Processes	Not				Active Present
Depth to Impermeable Layer	3 m +	1-3 m	50-100 cm	20-50 cm	20 cm
Permeability	Very Rapid	Rapid	Moderate	Slow	Very Slow
Drainage	Rapidly	Well to Moderately Well	Imperfectly	Poorly	Very Poorly
Duff Thickness	20 cm +	10-20 cm	2-10 cm	2 cm	No Duff

Adapted from Vold, 1981

CHEMICAL CHARACTERISTICS

Whereas standard analysis of physical properties of soils have had wide application both in engineering, agriculture and land reclamation, more specialized chemical testing methods have been developed for the evaluation of farm soils. It has been unfortunate that many agricultural methods have been used without sufficient thought as to how the analyses can best be applied to land reclamation problems.

As was noted previously, testing of the fertility status of farm soils has been refined for annual crops which often obtain most of their nutrients within the first 6 to 8 weeks of seeding. Generally, the methods involve the use of a variety of chemical extractants that are designed to bring particular elements into solution in an amount that is in some way proportional to plant uptake during the forthcoming growing season. Chadwick (1973) has pointed out that extraction methods are based upon an assumption that the solution comes into a rapid equilibrium with the solid soil phase, an assumption that may often be untrue with poorly buffered mine spoils. Also, as a more general observation, it seems that in mine reclamation we are equally interested in usefulness of mixtures of potential growth materials as with the individual soils on hand. This tends to place more emphasis on long term interactions as opposed to the short term fertility assessments that we are familiar with in agriculture.

pH

The relative acidity or alkalinity of a soil is generally viewed in terms of plant growth. The optimum pH range proposed depends on the preferences of the vegetation. A pH of about 6.5 is generally the "agricultural optimum" while pH in the 5.0 to 5.5 range may be considered as one "forestry optimum." However, soil pH is also a broad indicator of soil chemistry as well. The following are diagnostic:

pH below 5.0 - Calcium, magnesium, potassium and phosphorus low in solubility while most heavy metals become more soluble. Soluble aluminum and manganese may be present at levels toxic to plant roots.

pH 5.5 and above - Reduced solubility of heavy metals, aluminum and manganese unlikely to be toxic.

pH 7.8 to 8.2 - Soil liable to contain calcium carbonate and increasing concentration of soluble sodium.

pH 8.5 and above - Soil liable to contain sodium as the carbonate, bicarbonate and sulphate, with the possible development of sodic problems requiring the addition of calcium.

The usefulness of pH measurement may be in determining the effect of mixing different soil together in reducing metal toxicities, reducing acidity, or improving soil structure and water permeability.

SOLUBLE SALTS

The electrical conductivity (EC) of a saturated soil extract is normally used to assess the soluble salt content. Where a soil is found to be sodic, the saturated extract is often used to determine the sodium absorption ratio (SAR*). Interpretation of EC data relies heavily on the "2-4-8-16" table presented in the USDA Handbook No. 60 (Richards 1954), where 4.0 mmhos/cm is generally considered to be the good/bad borderline (see Table 3).

TABLE 3. INTERPRETATION OF ELECTRICAL CONDUCTIVITY

<2 mmhos	No salinity problems
2-4 mmhos	Restricts the growth of very salt sensitive plants
4-8 mmhos	Restricts the growth of many crops
8-16 mmhos	Restricts the growth of all but salt tolerant crops
>16 mmhos	Only a few salt tolerant crops make satisfactory yields

These guidelines are useful but for our purposes several other factors must also be considered.

$$*SAR = \frac{Na}{\frac{\sqrt{Ca + Mg}}{2}}$$

Where concentrations are in milliequivalents per liter of extract.

The relative tolerances of different plant species vary quite widely. The same plants at different stages of growth show variable sensitivity to salt. The effect of different ionic species creating the salt load may vary widely in terms of toxicity or creating ionic imbalances. Also, low EC values may apparently not affect cover but may reduce yield. The latter is quite important where disturbed areas are being returned to a former agricultural use as may be the case in surface coal mining or pipeline construction in the Great Plains area. Table 4 summarizes data for a range of agricultural crops.

TABLE 4. EFFECT OF ELECTRICAL CONDUCTIVITY ON CROP YIELD

	EC REQUIRED TO PRODUCE THE STATED YIELD REDUCTION (mmhos/cm)		
	0%	25%	100%
Forage Crops	1.5 - 7.5	3.6 - 13.3	10 - 32
Field Crops	1.7 - 8.0	3.8 - 13.0	10 - 28

Adapted from EPA, 1977.

Finally, the EC is not static but fluctuates with changes of water movement through the soil and with evapotranspiration characteristics. An initial high salt content may be tolerated in a well drained soil due to gradual leaching of the salt, while in arid or semi-arid climates, salts may move from depth and accumulate with time in surface horizons.

ORGANIC MATTER

The importance of organic matter in maintaining soil productivity through its effects on nutrition, structure and water holding is universally acclaimed. However, when we attempt to define minimum or optimum levels of organic matter for reclaimed soils, we run into trouble unless we look at the quality aspects as well. Desirable values within the 1% to 10% range have been suggested for agricultural, forestry and reclamation purposes (Nishimura 1974, Omodt et al 1975, Alberta Soils Advisory Committee 1979, Wilde et al 1972, van den Dreissche 1979).

But what is the quality of organic matter and how do we measure it? Certainly we realize that the organic materials in coal, tar sand, peat or the Ah horizons of a Chernozemic soil are not the same. Their benefit to reclamation bears no relationship to their organic carbon content which is the current way of determining the organic matter content of soil. Unfortunately, soil chemists in the past 100 years have produced a weighty literature discussing organic matter fractionation but have yet to explain its relationship to soil fertility. In mine reclamation, especially in the coal industry, an apparently desirable level of organic matter of largely inert coal-like carbon is included in the seedbed material without evidence to suggest any usefulness in nutrient cycling, moisture retention and the development of "the self-sustaining vegetative cover."

In addition, the methodologies available for determining carbon in soil which range from a variety of wet chemical procedures to the "Leco" dry combustion, vary in their effectiveness in oxidizing different types of organic carbon structures and in discriminating between organic and inorganic forms of carbon.

CATION EXCHANGE CAPACITY

The cation exchange capacity (CEC) is the amount of cations, usually in milliequivalents per 100 g, that a soil is able to hold due to attraction to negatively charged sites on the surfaces of clays, organic matter and hydrous oxides of iron and aluminum. Cations most commonly held are calcium, magnesium, potassium, sodium, aluminum, hydrogen, ammonium and, to a lesser extent, iron, manganese, zinc, copper and other metallic ions.

When asked what the significance of CEC in soils is, we normally answer that it is related to the retention of nutrients and in preventing their leaching from the soil. However, in reality, we probably place importance on CEC as a soil characteristic due to its direct relationship to organic matter and clay contents (see Table 5). In view of this and the analytical problems associated with its measurement, it is probably an unnecessary measurement as an initial assessment of soil characteristics. Rather than consider a CEC of 5 to 10 me/100 g as a minimum for reclamation, we would be better to set standards for clay and organic matter.

TABLE 5. APPROXIMATE RANGES OF CATION EXCHANGE CAPACITY

	CEC (me/100 g)
Sandy soils	1 - 10
Silt loams	12 - 20
Clay loams, clays and organic soils	> 20

The measurement of CEC is pH dependent since the negative charges associated with hydrous metal oxides and organic matter result from the dissociation of hydroxyl and carboxyl groups. Commonly, CEC is measured by the displacement of cations by a strong salt solution at a pH of 7.0. However, for the most realistic results, if we are really wanting to measure the cation absorptive power, it should be measured at the natural pH of the soil. In acidic soils, for instance, CEC measured at natural pH can be expected to be considerably less than that measured at neutrality. In addition, depending upon the particular method used, the measurement of individual exchangeable cations can be greatly overestimated in soils containing high concentrations of soluble salts or free lime. This is of some importance since many researchers believe that it is not necessarily the absolute concentration of exchangeable cations that is important in plant nutrition but the relative abundance of different species. Parnes (1978), for example, suggests an optimum balance of 70% calcium, 12% magnesium, 2% to 5% potassium (depending upon texture) and the balance largely as hydrogen. Other guidelines have Ca, 60% to 70%; Mg, 20% to 35%; K, 5% to 10%; and Na, less than 5% (EPA, 1977). By comparison, proposed absolute amounts vary widely depending upon the worker and plant types concerned, e.g. Ca, 100 ppm to 1600 ppm (0.5 to 8 me/100 g); Mg, 25 ppm to 250 mm (0.2 to 2 me/100 g) and K, 25 ppm to 150 ppm (0.07 to 0.4 me/100 g) (Doll and Lucas 1973, Wilde 1964b, van den Driessche 1979). Apparently, quite a wide variation in Ca:Mg is tolerated and probably adequate growth occurs unless Mg exceeds Ca on an equivalent basis or if Mg makes up 50% or more of the exchangeable bases.

SODIUM

As noted previously, when sodic conditions are indicated, it is common to determine the sodium absorption ratio (SAR) on the saturated ex-

tract. The SAR was originally developed to assess irrigation water and has become commonly used to study saline soils as well. Probably the exchangeable sodium percentage (ESP), the percentage as sodium making up the whole CEC, is more correctly applied to soils. However, ESP and SAR do show a well defined relationship within the ranges normally encountered for soils (see nomographs in Richards 1954).

A critical value for SAR is normally set at 9, the point where dispersion of clay minerals is liable to cause development of poor structural conditions and impaired drainage. However, it is likely that initiation of structural deterioration can be below this value depending on textural and aggregational differences. More realistic values using ESP have been set as follows:

- < 5% Satisfactory
- > 10% Liable to produce reduced permeability in fine textured soils
- > 20% Liable to produce reduced permeability in coarse textured soils

(EPA, 1977) MAJOR PLANT

NUTRIENTS

In disturbed areas, the question of the future nutrient status of the soil is at least equally important as the current condition of the seed bed. This brings into account time dependent aspects of weathering which may be greatly accelerated if previously buried materials are exposed and mixed at the land surface. We have to consider whether it is possible or even desirable to use testing methods to make fertilizer recommendation and to assess whether the testing methods are valid in a non-agricultural setting. A short discussion of testing for potassium, phosphorus and nitrogen is presented.

Potassium

Potassium analysis illustrates the concept of soil testing well. Most soils contain large quantities of the element potassium but only a small percentage, perhaps 1%, is in exchangeable form on the soil colloids and even less, a few ppm, is in the free soil water or soil solution. These different phases of potassium are in chemical equilibrium so that potassium removed by plant roots is replenished. Most soil potassium is

in primary minerals such as potassium feldspars, muscovite and biotite micas. These minerals release potassium very slowly by physical and chemical weathering. Some potassium is found within secondary clay mineral structures such as illite, vermiculite and chlorite, and is released slowly. Most of the remaining potassium is held on exchange sites with smaller amounts in the soil solutions and in these forms can be considered actively involved in plant uptake. Thus, conceptually, we consider soil potassium being divided into unavailable, slowly available and readily available forms. In agricultural assessments, it is normally found that exchangeable potassium, including solution-K, is directly related to plant available potassium. Therefore, the ammonium acetate extraction to measure exchangeable cations is used to provide an index of available soil potassium. Although it is probably an adequate test for available potassium in most cases, the use of a stronger acidic extractant that simulates chemical weathering may provide a better estimate of the long term potassium releasing characteristics of mine spoils.

Phosphorus

Study of the available phosphorus status of soils is difficult due to the complexity of soil phosphorus chemistry. Phosphorus forms sparingly soluble compounds with divalent and trivalent ions. Calcium phosphates are common in neutral and basic soils while iron and aluminum phosphates predominate in acidic soils. As with potassium, the amount of phosphorus present in the soil solution is very small but following plant uptake replenishment can be rapid. Soil testing methods have been developed which provide an index of availability by extracting solution phosphorus plus a fraction of non-solution phosphorus. Two different extractants are used in Western Canada: the Bray Reagent (0.025 N hydrochloric acid:0.03 N ammonium fluoride or slight modifications) for acidic to mildly basic soils and the Olsen Reagent (0.5 N sodium bicarbonate, pH 8.5) for more basic soils. Since the Bray Reagent extracts about three times the amount of phosphorus than the Olsen Reagent from soils of equivalent fertility, the methods have had to be specifically calibrated. Reclamation reports often omit to state precise methodology, an important point since numerically the data are not equivalent.

Although these test methods are probably of some use in land reclamation work, their relevance to longer term aspects of nutrient cycling and phosphorus economy in disturbed soils is more doubtful. Study of the

transformation or "turnover" of organic phosphorus may be more instructive.

Finally, the measurement of phosphorus absorption is most important in determining the fate of phosphorus fertilizers added to disturbed mine soils. In certain mine spoils with high absorption capacity, much of the added phosphorus could be fixed in a form largely unavailable to plant growth. In such cases, addition of more frequent small doses of phosphorus may be more effective to build up the phosphorus status of the site to acceptable levels. Methods for the measurement of phosphorus absorption capacities are described and discussed in Como et al (1978) and Enfield and Bledsoe (1975).

Nitrogen

In most surface soils, from 97% to 99% of the nitrogen is in organic form and must be mineralized by soil micro-organisms into plant available mineral forms. Being a biological process, the rate of nitrogen mineralization is largely dependent upon soil pH, temperature and aeration. The rate and net release is also dependent upon the nature of the organic materials in the soil. Net release or mobilization is favoured by narrow carbon:nitrogen content ratios (e.g., 20:1 and lower) in the organic matter. Decomposition of fresh plant residues high in cellulose, hemicelluloses and lignin but low in nitrogen may result in immobilization of available nitrogen into microbial tissues and deficiencies in plant growth.

Mineralization results in the formation of nitrogen as ammonium ions. In all but the more acidic soils, ammonium-N is "nitrified" into nitrate-N via the usually transitory intermediate nitrite. Ammonium can be held on the exchange complex while the nitrate anion may leach downwards in humid well drained soils and be lost below the rooting zone. Under warm water-saturated conditions, nitrate may be "denitrified" into gaseous forms of nitrogen by anaerobic bacteria and lost from the soil surface.

Since nitrogen is the most common element that limits plant growth, it rarely accumulates to any great extent. Soil testing by measuring nitrate and/or ammonium is generally only successful in predicting the nitrogen requirements for annual crops. In humid areas where nitrate may be leached below the sampling zone, even the nitrate test for annual

crops is unreliable. Applying this knowledge to land reclamation, we might expect reasonable usefulness from the measurement of mineral nitrogen levels prior to seeding prepared bare soil surfaces. However, we may be better advised to measure an index of the nitrogen supplying of potential soil mixes to show potential nitrogen fertility over a longer time span. "Mineralizable" nitrogen tests have found some success in assessing potential fertilizer responses in commercial forestry (Shumway and Atkinson 1978), a setting not dissimilar from many of our disturbed sites. In general, the anaerobic mineralization method (Waring and Bremner 1964) gives best results since it is convenient for soils varying widely in moisture holding capacity. It could conceivably be used to show changes in nitrogen cycling patterns with time but would require calibration to relate laboratory values to the potential release of nitrogen under field conditions.

WEATHERING AND THE RELEASE OF METALS

Probably little useful information can be derived from studying simulated weathering of undisturbed soils due to their inherent stability. However, estimates of weathering and induced chemical change are most important in disturbed sites, particularly where subsoils are exposed or where sulphide tailings present potential problems of heavy metal release as acidity is generated.

Several weathering methods may be useful to study physical or chemical weathering. However, insufficient research has been carried out on disturbed soils to indicate the best methodology or the practical interpretation of the data.

Field methods are generally too slow while laboratory simulations pose problems of relating lab time to field time scales. Henin and Pedro (1965) used a standard Soxhlet continuous extractor to study the weathering of rock fragments. The method enables study of both aerobic and anaerobic zones simultaneously by varying liquid levels of gas mixtures in the apparatus. A similar method was used by Como et al (1978) in studying weathering of metal tailings from mines in British Columbia. Accelerated weathering of minerals and organic materials used in the revegetation of tar sand tailings has also been studied using cycles of laboratory incubations interrupted by freeze/thaw cycles to simulate overwinter conditions (Rowell 1980).

Ultrasonic treatment has been used to study physical weathering of soft rocks (Overby and Henniger 1969, Laguros et al 1974) but has not been used for land reclamation studies. Using coarsely crushed Oklahoma shales, Laguros and co-workers estimated that one hour of ultrasonic treatment of 200 W at 20 kc and 70°F was equivalent to two years of field weathering. Changes were measured in particle size distribution and in liquid and plastic limits.

A rather straightforward but tedious method is described by Massey and Barnhisel (1972) where mine spoils were moistened to 1/3 bar and after a period of incubation were subjected to 15 bar suction to remove much of the soil water. Incubation cycles were repeated and the soil extracts produced were analyzed for metal release.

Alternate assessments of acid production from sulphide tailings have been discussed by Grube et al (1974). Lime requirements based on sulphur content were claimed to be valid if soluble sulphate was removed by acid washing, and presumably if weatherable basic constituents in the tailings were taken into consideration. Theoretically, we may calculate that tailings containing 0.1% of total sulphur as sulphide, and with a bulk density of 1.5 g/cm³ would require 468 kg of lime per cm depth per hectare to neutralize potential acidity. However, the real lime requirements would depend upon the rate of acid production and the effect of incorporating other amendments on both the acid buffering capacity and the rate of acidification.

It is important to stress that conventional lime requirement testing based on soil pH, buffer methods or incubation with liming materials will only indicate current lime requirement and will not take into account future acidity produced. As an example, Maclean and Dekker (1976) carried out growth chamber experiments on acid mine spoils that were limed according to rates obtained by incubations with lime. Initially the plants grew well but by the end of the experiment, the soils were very acidic again and required further liming. Similar cautionary tales are provided by Nyborg (1974) working on soils affected by sulphur dustfall from gas processing plants in Alberta.

Potential problems from acidic mine wastes arise not just from the effect of acidity on plant growth but from solubilization of metallic ions and their transport into the food chain via plants or drainage water.

In small doses, potential benefits could arise from increases in available copper, boron, molybdenum, zinc, cobalt and selenium which are deficient in some soils. However, the amount needed to correct deficiencies is generally quite small, for example, in the 25 kg/ha range for copper and zinc, less than 2.5 kg/ha for boron and less than 0.4 kg/ha for molybdenum.

Considerable confusion exists as to what the critical levels are for different metals in soils. Standard methods to indicate their availability to plants are less well developed than for the major elements. Metal chemistry in soil can be complicated and may involve fixation of metals as complexes and chelates with the humates and fulvates derived from humus, precipitation reactions as carbonates, sulphates and phosphates, absorption onto clay minerals, humus and hydrous oxides of iron, aluminum, manganese and silica, etc.

The relative solubility and toxicity is also related to the metal's valence state, red/ox conditions and to soil pH. Chromium IV, for instance, is very toxic but under normal conditions it occurs in the III state which is insoluble and much less toxic.

Liming acidic soils, mine spoil, and tailings will increase pH and generally reduce the availability of aluminum, cadmium, cobalt, fluoride, iron, manganese, nickel and zinc, and to a lesser extent, copper and boron. Liming tends to increase the availability of calcium and magnesium (often both present in the liming material as well), and molybdenum, phosphorus and potassium. Therefore, if we wish to produce guidelines for potential metal toxicity, we should take into account soil pH.

Methods for the appraisal of potential metal toxicity in soil have not been standardized. They range from a total elemental analysis to extraction methods involving chelates or weak acids that are hoped to extract a fraction of the total in some numerical relationship to plant uptake. A method that provides an index of potentially weatherable metal concentration, possibly that removed by 2 M HCL at 100°C, may be useful in mine reclamation assessments.

As can be appreciated, the interpretation of data can be very difficult. In many instances, the plant root seems to act as a barrier against excessive uptake and may bear no relationship with total

elemental concentrations in the soil. Often, critical levels are developed for plants in growth chamber experiments by defining the concentration required to produce, for example, a 25% yield reduction. However, the results do not take into account metal interactions, differences in chronic effects, subtle genetical or physiological changes, or the impact on animals eating the plants. Chumbley (1971) proposed for zinc, copper and nickel that the maximum additions to soils, at a pH above 6.5, should not exceed 250 ppm or the weighted equivalents of all three combined. For this purpose, copper was considered twice as toxic as zinc and nickel eight times as toxic as copper.

A comparison of proposed guidelines for soil is presented in Table 6. The loading rates quoted from EPA, 1977, were proposed for use in rapid infiltration effluent disposal systems where the soils would be freely drained and rather low in clay and organic matter.

TABLE 6. SOME PROPOSED GUIDELINES FOR METAL ADDITIONS TO SOILS

<u>Element</u>	<u>NATURAL LEVELS</u> (ppm)		<u>GUIDELINE LEVELS</u> (ppm)	
	<u>Mean</u>	<u>Range</u>	<u>I</u>	<u>II</u>
As	6	.1 - 40		13
Cd	.06	.01 - .07	5	1.4
Cr	100	5 - 3000	47	56
Cu	20	2 - 100	90	100
Hg	.03	.01 - .3		0.05
Mo	2	.2 - 5	5	1.6
Ni	40	10 - 1000	90	43
Pb	10	2 - 200	2285	56
Zn	50	10 - 300	920	216
Al			2285	1*
B			340	
Co			23	18
Fl			460	
Fe			2285	
Mn			90	20*
Se			9	1.6

*Soluble in 0.01 M CaCl₂.

I - Adapted from EPA, 1977.

II - Alberta Soils Advisory Committee, 1979.

CONCLUDING REMARKS

In land reclamation, the soil scientist is presented with many new problems and challenges. The wide array of chemical and physical tests already developed for engineering, agriculture and forestry may have a direct application to land reclamation problems. However, the study of many soil characteristics may require the modification of existing methods or the development of new procedures to cover the field from mine spoils to tailings.

The way we use the results must depend on clearly defined objectives for each phase of reclamation to the final land use. The soil characteristics and qualities that we define as optimum or minimum for one purpose may differ widely from another land use alternative. In addition, the initial objectives of reducing erosion and maintaining water quality may conflict with soil requirements for the final proposed use of the land.

Where we attempt to return disturbed agricultural and commercial forestry areas to a state at least equal in productivity, considerable forethought will be required. If we are unable to attain a stable state of soil quality and productivity, we must consider the soil to have been degraded and reclamation to have failed.

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