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FERTILIZERS AND SOIL AMENDMENTS
IN
MINE RECLAMATION

by

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FERTILIZERS AND SOIL AMENDMENTS

INTRODUCTION

The use of fertilizers and soil amendments for reclamation purposes is, in many ways, similar to their use in agricultural systems. In both situations the main objective is either to totally remove or to ameliorate a limiting plant growth factor(s). In both cases it is desirable to select the appropriate material at the least cost. On the other hand, the reclamationist is often not dealing with natural soils nor is he necessarily striving for maximum biomass production. Understanding unique and, in some cases, unstable growth media and managing for long-term stability of the plant community, assume greater importance in reclamation than dry matter accumulation.

In both agriculture and reclamation work a basic understanding of the fertility level of the growth media and a knowledge of the basic materials available for modifying soil fertility are prerequisites to establishing successful plant growth. In this presentation I have attempted to provide an overview of these topics.

SOIL FERTILITY ASSESSMENT

An evaluation of soil fertility is similar to a doctor diagnosing the health of a patient. The medical doctor observes the patient, obtains all the information possible with his questions, and then makes the appropriate tests. Similarly in plant diagnostic work, we observe the plants, find out as much as possible about the origin, characteristics and past management of the material to be vegetated, and then make tests on the plant or the growth media.

PLANT DEFICIENCY SYMPTOMS

Deficiency of an element may not directly produce visible symptoms. However, it will throw the plant's biochemical processes out of balance leading to a shortage of some organic compounds and an accumulation of others. While each symptom is related to some function of the element in the plant, a given element may have several functions, making it difficult to explain the physiological reason for a particular deficiency symptom. In other cases, the connection between the symptom and the element's function is clear. For example, the chlorotic plant tissue resulting from deficiencies of N or Mg can be directly related to their role as constituents of the chlorophyll molecule. Other elements such as Fe and Mn are involved in the formation of chlorophyll, and their deficiencies also appear in the form of chlorotic tissue.

Another important factor in determining the deficiency symptoms of the various elements is their mobility within the plant. Magnesium, for example, is mobile in plants and the typical interveinal chlorosis resulting from Mg deficiency would appear on the older leaves. Iron and Mn, on the other hand, are immobile in the plant and their deficiency symptoms would appear on the new growth.

Some deficiency symptoms associated with the essential plant nutrients are listed in Table 1. For a more complete discussion refer to Chapman (1966) or Sprague (1964). While the proper interpretation of deficiency symptoms can be a valuable tool, it is always better to practice preventive medicine, i.e. to predict deficiencies before they become serious enough to limit plant growth. Also, one may be faced with a situation in which two or more elements may be simultaneously deficient resulting in confusing visual symptoms. Where possible it is desirable to be able to predict nutrient deficiencies before they occur. One tool which can be useful in this regard is soil testing.

SOIL TESTING

Soil testing attempts to simulate the ability of the plant root system to acquire nutrients over the duration of the growing season. Currently, this involves the use of a chemical extractant which, hopefully, will extract from the soil a portion of the element in question which will correlate positively with plant uptake of that element and hence, growth. It must be stressed that the number derived in the laboratory analysis following extraction of the soil sample is virtually meaningless without same backup research both in a controlled environment and in field plot studies. It is dangerous to extrapolate from one agricultural soil to another, much less from agricultural soils to mine wastes.

With this precaution in mind, there are a number of soil test extractants available for most plant nutrients, under a variety of soil conditions (Table 2). Instrumentation for determining the various nutrients in the extracting solutions is both available and relatively inexpensive. Requirements would include an atomic absorption/flame emission spectrophotometer for Ca, K, Mg, Fe, Cu, Mn, Zn, and possibly Mo, and a colorimeter for P, N and S.

FOLIANT ANALYSES

In situations where there is not a reliable soil test, the reclamation worker can resort to tissue analysis. As with simple observation of deficiency symptoms, tissue analysis will provide an after-the-fact diagnosis of a current problem; however, it will enable the reclamationist to correct the situation by next season. Examples of the critical levels of elements in three plant species are shown in Table 3. In some cases the reclamationist may also want to calculate element ratios such as P/Fe, since elements such as these often interact both in the soil and the plant.

Table 1
NUTRIENT DEFICIENCY SYMPTOMS FOR SELECTED PLANTS

Element	(absorbed as)	Functions in Plant Growth (mobility)	Deficiency Symptoms
N	(NO_3,NH_4^+)	Constituent of protein and chlorophyll promotes vegetative growth, mobile	Chlorosis initiated on older leaves
P	($H_2PO^-{}_4$,HPO_4^{-2})	Biochemical energy transformations (ATP) constituent of ribonucleic acids, mobile	Purpling of young plant, general stunted appearance
K	(K^+)	Carbohydrate metabolism and translocation, protein synthesis, enzyme activator stomatal movement and water relations, mobile	Chlorosis on margins of older leaves
S	(SO_4^{-2})	Constituent of some amino acids, co-enzyme A, increases oil content of crops, related to cold resistance, part of nitrogenous enzyme system involved in N fixation, relatively immobile	Uniformly chlorotic plants, stunted, thin stemmed
Mg	(Mg^{+2})	Constituent of chlorophyll, related to P metabolism, plant respiration, mobile	Interveinal chlorosis on older leaves
Ca	(Ca^{+2})	Necessary for meristematic development, membrane integrity, immobile	Failure of terminal bud to develop
B	(H_3BO_3,B_4O_7,$^{-2}$)	Carbohydrate translocation, P metabolism, formation of growth hormones such as IAA, immobile	Chlorosis of younger leaves, internal breakdown of storage organs such as tubers
Fe	(Fe^{+2},Fe^{+3})	Activator of several enyzme systems, chlorophyll synthesis, immobile	Interveinal chlorosis on new leaves
Mn	(Mn^{+2})	Activator of enzymes concerned with carbohydrate metabolism, photosynthesis, immobile	Interveinal chlorosis on new leaves
Cu	(Cu^{+2})	Enzyme activator, photosynthesis, immobile	Chlorosis, distortion of younger leaves
Zn	(Zn^{+2})	Enzyme activator, immobile	Initially as an interveinal chlorosis on younger leaves followed by a large reduction in shoot growth, rosetting
Mo	(MoO_4^{-2})	N fixation, assimilation, protein synthesis	First as interveinal chlorosis, with legumes the same as N deficiency

Table 2

COMMONLY USED SOIL TEST EXTRACTANTS

Element		Extractant	Conditions
N	(NO_3 $^-$ form)	H_2O	Leaching not significant
	(Total N)	Kjeldahl digestion	Long-term N availability required
P	(orthophosphate)	Bray's P_1 (.03 NH_4f in .025 N HCl.)	Acid to neutral soils with low to medium cation exchange capacities
		Olsen's 0.05M $NaHCo_3$ method pH 8.5	Both calcareous and non-calcareous soils
		Mehlich's dilute acid method (0.05N HCl and 0.025 N H_2SO_4)	Acid, highly weathered soils
K, Ca, Mg (exchangeable)		Neutral 1.0 N Ammonium acetate	Broad application
S	($So_4$$^{-2}$)	0.1 M $CaCl_2$ Ca (H_2PO_4), .05M $NaHCO_3$ (pH 8.5)	To obtain H_2O soluble $SO_4$$^-$S. To obtain adsorbed $SO_4$$^-$S.
B		Hot water	Soils not subject to intense leaching
Fe, Cu, Mn		0.1 N HCl	To extract organic plus forms held in organic matter
Zn		Chelates such as D T P A, E D T A	

Table 3

SOME SELECTED CRITICAL LEAF TISSUE CONCENTRATIONS

Element	Alfalfa	Oats	Orchard grass
N	-	1.0	2.4
P, %	0.15	0.1	0.2
K	1.0	1.1	2.0
Ca, %	0.6	0.1	-
Mg, %	0.2	0.1	-
S, %	0.2	0.1	0.1
B, ppm	15	5	-
Mn, ppm	10	10	-
Zn, ppm	10	20	-
Cu, ppm	6	3	-
Mo, ppm	0.2	0.1	-
growth stage	early bloom	4-6 weeks	3-4 weeks

Tissue analysis can provide only a rough tool to establish the nutrient status of plants grown for reclamation purposes. Comparison with published critical values is hazardous since nutrient concentrations can change rapidly depending on the stage of growth. Tissue nutrient contents are useful in comparing treatment effects in field or controlled environment studies. Walsh and Beaton (1973) include several chapters on tissue analysis.

FERTILIZERS

Once the fertility requirements of the soil has been established, the next step is to determine the most appropriate method of supplying deficient nutrients. Usually, the most effective and simplest method is to add chemical fertilizers. The main exception to this statement could be N. It would seem to make sense to use symbiotic N fixing organisms whenever possible, because N requires the most energy to manufacture (N, *?2®5> ^2®* requires 77.5, 14 and 9.7 MJ/kg, respectively) and is more expensive than either of the two other macronutrients, P and K. The following discussion is limited to fertilizer nutrient sources. However, alternative nutrient sources, especially legumes, should be seriously considered in reclamation work.

TYPES OF FERTILIZERS

There is a wide range of fertilizers available today, which allows considerable flexibility in the form of the nutrient applied and in the ratios of the three macronutrients and S. By law, manufacturers must state a minimum guarantee of the plant nutrient content of fertilizers in terms of N, P_2O_5 and K_2O. The ratio of these nutrients in the fertilizer purchased should depend on the requirements of both the soil and the crop. For example, one might select a fertilizer with a 2-1-1 ratio for grasses or 1-2-2 for a stand of forages dominated by legumes. The trend in recent years has been to higher analysis fertilizers, motivated by the need to reduce the fixed costs of bagging, transporting and distributing the finished product.

The properties of five types of fertilizer will now be discussed.

Nitrogen - Two N sources, urea (46-0-0) and ammonium nitrate (34-0-0) make up the bulk of the W sold in western Canada. Most of the new fertilizer plants are designed to produce the less energy-requiring urea, rather than ammonium nitrate. Currently there is a cost differential of slightly over *10%* in favour of urea. Urea is not ideal in all circumstances, however. It hydrolyzes rapidly to NH_3 which can be lost as a gas (especially from calcareous soils), or it can be toxic to plants; consequently, greater care is required in its use.

Because N tends to be quite mobile in soils and is easily lost, considerable research has developed new methods of reducing M losses. One example is sulphur-coated urea, a slow release fertilizer (Sheard, 197b). Molten S, which is coated on the urea prill, mostly oxidizes before the urea-N can diffuse out into the soil. The release of N can be controlled from two months to two years or more by this method. Other slow release fertilizers include osmocote and urea-formaldehyde.

A second example is the use of nitrification inhibitors to delay the nitrification of NH_4-N to $N0_3$-N. Research in the U.S. has shown two materials, N-Serve [2-chloro-6-trichloro methyl pyridine] and ATC (4-amino-l,2,4-triazole), to be effective nitrification inhibitors. Work at U.B.C. by Guthrie and Bomke (In Press) has indicated that N-Serve, because of its volatility, is not as effective in coarse textured soils as is ATC. ATC was shown to inhibit nitrification to some extent for up to three months when applied at a rate of 1 kg/ha with band applied urea. It was ineffective with broadcast urea.

Phosphorus - Because of its high water solubility, high P content, ease of handling and application, and relatively low cost, 0-46-0 triple super phosphate [$Ca(H_2PO_4)_2$] is currently the most popular P source. Other P sources include 0-20-0 (super phosphate) and rock phosphate. The latter has a low P content relative to triple super phosphate and is slightly soluble P source which can be used only on acid soils.

Potassium - The main source of K is KCl, 0-0-60. This is a high analysis and economical source of K. Most mine waste materials would require considerably less K than N or P.

Sulphur - The ready availability and economy of granular S in western Canada plus its high analysis (90 + % S) make it an ideal source of S. It can either be added singly or blended with N-P-K fertilizers.

Mixed Fertilizers - The above mentioned single nutrient fertilizers may be blended to produce complete or compound fertilizers. Fertilizers with ratios high in N and P (e.g. 3-4-1) should be appropriate for mine wastes, if there is no soil test information available. Another class of compound fertilizers is the ammonium phosphates such as monoammonium phosphates (11-55-0) and diammonium phosphate (18-46-0). These materials may be quite valuable in reclamation work because of their high proportions of N and P.

FERTILIZER CHARACTERISTICS

The proper use of any tool requires that its characteristics be understood. This section summarizes some of the relevant characteristics of fertilizers. As can be seen in Table 4, NH_4-N sources are significant producers of acidity. This effect would develop quite rapidly in coarse textured and poorly buffered mine wastes. Phosphorus, K and ~N fertilizers have little effect on soil pH.

A second important property of fertilizers is expressed in terms of their salt index (Table 5). Fertilizers with a high salt index (N, K

Table 4

ACIDITY OR BASICITY OF COMMONLY USED FERTILIZERS

		kg of pure CaC03	
Material	*% H*	Per kg of N	Per 100 kg of Material
Ammonium sulphate	21	5.4	110
Urea	46	1.8	84
Ammonium nitrate	34	1.7	59
Ammonium phosphate	11	5.9	65
Calcium nitrate	15	1.4 B	20 B*
K C 1 (60-60)	0	0	0
Triple superphosphate	0	0	0

*B = indicates that the material is a base former in the soil.

Table 5 SALT INDEX OF SOME COMMOM FERTILIZER MATERIALS

		Salt Index	
Material	Analysis *(%)*	Per Equal Weight of Material*	Per Unit of Plant Material
Ammonium nitrate	34	104.7	3.0
Ammonium sulphate	21	69.0	3.2
Urea	46	75.4	1.6
Calcium nitrate	15	65.0	4.2
KCl	60	116.3	1.9
Triple superphosphate	45	10.1	0.2

*$NaN0_3$ = 100

sources) require care if they are being placed with the seed or are applied in contact with plant tissue. High salt concentrations around seedlings or roots give rise to high osmotic pressures which increases the plant's difficulty in acquiring water. The Salt Index is related to another property of fertilizers, namely solubility. P fertilizers are relatively insoluble when applied to the soil, resulting in minimal salt content in the soil solution as compared to the soluble N and K fertilizers.

The final property to be discussed, hygroscopicity, relates to the storage characteristics of fertilizers. Hygroscopicity is the tendency of salts to adsorb water whenever the vapour pressure of moisture in the air exceeds that of a saturated solution of the salt. Hygroscopicity increases in the following order: ammonium phosphate < potassium chloride < urea < ammonium nitrate < calcium nitrate. This property causes the caking and hardening of bagged fertilizer which, although not usually a problem for P or K fertilizers, can be a problem for improperly stored N fertilizers.

RATES AND METHODS OF APPLICATION

Most experiments on disturbed lands have used fertilizer rates similar to those recommended for infertile agricultural soils. These rates may be inadequate since some mine wastes are essentially devoid of N and may fix applied P into unavailable forms. Higher rates may, therefore, be required. If a legume is part of the seed mix, N rates should be reduced to allow the legumes an opportunity to compete with grass components of the mix. Trees used in revegetation will likely have a lower fertility requirement than herbaceous species. Growth rates may be lower and mycorhizal relationships on their roots may enable them to acquire relatively unavailable forms of P.

The method of application depends heavily on the type of area to be fertilized. A level tailings pond for example would be quite amenable to a broadcast application followed by incorporation of fertilizer. This may be beneficial prior to the seeding of perennial species, since P, K, and lime are relatively immobile in the soil and will not descend more than 5 cm below the soil surface following a topdressing. Un rough or rocky terrain the fertilizer will likely have to be applied without the benefit of incorporation. Established forages are usually successful in obtaining adequate P and K from surface applications, although nutrients in a dry soil zone will be at least temporarily unavailable.

Foliar fertilization is not a viable alternative in reclamation work except in the case of micronutrients. The cost of transporting bulky liquid fertilizers, the high costs of highly soluble grades of fertilizers required, and the difficulties of supplying adequate M, P and K without damaging the foliage all severely limit the usefulness of foliar fertilization with macronutrients, except possibly in intensive horticultural production.

In summary, N and P and occasionally K fertilizers are valuable tools in revegetation work. It should be possible to build up the available pool of P and K, although long-term N fertility may be a problem. The solution may be in the use of leguminous species in seeo. mixes or perhaps the addition of nitrogenous organic amendments. This will be discussed in more detail in the next section. For a more complete discussion of fertilizers, consult the textbook entitled Soil Fertility and Fertilizers by Tisdale and Nelson (1975).

The cost of fertilizers may be as little as 1/100 of the total cost of reclamation. It is, therefore, important to augment the fertility of the material to be reclaimed in the initial stages of the vegetative process in order to insure that the investment of reclamation is protected. Also, because of the other costs involved in reclamation, the precision required in agricultural soil testing programs may not be necessary in reclamation. The site-specific nature of most projects will also dictate this.

SOIL AMENDMENTS

A soil amendment is any substance such as lime, sulphur, gypsum or organic materials which is used to alter the properties of the soil, generally to make it more productive. The term usually does not include highly concentrated nutrient sources such as fertilizers.

ORGANIC AMENDMENTS

Organic materials may or may not have beneficial effects on the available nutrient supply in the soil. The main determining factors include the C/N ratio and the physical state of the material. When an organic material is added to the soil, the microbial population rapidly increases in response to the increased substrate. If the material is well endowed with N relative to C, a net release of N into the soil mineral N pool will occur. On the other hand, a large amount of C relative to N (wide C/N) would tie up or immobolize soil N. A C/N > 30 will likely result in N immobilization, and one less than 20 in N mineralization. Some organic materials and C/N ratios are given below:

poultry manure	7
well rotted barnyard manure	20
clover residues	23
grain straw	80
sawdust	400

Any material with an N% < 1% will likely immobolize N, while a material with an N% > 1.5-1.7 will mineralize N. A wide C/N ratio can be reduced by the addition of N fertilizer to the material. The rate of breakdown is also dependent upon the particle size of the material. For example, smaller particles such as sawdust will decompose more quickly than wood chips.

In addition to the possible fertilizer value, some organic amendments may have other beneficial effects when incorporated into soils. These include:

a. increasing the water holding capacity of the soil;

b. increasing the cation exchange capacity and the nutrient holding ability of the soils;

c. improving the structure and aeration of fine textured soils.

Since the materials to be revegetated are often coarse textured and may have a high percentage of coarse fragments, a. and b. above are especially important in reclamation. Greenhouse experiments at U.B.C. demonstrated the beneficial effects of poultry and cow manures on severely acid sulphide tailings.

Mulches are unincorporated organic materials used for stabilizing soils, conserving moisture, moderating temperature fluctuations, controlling weeds and reducing seed loss prior to germination. Mulches may be locally available waste products such as forest by-products, or commercially available mulches such as those available as by-products from grass seed production. In order to be effective, minimum rates of 1100 to 1700 kg/ha of wood wastes, or 2200 to 4500 kg/ha of straw or hay are required. Additionally, an effective mulch must stay put, must not impede the infiltration of water or the diffusion of gasses into or out of the soil, or have a deleterious effect on the plant cover. Because of the bulky nature of mulches, it is best to use locally available materials such as wood wastes in B.C. For further information the reader is referred to Plass (1978) and Kay (1978).

INORGANIC AMENDMENTS

Limestone is the most common inorganic amendment. Acid materials such as some sulphide tailings could benefit from lime addition as would exposed acid subsoils. The feasiblity of liming depends on the location of the site to be revegetated and the amount of lime required. For example, we determined in a greenhouse study that short-term neutralization of acid sulphide tailings from a northern Vancouver Island mine required nearly 50 t/ha. Obviously it would be impractical to try to improve these tailings by liming.

Highly calcareous materials can also present problems in P and micro-nutrient availability. Sulphur may be used as a soil amendment to acidify calcareous materials as a result of the following reaction:

$$S + 3/2\ O_2 + H_2O \xrightarrow[\text{spp}]{\text{Thiobacillus}} H_2SO_4$$

One kg of S Is equivalent to approximately 3 kg of CaCOj.

I have attempted to outline the methods of assessing the fertility of disturbed lands, and have described the fertilizers and soil amendments available for improving tailings productivity. Both fertilizers and soil amendments can play a role in reclamation work, depending on the economics, and the soil factors which require modification. In all cases, practices which encourage short-term rapid growth at the expense of long-term vegetative stability should be avoided.

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DISCUSSION RELATED TO A. BOMKE'S PAPER

Niel Duncan - Energy Resources Conservation Board, Alberta: With the possibility of a coal-fired station near Cache Creek, what is the chance of using fly ash as an inorganic amendment?

Answer: I'm sorry. I haven't had any experience with fly ash.

A. Reed, Afton Mines Ltd.: Would a low grade coal such as the Hat Creek deposit qualify as an organic amendment?

Answer: Well, let's look at what it might be used for. I don't think that it would be suitable as a mulch material. It doesn't have the characteristics that I'd like to see in a mulch, so we could rule that out. Now, whether it has any useful significance as an incorporative material, I can't say. Some of the coals tend to be resistant to decomposition, and some do not readily release nutrient such as nitrogen. I don't know specifically about any tests at Hat Creek. Perhaps the (Acres) people could tell us.

Acres: I think I can answer your question. There are far too many of the so called order of metals and elements in the Hat Creek coal to ever dare consider (Editor: we regret that the remainder of this answer was not recoverable from the taping).

Zig Hawthorn - B.C. Hydro: We have tried growing vegetation on waste coal at Hat Creek. It does grow, but it's difficult. Topsoil on the waste coal does improve the vegetative success rate, but again growth is difficult to achieve. We haven't tried it the other way around, where we add a little bit of coal to a lot of soil, so we can't really answer that question.

Questioner Unidentified: (Distorted Recording. Question related to the properties of selenium and its effect on foraging animals on reclaimed land.)

Answer: I think it is reasonably clear that selenium is not an essential element for plants. It is taken up depending upon how much of it is present in the soil. I don't know of any work on a field scale where people have taken selenium and applied it in order to increase the selenium content of forage. I think it is a very risky proposition. It's more likely that we will be successful by some sort of injection, or perhaps even a mineral block of something. I might also add that selenium deficiencies seem to be accented by sulphur fertilization. So, if it is seen that sulphur gives a good response and they really chuck the sulphur on, this can actually compete with selenium uptake and decrease the value of that material as a forage by creating problems such as White Muscle Disease.