USING COMPUTERIZED EXPERT SYSTEMS, UNIQUE SOIL TESTING METHODS, AND MONITORING DATA IN LAND MANAGEMENT DECISIONS

Dale E. Baker and John K. Buck

The Pennsylvania State University, University Park, Pennsylvania; and
GAI Consultants, Inc., Monroeville, Pennsylvania

Abstract.--Expert system development software adds new dimensions to computerized interpretation of chemical monitoring data for soil, water, and air. What has come to be known as the Baker Soil Test is an example of an expert system used for land management decisions. The new computer software can make this and other monitoring data even more beneficial to one making land management decisions because more explanation and/or guidance may be passed from the "expert" to the decision maker. Computerized expert systems may be model driven, data driven, and/or expert driven. Reliable systems for land management decisions require a combination of all three approaches and often involve more than one technology. The Baker Soil Test involves a model derived from aqueous solution thermodynamics. The approach places emphasis on the soil solution as a biologically active, dynamic phase with extensive properties attributed to soil solids handled as a "black box". The method was first applied in 1970 to well-characterized agricultural soils with additional correlation data from other soil test methods. The Baker Soil Test has since been used to evaluate "non-soils", including fly ash, coal refuse, and steelmaking slag as well as contaminated soils for their chemical suitability as growing media, and, if vegetated, for potential soil/food-web interactions. The computerized system is consistent, but may not be comprehensive, accessible, or perhaps even logical to some decision makers. Monitoring data and recommendations for land management decisions must be obtained in a consistent and reliable manner and re-evaluated such that decision-making software in expert systems is improved over time. This presentation will review case studies where the Baker Soil Test monitoring data have been used for decision support. The goal of this presentation is to have scientists, consultants, governmental agency regulators, and those making decisions and paying for land management operations become more aware of the need for interaction in the development of alternatives in land management.

INTRODUCTION

Use of a computerized decision-making process to evaluate potential land use requires much integration of knowledge, theory, and data developed over time. Monitoring data must be backed by theoretically sound concepts or approaches; otherwise, the results obtained at one site are not likely to be

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of value at another location. One objective of this paper is to relate the theory and practice in soil testing which lead to the development of the Baker Soil Test, and the applications of this method for use in decision-making for management and chemical monitoring of disturbed spoils, spoils, coal refuse, coal fly ash and other potential plant growth media.

A second objective is to present the hypothesis that computerized systems can be used by decision makers to obtain the information needed to relate monitoring data and existing technology to site-specific requirements. Experience has shown that specific recommendations made from monitoring data alone are not always sufficient.

EVOLUTION OF THE BAKER SOIL TEST

The Baker Soil Test was developed as a means of evaluating onsite materials for their potential to become growing media, especially where soil cover is unavailable or impractical to obtain. In the 17th century, the Van Helmont experiment demonstrated that soils themselves do not serve as nourishment for plants but simply provide plants with a physical medium of support and with available water containing essential nutrient ions. In addition to water and nutrients from soil, oxygen, carbon dioxide, and sunlight are required for plant growth.

The Van Helmont (1577-1644) experiment was a classical example to support Francis Bacon, who believed that water formed the "principal nourishment" of plants (E.W. Russell 1973). Van Helmont grew a 5-lb willow shoot in 200 lb of dried soil to which he added rain water for exactly 5 years. The resulting tree weighed 169 lb, 3 oz and the soil still weighed 200 lb minus 2 oz. Van Helmont concluded "therefore the 164 pounds of wood, bark, and root arose from the water alone". Later it was postulated that the 2 oz of lost material represented the salts which are essential for plant growth.

Soil fertility experiments today continue to strive to establish optimum levels of salts of the essential chemical elements to add as fertilizers to soil for maximum economical production of specific crops. It is known that carbon (C), hydrogen (H), and oxygen (O), from O_2 and CO_2 in the air plus water, are the most abundant components of plants followed in their general order by nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), sulfur (S), iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), and chlorine (Cl). In addition, animals require macro amounts of sodium (Na) and micro amounts of cobalt (Co), selenium (Se), and probably also chromium (Cr) and nickel (Ni). Producers of field crops know from experience that for every part of N consumed by vegetation, the air, water, and sunlight together supply 40 to 80 parts of dry matter. This synthesis requires optimization of the other essential elements. Over time, the physiology of plants and their mineral nutrition have become very well understood, yet the humus factor in soil management remains to be quantified.

Soil Factors

Management of soil resources requires an integration of all of this technology. It may appear as an oversimplification, but an approach to integration stems from the concept that plants grow in water (the soil solution) which is the continuous phase in the soil-water-air system. Oxygen (O_2) enters the plant root system and carbon dioxide (CO_2) escapes from the respiring root system via diffusion across the water film separating plant roots and soil particles from the large air-filled pores in soils. Soil air is in dynamic equilibrium with the atmosphere through diffusion. Ions essential and nonessential for plant growth are in a dynamic equilibrium with the soil solid phase and the ion absorption sites of plant roots via soil water. Water in soil is exposed to the atmosphere at the soil surface (evaporation) and at the surface of plant leaves (transpiration). Water exists in soil-plant systems as thinly stretched films. The free energy or vapor pressure of soil water must remain between 99 and 100 percent of that of unbound, pure water or plants wilt.

Theory of the Baker of Soil Test

The Baker Soil Test was developed from the hypothesis that plant growth rates are a function of the free energy or chemical potential of ions in the soil solution at the absorption sites on the plant root surface. As ions are absorbed at the root surface, they are replenished by the solid phase via dissolution, desorption, decay in the case of organic matter, or from application of soil amendments. In addition to pH of the soil solution, one must manage soils for pH_2O, pK, pCa, pMg, pH_2PO_4, etc. for every ion and compound essential or beneficial for plant growth and affecting the food web.

In the development of the Baker Soil Test, it was first shown that the activity of an ion (metal or non-metal) and not simply the concentration determines bioavailability of that ion (Baker and Low 1970). From this concept, published data were used to establish boundaries for the appropriate equations relating intensive and relative intensive properties for ions in soil solutions. Standard values for ranges were established for pH, pK, pCa, pMg, pH-1/2p(Ca+Mg), etc. (Baker 1971). Subsequently, the concept was extended to include trace metals (Baker 1973). At this time, the Baker test includes values for the labile quantity and intensity of Ca, Mg, K, Mn, Fe, Cu, Zn, Na, Al, Pb, Ni, and Cd (Baker and Amacher 1981). Assays for plant-available Mo are now under consideration for incorporation into the Baker testing method. Conceptually then, the soil solid phase may be composed of any material which maintains or can be treated to maintain pH_2O, pO_2, pH, pK, pCa, pMg, pH_2PO_4, $pHPO_4$, pNO_3, pNH_4, pZn, pCu, etc., for essential and nonessential elements. In addition to existing standard ranges for each element to predict plant growth and composition, computerized systems could provide more information regarding theory and application.

Use of Non-ideal Growing Media

Economical reclamation and management of disturbed land, especially land disturbed by mining, necessitates the use of non-ideal growing media. Where soil cover is unavailable or impractical to obtain, reclamation practitioners need systems for evaluating the materials available onsite for their potential to become growing media (via amendment). In addition to the potential growing media's physical properties, the chemistry of growing media must be considered:

1) for the present (soil solution nutrient/contaminant ion intensity);

2) in the near future (1-2 growing season soil nutrient/contaminant quantity factors); and

3) in the long term (e.g. potential acidity and associated toxicities from pyrite oxidation).

Examples of these chemical factors, respectively, include:

1) pH, and activity of Fe, Mn, Al, and other nutrients and potentially toxic elements in solution;

2) immediate acidity, labile nutrient/toxic element pool; and,

3) long-term acid production via pyrite oxidation.

EXPERT SYSTEMS APPLIED TO REVEGETATION

The computerized system must establish an If, Then, Else decision-making flow path. For the case of identifying the potential of a waste material to serve in lieu of soil as a growing medium, the investigator determines: 1) if the materials on site are growing media; 2) if not, can they then be amended to become growing media; and 3) if that is not feasible what else can be done with the site (e.g., cover with better material)?

Limiting Factors and Sampling

In determining if the materials onsite are growing media, great cost and time savings can be achieved by first identifying the factor(s) most limiting the development of vegetation on the particular site or portion of the site. This requires some understanding of the history of the site, a field view of current site conditions, and a sampling and analysis program which takes site spatial variability of potential growing media into account. For example, direct revegetation of a coal waste or a heavy metal contaminated site with use of soil or fly-ash or combinations requires that the "worst" materials on site be identified and treated, (not simply the "average" materials represented by composite samples).

Unlike natural soils, sampling of heterogeneous disturbed sites may require that many separate subsamples be analyzed for some or all parameters before composite samples can reasonably be made. Because such a multiple analysis program can be costly, assays for critical parameters which can be done at low cost (e.g., pH and immediate acidity) should be done first. This will help establish the variability of site materials prior to compositing of samples or selecting particular samples for assays of the most expensive of the critical parameters (e.g., potential acidity as pyrite).

Where limiting factors are identified and the range of material characteristics is established, the investigator must then consider whether the worst materials can be selectively treated (e.g., limed) or removed (e.g., excavated and buried), or if a nonselective site-wide treatment aimed at amending the worst materials can be successfully applied yet not compromise the physical and chemical properties of other materials. The more demanding amendment schemes being considered should be experimentally simulated in the laboratory (e.g. liming and wetting/redrying cycles, batch test, etc.) for a wide range of sample types. Then amended samples can be reevaluated for critical parameters as well as parameters of secondary importance.

If the material is a potential growing medium, at least two technical considerations remain: 1) what limitations exist to the final use of the site, specifically, what sort of soil-water plant-herbivore relationships are possible; and, 2) how will the physical and chemical properties of the growing media change over time? The first question is most important for agricultural and, to a lesser extent, wildlife uses, especially for species with broad home ranges--will vegetation produced on alternative growing media be wholesome food for animals? The second question concerns changes in chemistry which may occur with weathering over time. In most humid environments, rainfall and freeze/thaw weathering reactions usually improve the chemical and physical properties of alternative growing media--soluble salts and potentially phytotoxic elements leach out of the root zone. However, the chemistry of pyritic materials may degrade a site over time.

Pyritic Materials--A Long Term Concern

In the case of many mining spoils and coal processing refuse materials, intense acidity generated by pyrite oxidation may radically degrade the amended materials over time and result in the elimination of a vegetative cover. Acidity produced by pyrite oxidation can degrade the soil solution plants depend on, as well as degrade surface and ground water quality. Reclamation of pyritic materials requires that acidity generation be either prevented or neutralized by placement of effective neutralizing agents as it is generated. Although short-term use of anionic surfactants combined with self-sustaining complexing agents produced by vegetation (organic acids) may prevent pyrite oxidation and represent a permanent fix in some cases, the long-term effectiveness of a preventative approach is still under evaluation. Methods of controlling or compensating for pyrite oxidation have been reviewed by Kleinmann and Erickson (1987).

Acid-base accounting methods, while intuitively reasonable, have not been the best predictors of actual pyrite oxidation and acid mine drainage generation (Erickson 1987). The fundamental weakness of the acid-base accounting approach is that it does not consider the relative reactivity of materials and chemical reactions responsible for acid production and neutralization, respectively, by pyrite and carbonate constituents in mineral processing refuse and spoils. Most carbonates present in refuse and spoil materials are in the relatively large (>2 mm) fraction of the particle size distribution and are thus slow to react or are essentially inert. Thus, like Nawrot et. al. (1987), the authors advocate a conservative approach to revegetation of pyritic materials-consider potential acidity from pyrite without regard for native carbonate minerals in the material.

The acidity compensation approach, in which enough limestone is applied to neutralize both immediate and potential (pyrite caused) acidity, is a relatively sure approach as long as 1) the "worst" materials are identified and appropriately treated; 2) treatments are deep enough to allow development of deep, drought-resistant root systems in amended materials; 3) limestone of sufficient fineness is used to assure rapid neutralization of acidity as it is generated; and, 4) acidified water movement from unamended zones does not encroach upon amended zones. Where excess alkalinity is supplied in the form of finely ground agricultural-grade limestone, low carbonate solubility will prevent loss of neutralizing capability by leaching, plus will keep the growing media pH from exceeding approximately pH 8.2. At a soil pH of 8.2, some trace element deficiencies are possible, so the expert system should include laboratory evaluations of such "over-limed" materials to assess the availability of major and trace elements. If such amendment schemes are properly designed, the pH of the materials should be maintained above pH 5.5 and below pH 8.2, even if pyrite oxidation and acid production reaches its potential maximum.

Chemical Evaluation of Alternative Growing Media

All growing media, particularly those which are not natural, uncontaminated soils should be evaluated for their ability to supply essential nutrients and trace/potentially toxic elements to plants. Evaluation of the nutrient/trace element status of an alternative growing medium has historically been made difficult because most conventional soil test interpretive criteria are based on agricultural soils' correlations between fertilizer-dose/yield-response and corresponding soil assay values. Such empirically derived criteria (e.g., the basic cation saturation ratio approach) have little theoretical foundation for application to very dissimilar soils, or to nonsoil alternative growing media such as coal refuse overburden/spoil materials or fly ash. Discussion of the applicability of and limitations on the use of conventional soil tests on drastically disturbed land is presented by Berg, 1978.

The Baker Soil Test is a unique approach which evaluates the nutrient/trace element availability of any growing media on a basis independent of assumptions and empirical relationships obtained from agricultural field plot trials. This approach estimates: 1) the immediate influence of the growing medium on the equilibrium soil solution composition [nutrient and trace/potentially-toxic element intensity (activity)]; and, 2) the size of the labile pool (reserve) in the solid phase of the growing medium capable of buffering solution ion activity.

The Baker test does not measure immediate or potential acidity--this must be addressed using other tests. It is important to note that the Baker test is most useful at or near the pH range that plants can tolerate (pH 5 to 8), so the test should be applied to materials which are (through laboratory amendment where necessary) near this optimal pH range.

The Baker test has been used successfully in many full-scale revegetation projects to check nutrient and trace element balance before and after reclamation. Use of the Baker test to check the chemistry of experimental mixtures of amendments and potential growing media can spare reclamation practitioners the time and expense lost in testing experimental approaches in the field. The approach is also useful in diagnosing causes of differential vegetation success or failure, or differences in plant uptake of particular elements in the field.

Applications of the Expert System Approach Using the Baker Soil Test

From 1974 to 1985, the Baker Soil Test was applied extensively in experiments designed to protect the food chain from excessive accumulations of Cd and other potentially toxic metals applied with sewage sludge and other wastes (Baker et al. 1979, Baker and Chesnin 1975, Hornick et al. 1976, Baker and Amacher 1981, Baker et al. 1984, Williams et al. 1978). In Penn State field plot and greenhouse trials, strong relationships were observed between plant performance, plant major nutrient and trace/toxic element uptake, and Baker Soil Test values of key nutrients and trace/toxic elements. Over time it became increasingly evident that the Baker soil test was an extremely reliable approach for decision support in soil management.

From 1974 to 1982, through the support of Pennsylvania Electric Company, Johnstown, PA, the Baker Soil Test was applied experimentally to nonsoil material (fly ash) and soil-fly ash mixtures. The experiments conducted by Pannebaker (1978) were successful in demonstrating that the Baker soil test provides much of the data needed for the development of a soil and fly ash monitoring program to enable the successful establishment of vegetative cover on fly ash disposal sites using reduced soil cover. Costs of revegetation were minimized by using a minimum soil cover depth and a combination of: 1) soil cover and/or soil-fly ash mixture; (2) chemical fertilizer and lime; 3) selected plant species; and 4) proper management in the establishment phase.

The hypothesis tested by Pannebaker (1978) was that the Baker Soil Test, in conjunction with other soil assays, could be used to predict plant availability of elements which might interfere with successful establishment of vegetation. Many researchers have used comparisons of total elemental analyses of the fly ash with analyses of plant tissue (if plants grew at all) to assess fly ash effects on plant elemental deficiencies or toxicities (Adams et al. 1972; Capp and Adams 1971; Kovacic and Hardy 1972; Capp 1978). As discussed by Baker and Chesnin (1975), total composition results for fly ash or other wastes reflect the relative abundance of elements in the ash compared with the average content in soils or parent materials. However, total abundance is not a reliable predictor of plant availability of chemical elements.

Results of the total elemental analysis of Station 1 fly ash to be stabilized by vegetative cover are reported in table 1. These results showed that the ash is much higher in Al and Fe than normal mineral soils. However, Baker Soil Test results (table 2) indicated that for unweathered fly ash, Al and Fe were normal, but Ca was very high. After 2 years of weathering, the Ca had leached out of the fly ash to nearly normal levels.

The pH of the fly ash (pH 8.6) in a 1:1 ash-water suspension indicated the presence of free CaO and that the fly ash might be used to lime the acid (pH = 4.7) soil. One part ash to 2 parts soil and equal volumes of each were sufficient to give a pH value of 5.5 and 7.0, respectively, after 14 days of equilibration together.

The soluble electrolytes of the fresh ash were high (200 mhos x 10-5/cm)--well above the value of 100 mhos x 10-5/cm tolerated by salt-sensitive field crops grown in Pennsylvania. A 1:2 soil:fly ash mixture reduced the electrical conductivity to desirable levels (less than 100 mhos x 10-5/cm). Thus, the initial experiment indicated that by mixing a 7.5 cm thickness of soil into the upper 15 cm of ash, the soil solution for the resultant 1:2 mixture would have desirable pH and electrical conductivity.

The soil alone was low in K, but the soil-ash mixture substantially increased K availability. Results for a preliminary greenhouse experiment confirmed the validity of the Baker Soil Test results; Pannebaker, 1978.

Field experiments were initiated in the spring of 1976. At that time PaDER (Pennsylvania Department of Environmental Resources) required that closure of a disposal site be accomplished by covering the fly ash with 2 ft of cover soil and establishing a permanent vegetative cover on the soil "unless it is demonstrated....that adequate permanent vegetation can be established with less than 24 inches of cover soil". The goal of the field experiments was to determine the conditions under which much less than twenty-four inches of soil is needed to establish "adequate permanent vegetation" on fly ash disposal areas. The experiments evaluated whether soil-stabilizing vegetative cover could be established on fly ash covered with 0, 6, 12, and 24 inches of soil material and which of these treatments were adequate. The soil material was a mixture of the

Table 1. Elemental compositions (in ppm of dry matter) for soils, and fly ash samples as obtained from complete dissolution of the materials by Na_2CO_3 fusion, or $HClO_3$, HF digestion, and fly ash as found in the literature.

	Soils*		Fly Ash	
Element	Average	Usual Range	Conemaugh Fly Ash Range	Examples from Literature**
P	--	400-3,000	--	300-2,800
S	850	100-1,500	--	400-4,800
Fe	--	14,000-40,000	52,000-132,000	60,900-150,000
Al	--	5,000-32,000	105,000-136,000	76,000-140,000
Mn	850	200-3,000	100-260	200-848
Zn	50	10-300	80-170	90-5,900
Cu	20	2-100	150-180	40-248
B	10	2-100	21-55	48-618
Mo	2	0.2-5	--	20-100
Co	8	1-40	--	65-100
Ba	500	100-3,000	--	750
Cr	200	5-1,000	150-250	900
F	200	--	--	--
Se	0.01	0.1-2.0	--	1.2-16.4
V	100	20-500	--	1,180
As	5	1-50	--	440
Be	6	--	--	--
Bi	1	--	--	--
Cd	0.5	0.01-0.7	.01-.43	51
Cs	5	0.3-26	--	27
Hg	0.03	0.03-0.3	--	--
Li	30	5-200	--	--
Ni	40	5-500	160-180	--
Pb	10	2-200	80-510	650

*From Baker and Chesnin, 1975

**Cope, F. 1961. The Agronomic Value of Power Station Waste Ash. Ph.D. Thesis, University of Leeds.

Table 2. Concentrations of ions as measured by the Baker soil test* in unweathered fly ash, fly ash weathered for two years, and soil material from the Station 1 disposal site.

	K	Ca	Mg	Na	Zn	Cu	Mn	Fe	Al	H_2O pH
	---------M x 10-4**---------				-------------ppm*-------------					
Unweathered fly ash	6.07	116.85	10.36	2.87	1.3	2.4	1.6	25.1	7.1	8.6
Weathered fly ash	3.03	64.89	9.97	2.87	0.6	1.0	1.6	23.5	5.5	--
Soil material	3.60	40.31	12.31	1.31	1.4	0.7	23.1	12.0	85.1	4.7

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*Calibration values for Baker soil test:

Low	<1.5	<40	<5	<2	<10	<10	<50	<25	<5	<5.5
Normal	1.5-4	40-60	5-16	2-10	10-75	10-40	50-100	25-75	5-20	6-7.3
High	>4	>60	>16	>10	>75	>40	>100	>75	>20	>7.3

**K, Ca, Mg and Na are expressed as concentrations in the small exchange extract and all others are amounts desorbed from the soil (solution concentration x 10).

unconsolidated regolith above the bedrock. The plots were 12 by 12m, seeded with several plant species and mulched with straw.

Initially the dominant plant species at the Station 1 test plots were sweet clover, tall fescue, and ryegrass. Birdsfoot trefoil became established on some plots the second year and gradually crown vetch became the dominant species. By the fall of 1976 a dense cover was established over all plots except on bare fly ash high in soluble salts and on soil materials high in coarse fragments. Several other vegetative cover experiments were conducted after the initial experiment, and it was shown that an adequate vegetative cover could be established on slopes of up to 9 percent and 200 ft long by mixing just enough soil into the fly ash to neutralize the excess CaO in the ash and bring the pH and electrical conductivity down.

Using the data from the Penn State studies, (Pannebaker 1981 and Lehrsch, 1981) and other data (e.g., Adriano et. al. 1980), the decision-making flow path and the criteria used are outlined graphically in figure 1. The manual prepared by GAI Consultants from this work was subsequently approved by PaDER for use at all such sites. Primary limitations to plant growth on fly ash (or fly ash-amended soils) identified early in the testing scheme are pH extremes, excessive levels of soluble salts, and excessive levels of boron (B) availability. The first two criteria are based on the report and experience at the Conemaugh location by Baker (1981) and coworkers. The boron criterion was based on the hot water soluble boron method and plant toxicity threshold reported by Adriano, et. al. (1980).

If the growing medium "fails" by the primary criteria, amendments can be considered to bring the resulting chemistry into a more favorable range. If the potential growing media considered are not toxic to plants based on the primary criteria described above, secondary tests for evaluating nutrient and trace/toxic element status of the growing medium are applied.

Secondary tests consist of the Baker test for available Ca, Mg, K, Fe, Mn, Cu, Zn, Na, Al, Pb, Ni, and Cd, plus conventional tests for oxalate extractable Mo and total Se. The latter two tests were based on concerns for excessive uptake of Mo and Se by plants. Neither Mo nor Se are toxic to plants, but excessive uptake of these elements by plants and subsequent consumption by foraging animals was a concern.

The methods described in the manual by GAI Consultants (1982) have been successfully applied by the consulting firm at at least seven permitted sites in Pennsylvania, and at one site each in Connecticut and Ohio. The analyses at each of these sites concluded in projects where 4 to 6 inches of soil, mixed into the surface 6 to 4 inches of fly ash, were used in lieu of 24 inches of soil cover. Sections of two of the fly ash sites were specified to be directly vegetated on fly ash without using any soil.

Revegetation success at fly ash disposal sites using these methods has led to adaptation of the methods to revegetation of coal refuse and steelmaking slag disposal sites using little or no soil cover. At four anthracite refuse sites the authors have designed revegetation plans using mixtures of fly ash and coal refuse in lieu of soil cover--with excellent results. Details of the analytical approach and results at the first of these sites are described in other reports (Buck and Houston 1988, Buck and Houston 1987, Buck 1987).

Monitoring

Monitoring of vegetation success and soil chemistry has been done for fly ash/soil mixtures and fly ash/coal refuse mixtures used in lieu of soil at these sites. The Baker test, 1:1 water pH, lime requirement by the SMP buffer method, oxalate extractable Mo, total Se, extractable B, and soluble salts assays were performed. In each case, the tests on laboratory mixtures of fly ash with soil (or coal refuse) adequately predicted the initial chemistry of the mixtures created in the field, as well as the suitability of the mixtures for plant growth (vegetation grew vigorously). The chemistry of field mixtures remained approximately the same over time with the exception of B, Mo, and/or Se. At fly ash disposal sites Mo and Se rapidly leeched out of the fly ash/soil surface (table 3), whereas over 3 years fly ash-amended anthracite wastes lost very little Mo and Se to leaching (Buck and Houston 1988, Buck 1987). Some extractable B weathered out of fly ash-amended coal refuse and fly ash/soil mixtures over time. Soil pH and Baker soil test parameters changed little, except for loss of excess Ca.

At the fly ash disposal sites, initial (laboratory mixture) Mo and Se levels in the alternative growing media were high which could preclude agricultural use of forages grown onsite, but less than 2 years of weathering reduced Mo and Se concentrations substantially. The soil chemistry results at the fly ash-amended coal waste site were followed up by plant tissue analyses for Mo and Se (Buck and Houston 1988, Buck 1987).

Concentrations of Mo and Se in plants grown on fly ash-amended coal refuse barely exceeded National Research Council (1980) guidelines for livestock rations,

Table 3. Summary of parameters of concern at the Station 2 disposal site.

Sample Description	pH	Saturation Extract Soluble Salts (EC, mmho/cm)	Saturation Extract Boron (ppm)	Hot Water Soluble Boron (ppm)	Total Selenium (ppm)	Oxalate Extractable Molybdenum (ppm)
Borrow Soil	5.0	0.80	<0.002	0.8	<0.5	<0.5
Unweathered Fly Ash	8.2	3.20	0.16	17.9	8.2	16.6
Lab 1:1 Soil:Ash Mixture	7.3	2.80	0.22	6.9	4.7	8.1
Lab 1:2 Soil:Ash Mixture	6.8	2.60	0.41	5.4	3.0	5.6
Weathered (Field) Ash/Soil (0-1.0' depth)	6.8	3.00	0.02	1.4	1.7	1.5
Weatherd (Field) Ash (1.0-2.0' depth)	8.2	2.10	0.15	5.5	2.7	4.2
Literature Toxicity Guidelines*	<4.0-5.5	>2-13	>1-15	>20.0	--	--

*Value ranges reflect species-specific tolerance ranges or differences in soil assay/plant uptake relationships due to soil type.

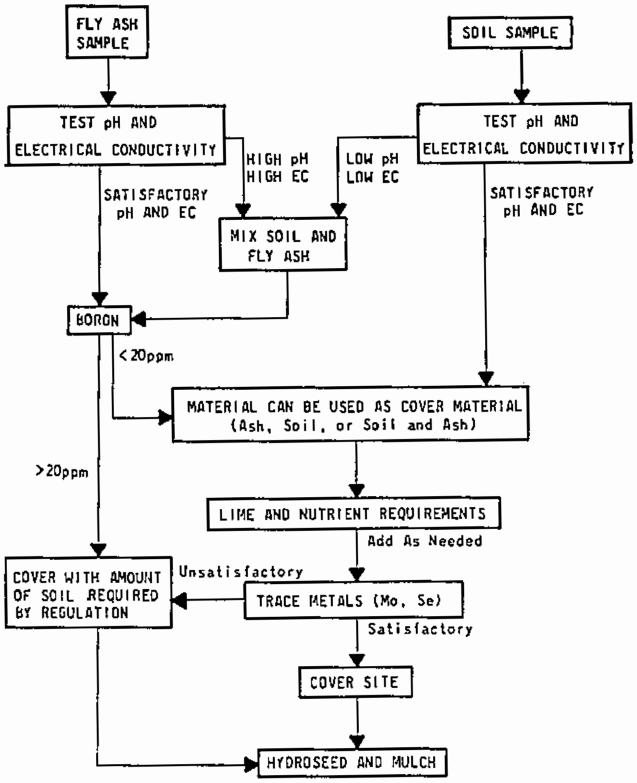

Figure 1. Flow chart to determine type of cover material at fly ash disposal sites (GAI Consultants, 1982).

confirming soil test expectations. Because livestock and wildlife do not intensively graze on the subject site, the magnitude of plant Mo and Se uptake was not a concern under that land use. All other elements tested in the normal or safe range for livestock forage.

Monitoring at sites where fly ash was used as an unconventional growing medium or soil amendment indicated that the Baker test, when used in conjunction with B, Mo, Se, pH, lime requirement, and soluble salts tests, adequately evaluated the suitability of the media used in lieu of soil as growing media. Weathering effects on Mo and Se were inconsistent, but other parameters remained the same or improved with time. These preliminary monitoring data suggest that changes in growing media chemistry over time may or may not improve the potential of an alternative growing medium to produce wholesome food or forage. Thus, changes in land use (such as a shift from wildlife habitat to agriculture) should be based on monitoring data, not assumptions, for trace elements of concern.

Refinement of Testing Methods and Interpretive Criteria

Experience of the authors and others has brought and will continue to bring about changes in methods and interpretive criteria. For example, most of the plant toxicity thresholds for salts, boron, etc. are based on soil concentrations which cause yield reductions, or visual symptoms of toxicity in agricultural crops. Soil conditions causing yield reductions with crops may still be adequate from most land reclamation perspectives. Yield reductions may be avoided via use of tolerant plant materials. The concept of yield adequacy must be refined to apply to post-reclamation land uses.

Increased sophistication in soil analysis must be continually incorporated into expert systems for land reclamation. For example, hot water soluble B assays are good to test for B-sufficiency (B is a plant micronutrient), but saturation extract B concentrations are better indicators of potentially phytotoxic soil conditions (Keren and Bingham 1985). Likewise, a modified Baker test (currently under investigation) may be a better measure of the threat of excess soil Mo and Se to foraging animals.

CONCLUSIONS

The decision-making flow path described in figure 1 and this text is an example expert system specifically designed to support evaluation of alternatives to soil as growing media at fly ash disposal sites. The expert system described here is based on the manual by GAI Consultants, Inc., (1982) and a unique approach to soil testing, the Baker soil test.

Monitoring the results from use of these methods at fly ash sites has been encouraging and has also pointed out the need for continual revision of methods and interpretive criteria as the state-of-art advances. The system used to evaluate growing media at fly ash disposal sites has been successfully adapted to meet other reclamation challenges (coal refuse and slag sites with little or no soil).

Computerization of this soil chemistry system and similar decision-making systems would have several advantages:

1. Like the manual form, computerized systems would introduce logical consistency to reclamation problem solving;
2. Monitoring methods, if integrated into the systems, can be used to test the strengths and weaknesses of the system, especially with regard to the ability of the system to predict the results of a land management technique;
3. Computerized systems are easy to revise as technology evolves (e.g., changing testing parameters, methods, and interpretive criteria);
4. Computerized systems can be easily expanded to handle new situations (e.g., soil salinization, smelter contaminated soils); and
5. Computerized systems can make the advice of "experts" more accessible to reclamation practitioners and regulators.

The Soil Conservation Service's Plant Adaption Data System (PADS) is an existing example of a successful computerized expert system for matching plant species with site conditions and land management goals. Although the examples discussed in this paper were confined to soil chemistry issues of concern to land reclamation, the potential scope of expert systems in land reclamation is unlimited.

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