A Comparison of greenhouse methods as diagnostic tools for reclamation planning
by Timothy Martin Byron

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University

Abstract:
Greenhouse studies have been used in reclamation planning to test the suitability of potential minesoil materials for plant growth. The Jenny pot-culture is a greenhouse technique used for this purpose. The large sample weight and lengthy trial period required for this method inflate the cost of greenhouse testing. The Neubauer seedling technique is a greenhouse method requiring a smaller sample weight and a shorter trial time. This study compared western wheatgrass (Aeropyron smithii var. Rosanna) yield response by these methods to learn if the Neubauer technique could replace the Jenny pot-culture as a diagnostic tool in reclamation planning. The comparison was carried out on 22 growth media samples that were analyzed for their chemical and physical properties. Shoot yield and elemental uptake differences were analyzed by analysis of variance. The Spearman's rank order correlation coefficient was used to measure the degree of association between the Jenny and Neubauer yield-based rankings of the growth media. Multiple regression analysis was used to identify yield-influencing properties for each greenhouse method.

Significant yield and elemental uptake differences were observed between the two methods. A rank order correlation coefficient of 0.46 indicated a poor association between the yield-based rankings by the two methods. Jenny pot-culture yield had a closer relationship with more growth media parameters than did Neubauer seedling yield. Therefore, the Jenny pot-culture was deemed superior to the Neubauer method as a diagnostic tool.

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ABSTRACT

Greenhouse studies have been used in reclamation planning to test the suitability of potential minesoil materials for plant growth. The Jenny pot-culture is a greenhouse technique used for this purpose. The large sample weight and lengthy trial period required for this method inflate the cost of greenhouse testing. The Neubauer seedling technique is a greenhouse method requiring a smaller sample weight and a shorter trial time. This study compared western wheatgrass (Agropyron smithii var. Rosanna) yield response by these methods to learn if the Neubauer technique could replace the Jenny pot-culture as a diagnostic tool in reclamation planning. The comparison was carried out on 22 growth media samples that were analyzed for their chemical and physical properties. Shoot yield and elemental uptake differences were analyzed by analysis of variance. The Spearman's rank order correlation coefficient was used to measure the degree of association between the Jenny and Neubauer yield-based rankings of the growth media. Multiple regression analysis was used to identify yield-influencing properties for each greenhouse method.

Significant yield and elemental uptake differences were observed between the two methods. A rank order correlation coefficient of 0.46 indicated a poor association between the yield-based rankings by the two methods. Jenny pot-culture yield had a closer relationship with more growth media parameters than did Neubauer seedling yield. Therefore, the Jenny pot-culture was deemed superior to the Neubauer method as a diagnostic tool.

INTRODUCTION

Reclamation of disturbed land requires an inventory of its suitable plant growth media. Plant establishment can be improved if reclamation planners know the growth media potential of available soil and overburden materials. Coversoil characteristics affecting plant growth can be evaluated in the laboratory, in the greenhouse and in the field. Each mode of analysis makes a unique contribution to the inventory. Laboratory analyses usually provide information about specific chemical or physical properties; greenhouse studies measure plant response under relatively stable environmental conditions; field trials measure plant response to natural soil volumes and nutrient capacities, natural climate and interspecies competition. A correlation of results from these three analytical approaches is a valuable decision-making tool for the reclamation planner.

Greenhouse yield and plant tissue analysis studies have a long history of use in agronomy. Growth response and tissue analysis data have been used to measure plant available nutrients in many soils for a variety of crop species. Similar studies relating plant response to growth media characteristics are needed to establish a data base which can be directly applied to revegetation of disturbed land. Correlation data, based on work with native plant species grown in coversoil materials, would provide the basic information needed to interpret the results of a more detailed greenhouse testing program.

This background research should employ standardized greenhouse and laboratory methods which are reliable and economical.

The Jenny pot-culture and the Neubauer seedling technique are greenhouse methods used to study the nutrient status of soils. The original Jenny method measured soil nitrogen (N), phosphorus (P) and potassium (K) availability in terms of yield of a test-plant grown in 1.6 kg of soil for 60 days (Jenny et al. 1950). Modifications of the original procedure have been used to identify plant nutrient problems for reclamation planning. The costs of obtaining the large sample volumes and maintaining plants over the lengthy growth period have prompted the search for a greenhouse method requiring smaller sample volumes and having a shorter growth trial. The Neubauer technique is a relatively rapid method that measures fertility as the amounts of nutrient elements extracted from 100 g of soil by rye seedlings grown for 17 days (McGeorge 1946). This method was originally designed to measure soil P and K availability (Thornton 1935).

The smaller sample volume and shorter growth period of the Neubauer technique would make it an economical alternative to the Jenny pot-culture if shoot yield rather than plant uptake could be used as the evaluating criterion. The objectives of this study are:

(1). Compare the Jenny and Neubauer methods as diagnostic techniques for assessing plant growth media on the basis of test-plant yield.

(2). Evaluate 22 soils, geologic materials and mine spoil materials as plant growth media using laboratory and greenhouse analyses.

LITERATURE REVIEW

Greenhouse Studies In Reclamation

Greenhouse studies quantifying the relationship between plant response and soil nutrient capacity have been conducted by many investigators. Cope and Rouse (1973) stated that plant growth under artificial conditions does not permit plant differences to be expressed as they would be under field conditions, therefore, correlation between laboratory soil analysis and plant reponse in the greenhouse cannot be used as a guide for crop production. Peck and Melstead (1973) found greenhouse studies to be costly, time-consuming and limited in the number of soil samples which can be handled. They also pointed out that post-mortem plant tissue analysis has limited value for prescribing management practices to maximize yield. They stressed that plant response under greenhouse conditions must be calibrated with field trials to account for factors such as natural soil rooting volumes, atmospheric conditions and interspecies competition.

Steenbjerg and Jacobsen (1963) stated that the constants in yield equations are not true constants because growth response in the field varies with plant species and environmental conditions. The number of uncontrolled variables in field experimentation have confounded efforts to refine plant analysis techniques and determine critical nutrient levels (Munson and Nelson 1973). Some of these factors, such as day length, temperature and moisture can be controlled in the greenhouse. Berg (1978) stated that long-term greenhouse trials with samples kept at field capacity could identify changes in nutrient capacity with weathering. Such trials could also serve to evaluate the effect of particle size on soil salinity. Arminger and others (1976) stated that greenhouse evaluation of mine soils is more meaningful because the chemical aspects of plant development can be studied with more control. Identification of growth-limiting factors in the greenhouse will save time and money in developing a more complicated field testing program.

Recent investigation into the use of greenhouse trials for reclamation planning has been implemented under the Energy Minerals Rehabilitation Inventory and Analysis (EMRIA) program. EMRIA was coordinated by the United States Department of the Interior (USDI) to assure adequate baseline data for selecting reclamation goals and mineral lease stipulations in six western states (Hodder and Jewell 1979). Greenhouse studies were used to assess soils and overburden as plant growth media and verify their suitability as predicted by physical and chemical laboratory analysis (Heil and Deutsch 1980). Investigators grew native species in 1 kg samples for 57 days. The growth media were fertilized with N and P and maintained at 1/3 bar moisture content. Shoot weight was recorded as relative percent yield based on growth in a standard soil. Materials with yield percentages of 33 or less rated as poor growth media; percentages from 34 to 64 rated as fair; percentages greater than 64 were rated as suitable plant growth media.

Although correlations of yield-based ratings with laboratory characterization data often identified limiting factors for growth, many relationships were contradictory. The conclusions drawn from a greenhouse study of growth media from Lay Creek, Colorado are an example. Although sodicity and salinity tended to reduce yields, materials with pH values greater than 8.9 and exchangeable sodium percentages (ESP) from 10 to 15 often produced among the highest yields (Heil and Deutsch 1980). The authors stressed that these results should be interpreted with knowledge of the differences between field and greenhouse moisture conditions. Based on yield in the Lay Creek study, pH, conductance, organic matter content, ESP and texture were identified as important parameters for revegetation of surface-mined lands.

Greenhouse studies were also used to assess soil and overburden materials from the Bear Creek study area in Montana (USDI 1977). Forty seeds of western wheatgrass (Agropyron smithii) were grown in 1 kg of material fertilized with N and P. Plants were thinned to 14 per container and grown for 50 to 60 days. Shoot yields and relative yield percentages based on highest production were correlated with laboratory characterization data. The results showed a strong positive relationship between yield and field capacity moisture content. Surface soil samples produced higher yields than overburden materials. Surface cracking and crusting problems were consistently observed on low-yielding materials. A consistent relationship was observed between increased sodicity and salinity and decreased yield. Materials yielding less than 90 percent of highest production commonly had low zinc (Zn) and copper (Cu) levels (USDI 1977). In these studies, however, the data were inadequate to determine if the observed Zn and Cu levels were critical for western wheatgrass.

A greenhouse bioassay was used to detect toxicities in overburden and soils from the Henry Mountain coal field in Utah (McKell 1978). Russian wildrye (Elymus junceus) was grown in 900 g of material fertilized with N and P. Plantings were thinned to 5 plants per pot and harvested after 60 days. Shoot weight was correlated with laboratory chemical data. Significant correlations were observed between shoot yield and pH, electrical conductivity (EC), and cold water soluble boron (B).

Greenhouse trials were conducted by McFee and others (1981) to evaluate overburden materials from surface coal mines in southwestern Indiana. Alfalfa (Medicago sativa) and wheat (Triticum vulgare) were grown for 12 weeks in clay pots containing 5.5 kg of sample. Regression analysis of yield against 20 chemical and physical parameters did not reveal properties that could consistently predict plant growth potentials. The study did, however, identify EC and water storage capacity as having significant relationships with yield.

Dancer and Jansen (1981) conducted a greenhouse evaluation of solum and substratum materials from the southern Illinois coal field. They grew perennial ryegrass (Lolium perenne), red clover (Trifolium pratense) and sudangrass (Sorghum sudanensis) in 500 g of sample with fertilized and unfertilized treatments. Highly significant differences were observed between surface and overburden materials. Differences were less pronounced with fertilization. Their results also indicated that the detrimental effects of acidic and clayey samples could be amended by blending with more alkaline and coarse-textured materials.

Mitchell (1979) used greenhouse yield of both native and crop species to evaluate coal mine overburden from Black Mesa, New Mexico. A close relationship was observed between yield and available levels of N and P.

Plant shoot yield has been the primary response variable in most of the greenhouse studies cited above. The studies have used native and introduced test-plant species grown in various amounts of surface and subsurface materials for different durations. Growth media sample weights have ranged from 0.5 to 5.5 kg and trial periods have been from 7 to 13 weeks. A diagnostic technique using a smaller growth medium sample and having a shorter trial time would be desirable in developing an efficient greenhouse testing program for potential minesoil materials.

The Neubauer Method

A greenhouse method which requires a relatively small sample weight per container and a short growth period is the Neubauer seedling technique (Neubauer and Schneider 1923). The Neubauer technique was among the first generally accepted methods of growth media assessment based upon plant nutrient uptake (Fried and Broeshart 1967). The original method was based upon the assumption that a large number of seedlings growing in a small amount of soil would rapidly exhaust the nutrient supply because of strong seedling feeding power during early development (Thornton 1935, Vandecaveye 1948).

According to the original procedure, an air-dry, 100 g sample passing a 2 mm sieve was mixed with 50 g of nutrient-free quartz sand. This mixture was spread evenly in the bottom of a small glass dish and covered with 150 g of dry sand. One hundred rye seeds were planted on the sand layer. The seeds were covered with a final 100 g layer of dry sand. Each container received 80 ml of distilled water and the final weight of the containers was maintained by daily watering. After 17 days the seedling shoots were harvested, rinsed with distilled water and ashed at 550 C. The ash was dissolved in HCl and tested for its content of P and K. Values were calibrated with soil test results to determine the limiting levels for P and K (Thornton 1935).

Modifications of the original procedure have been developed by Ames and Gerdel (1927), McGeorge and Breazeale (1956) and Prabhakarannair and Cottenie (1969). These studies observed the effects of variation in soil sample weight, kind of container, test-plant species and method of planting. Prabhakarannair and Cottenie (1969) modified the method to measure trace element uptake over time by barley seedlings. They support the technique as a means of studying the effect of rhizosphere pH changes on trace element uptake. McGeorge (1946) believed that some modifications could be made without jeopardizing the results, but recommended close adherence to the original procedure.

The Jenny Pot-culture

The second greenhouse technique used in this study was the Jenny pot-culture method. The original method assessed primary nutrient availability as indicated by yield response of a test-plant grown in 1.6 kg of soil for 60 days (Jenny et al. 1950). Each soil test consisted of four replications of five treatments: a "standard" full treatment fertilized with N, P and K; a check to which no nutrients were added; and three partial treatments, each omitting a single nutrient. Soil samples were air-dried, passed through a 5 mm mesh and placed in 15 cm flower pots. The test used Romaine lettuce as an indicator plant because it grew rapidly and was relatively free from disease. After 60 days plant shoots were harvested, dried and weighed. Mean weights from four replications and relative yield percentages, obtained by comparison with the full treatment, were used to estimate soil deficiencies. The method was calibrated with field experiments and gave reliable indications that crops would respond to N, P and K fertilization of soils identified as deficient by the pot-culture.

Since its development, modifications of the Jenny method have taken many forms. Crop and native species were used to investigate the calcium (Ca) and magnesium (Mg) nutrition of serpentine soils (Walker 1954, Walker et al. 1955). Ozus and Hanway (1966) studied soil N and P availability using crop and pasture species grown in 1.5 kg of soil. Barret and others (1980) recommended soil weights from 0.5 to 1 kg using test-plants that are appropriate for specific research objectives. Heil (1983) reported that western wheatgrass grown in 1 to 2 kg of material obtained the best results for characterization of soils and geologic materials in reclamation planning.

The lengthy growth periods and large sample weights required for these modifications increase the time, effort and expense of greenhouse characterization. The shorter trial time and smaller sample weights required for the Neubauer method make it an attractive alternative for reducing the costs of such studies. The original Neubauer technique, however, was developed to assess fertility in terms of nutrient uptake rather than yield. The literature contains no assessment of Neubauer yield as a measure of soil fertility. Although the planting density for the Neubauer method is higher in each container, the influences of the short growth trial and small sample volume may reduce shoot yield to less than that obtained by the Jenny method. The principle objective of this study was to compare the yield response of a test-plant grown under the conditions of the Jenny and Neubauer methods and identify growth media parameters important to yield in each technique. The comparison would determine whether Neubauer yield responses reflect Jenny yield responses to a set of growth media having diverse chemical and physical properties.

METHODS AND MATERIALS

Sample Preparation

Twenty-two growth media were included in the comparison of the greenhouse techniques. These media consisted of 14 soil samples, 6 geologic materials and 2 mine spoils. The samples were received in plastic-lined boxes and were accompanied by field notes taken during sampling by Bureau of Land Management (BLM) staff.

Individual descriptions of the growth media were prepared according to guidelines published in Soil Taxonomy (Soil Survey Staff 1975) and the Soil Survey Manual (Soil Survey Staff 1951). Sample descriptions were also based on field notes supplied by BLM staff.

All of the soil samples were air-dried and passed through a 2 mm sieve. Only the Fine earth fraction (<2 mm) of the soil samples was used for both laboratory and greenhouse analysis. The overburden and spoil samples were air-dried and passed through a 5 mm sieve. The remaining coarse fragments were then crushed with a hammer until small enough to be ground in a flail-type grinder. The sieved and ground portions were thoroughly mixed to achieve homogeneity. Only the fine earth fraction of the overburden and spoil samples was used for laboratory analysis. Coarse fragments were retained for the greenhouse analysis because their removal would have reduced the sample volumes below what was needed for replication.

Physical Analysis

Particle size analysis was carried out according to the method of Day (1965). Water content at 1/3 and 15 bar tension was measured using a pressure plate apparatus (Richards 1969). Moisture content at saturation was determined from an oven-dried sample of a saturated paste (Richards 1969).

Chemical Analysis

Table 1 lists the chemical analyses used for characterization.

Table 1. Chemical analysis methods.

Measured Parameter	Extraction Method	Reference
Ca, Mg, Na, K SO_4, NO_3, CO_3 HCO_3, Cl, pH EC, SAR	Saturation Extract	Richards (1969)
Ca, Mg, Na, K Zn, Cu, Mn, Fe Pb, Cd, Ni	1 N NH_4OAc	Richards (1969)
Zn, Cu, Mn, Fe Pb, Cd, Ni	DTPA/TEA	Follett and Lindsay (1971)
P	$NaHCO_3$	Olsen and Dean (1965)
B	Hot Water Solution	Wear (1965)
Se	Hot water Solution	Fine (1965)
Mo	Tamm's Reagent	Reinsenauer (1965)
CEC	NaOAc	Richards (1969)
Organic Matter	$K_2Cr_2O_7$-H_2SO_4	Sims and Haby (1971)

Soluble and extractable concentrations and cation exchange capacity (CEC) were determined using a Varion Techtron, model AA6, atomic absorption spectrophotometer. Exchangeable Ca, Mg, Na, and K were calculated by subtracting soluble from extractable concentrations (Richards 1969). Exchangeable concentrations were used to calculate Ca:Mg ratios. Extractions by DTPA/TEA were carried out only on neutral and alkaline samples. A single laboratory determination was made on each growth medium for each parameter. The results served as independent variables in the regression analysis.

Modified Neubauer Method

An air-dry, 100 g sample of each growth medium was mixed with 50 g of acid-washed quartz sand. The mixture was spread evenly in the bottom of a plastic container 11 cm in diameter by 8 cm deep. The sand-soil mixture was covered with 150 g of dry sand and 150 western wheatgrass seeds (Agropyron smithii var. Rosanna) were spread uniformly over the sand surface. The seeds were covered with an additional 100 g layer of dry sand. Each container received 80 ml of distilled water and was covered. The final weight of each container was maintained with daily additions of distilled water. The covers were removed after they had been touched by emerged seedlings. After 45 days the plant shoots were harvested and rinsed with distilled water to remove any adhering soil particles. Figure 1 illustrates the preparation of the Neubauer containers.

The original Neubauer method suggested that 100 seedlings be grown for 17 days (McGeorge 1946). To correct for 70 percent germination in the seed and the 28-day germination period required for western wheatgrass (Copeland 1981), the method was modified by planting 150 seeds per container and extending the trial period to 45 days.

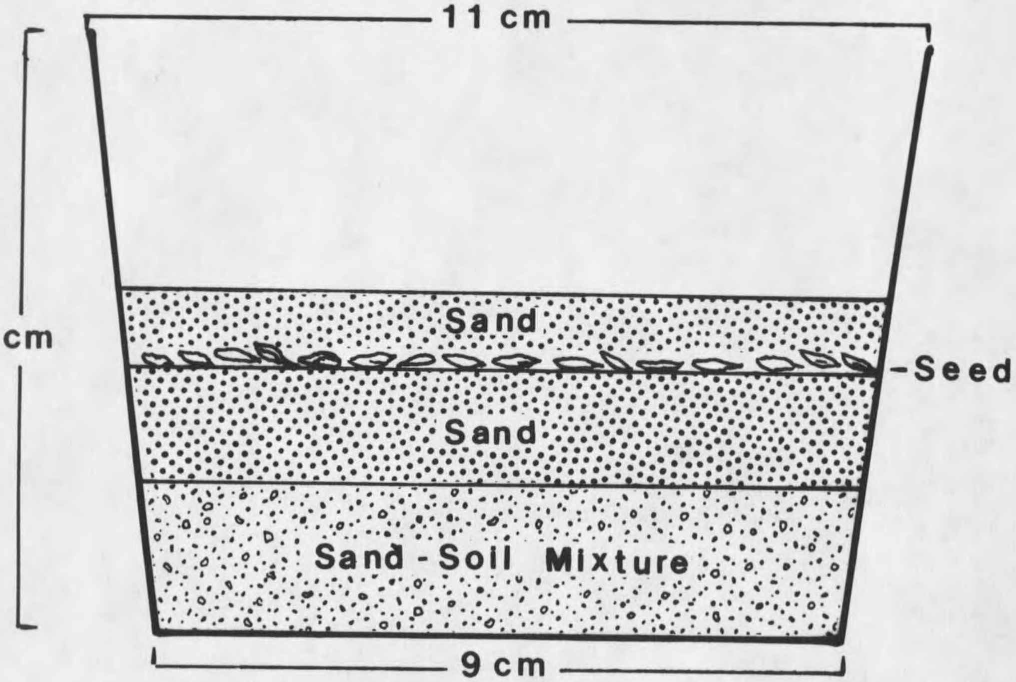

Figure 1. Cross-section of Neubauer container showing the positions of the sand-soil mixture, the sand layers and seed.

Modified Jenny Pot-culture

An air-dry sample of each growth medium (1 kg) was placed in a plastic pot 15 cm in diameter by 12 cm deep. Each pot received 15 seeds of western wheatgrass planted 1 cm deep. Containers were weighed every other day and brought to 1/3 bar moisture content. Day length during the trial was approximately 14 hours. After 60 days the plants were harvested and rinsed as in the Neubauer method.

Western wheatgrass was used as the test-plant because it was identified at several of the sites where the soil materials were collected. The Rosanna variety was used because it is the most adaptive and successful cultivar produced commercially on the Northern Great Plains (Thornburg 1982).

Vegetation Analysis

Shoot yield was used as the primary response variable . Its ease and low cost of measurement are desirable for development of a rapid greenhouse method. Shoot yield is also an integrator of the many factors affecting plant health (Heil 1983). Tissue concentrations of 13 elements were also measured to determine if the two greenhouse methods differed in the amounts the plants extracted from the growth media. Elemental tissue analyses were conducted on composite samples composed of plant material from each set of replications.

After harvesting, the plant material was oven-dried to constant weight at 70 C. Yield in each replication of each growth medium was recorded in grams per container for both of the greenhouse methods. Plant P was determined colorimetrically after complexation with ammonium molybdate solution (Horwitz 1975). Tissue concentrations of Ca, Mg, K, Zn and iron (Fe) were determined by flame atomic absorption spectrometry after acid digestion (Munshower and Neuman 1978). Tissue concentrations of molybdenum (Mo), cadmium (Cd), nickel (Ni), lead (Pb) and Cu were determined by electrothermal atomic absorption spectrometry after digestion with nitric and perchloric acids (Neuman and Munshower 1981). Total plant N was determined using an improved Kjeldahl method (Horwitz 1975).

Statistical Analysis

Each potting technique was replicated 10 times for each of the 22 growth media. A randomized complete block design was used. Blocks were randomly rotated over the greenhouse tables to equalize the effects of changing light and temperature conditions. Shoot yield and elemental tissue concentrations were used as response variables in the statistical analysis. Laboratory characterization data served as independent variables.

Analysis of variance was used to observe the variability in yield attributed to growth medium and greenhouse method. Analysis of variance was also used to observe the variability in elemental uptake attributed to growth medium and greenhouse method. The Spearman's rank order correlation coefficient (r_s) was computed to quantify the degree of association between the yield-based rankings of the growth media by the Jenny and Neubauer methods (Steel and Torrie 1980). Multiple stepwise linear regression analysis was used to identify growth media parameters important to yield in each of the potting techniques. This analysis was carried out using a computer program from the Statistical Package for the Social Sciences (SPSS) (Nie et al. 1975). The SPSS program was used because it contained an option for including cases with missing data. The data base could be maintained by including a case (trial on a single growth medium) with missing values for certain variables. For example, trace element analysis by DTPA/TEA extraction was done only on neutral and alkaline samples. The missing data for the five acidic media would have eliminated them from the analysis and reduced the number of cases.

The computer program listed three criteria to determine which independent variables would enter a regression equation. These criteria were: (1) the number of variables allowed to enter an equation, (2) the F-ratio, (3) the tolerance level (Nie et al. 1975). For this analysis, these values were set at 5.0, 2.0 and 0.01 respectively. It was felt that these restrictions would identify the important variables and improve the significance of the results. Levels of statistical significance were determined from standard F-tables (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Introduction

The growth media used in this study included soil materials sampled at various depths from 12 different profiles (samples 1-14), geologic materials of different lithologies (samples 15-20) and spoil materials from two surface coal mines (samples 21,22). Growth media descriptions are given in Appendix I. They were prepared according to procedures recommended by the Soil Survey Staff (1951, 1975) and supplemented with field notes supplied by BLM staff.

Complete results of the laboratory physical and chemical growth media analysis are given in Appendix II, Tables 9 and 10. The results of the laboratory characterization were interpreted using four sets of criteria. Table 2 contains the suspect levels for soil and overburden parameters outlined by the Montana Department of State Lands (MDSL 1977). Plant production is assumed to be restricted by these levels. They are useful guidelines but the authors suggested that they not be considered as absolutes. The potentially undesirable level for a single parameter could be controlled by other properties such as pH, organic matter content, levels of other elements or the plant species affected. Guidelines for interpretation of DTPA-extractable levels of Zn, Fe, Mn and Cu were suggested by Follett and Lindsay (1970). Their study of micronutrient distributions within soil profiles was conducted to predict deficiencies resulting from topsoil removal. This emphasis makes their findings relevant to reclamation planning. Other sets of criteria were compiled by Barrett and co-workers (1980) and the United States Bureau of Reclamation (USBR 1981). They contain guidelines for assessment of fertility, pH, salinity, sodicity, texture and trace element relationships for reclamation planning.

Table 2. MDSL guidelines for suspect levels in soil and overburden material (MDSL 1977).

Parameter	Suspect Level
Conductance	>4-6 mmhos/cm
Sodium adsorption ratio	>12
Mechanical analysis	Clay > 40 % Sand > 70%
Saturation %	No Guideline
pH	>8.8-9.0
PO_4-P	No Guideline
NO_3-N	>10-20 ppm
NH_4-N	>10-20 ppm
Cd	>0.1-1.0 ppm
Cu	>40 ppm
Fe	No Guideline
Pb	pH <6, >10-15 ppm pH >6, >15-20 ppm
Mn	>60 ppm
Hg	>0.4-0.5 ppm
Se	>2.0 ppm
Mo	>0.3 ppm
B	>8.0 ppm
Zn	>30-40 ppm
Ni	DTPA extraction >1.0 ppm Acid extraction >5.0 ppm

Physical Analysis

Complete results of the physical analysis of the growth media are listed in Appedix II, Table 9. The physical analysis results are summarized in Table 3. A comparison of these results with the MDSL criteria for mechanical analysis indicated that 8 of 22 samples exceeded the 40 percent level for clay content. The clayey materials included three samples derived from Bear Paw Shale (samples 1,2,15), the montmorillonitic soils of the Midway and McKenzie series (samples 5,7), a Fort Union interbedded sandstone and shale (sample 20), a gray fissile shale (sample 19) and a mine spoil material (sample 22).

Table 3. Summary of physical analysis data.

Parameter	Mean	S.D.	Range Min. - Max.
Sand (%)	28.7	15.0	3.9 - 65.1
Silt (%)	36.8	10.6	22.0 - 70.1
Clay (%)	34.4	16.2	10.8 - 66.8
Saturation (%)	66.0	46.0	33.7 - 227.0
1/3 bar moisture (%)	26.9	9.9	16.3 - 52.9
15 bar moisture (%)	17.6	7.7	9.3 - 38.5

High saturation percentages were associated with high clay content. Except for a gray Fort Union mudstone (sample 17), all materials with saturation percentages greater than 50 exceeded the suspect level for clay content. Mechanical analysis of sample 17 indicated a clay content of only 22 percent, yet the saturation percentage was 227. Dispersion with sodium hexametaphosphate, using an electric mixer, may be inadequate for complete particle separation in consolidated samples of this material.

After initial watering, surface crusting and cracking were observed in several of the clayey samples. Cracks that formed in a soil material weathered from Bear Paw Shale (sample 2) are shown in Figure 2. Cracking in this material was probably caused by its mineralogy of mixed-layer illite-montmorillonite and sodium-rich montmorillonite clays (Schultz 1978).

Figure 2. Cracks which formed in a soil weathered from Bear Paw Shale.

None of the samples exceeded the suspect sand content of 70 percent. Textural classes of the growth media ranged from sandy loam to clay. According to USBR (1981) criteria for evaluating textural class, 11 samples rated as good growth media, 3 samples rated as fair and 8 samples received a poor rating.

Chemical Analysis

Complete results of the chemical characterization are given in Appeddix II, Table 10. Table 4 contains a summary of this data.

Table 4. Summary of chemical analysis data.

Parameter	Mean	S.D.	Range Min. -	Max.
pH	6.95	1.98	3.80 -	9.40
EC (mmhos/cm)	2.92	5.33	0.09 -	23.90
CEC (me/100g)	19.70	9.20	3.50 -	38.10
SAR	4.30	9.40	0.04 -	34.70
Exchangeable Ca (me/100g)1/	43.80	37.50	9.40 -	178.70
Exchangeable Mg (me/100g)1/	11.40	6.10	0.09 -	25.60
Exchangeable Na (me/100g)1/	3.40	7.70	0.02 -	31.50
Exchangeable K (me/100g)1/	1.10	0.60	0.02 -	3.30
Ca:Mg2/	13.20	41.60	0.54 -	198.50
Soluble NO_3 (mg/l)	58.20	182.70	0.25 -	383.80
Soluble SO_4 (mg/l)	2900.50	6480.60	7.00 -	29508.00
Soluble Cl (mg/l)	48.30	130.20	0.10 -	616.80
Soluble HCO_3 (mg/l)	94.00	87.60	0.10 -	929.80
Soluble B (ppm)	1.76	1.92	0.05 -	7.99
Extractable P (ppm)	3.69	5.42	0.10 -	24.20
Extractable Mo (ppm)	0.28	0.17	0.06 -	0.66
NH_4OAc-extractable Fe (ppm)	1.60	0.80	0.70 -	4.00
NH_4OAc-extractable Mn (ppm)	13.60	16.40	1.20 -	70.40
NH_4OAc-extractable Zn (ppm)	4.00	5.20	0.90 -	8.80
NH_4OAc-extractable Cu (ppm)	1.60	2.40	0.10 -	9.60
NH_4OAc-extractable Ni (ppm)	1.60	2.00	0.20 -	10.00
NH_4OAc-extractable Pb (ppm)	0.40	0.30	0.40 -	1.60
DTPA-extractable Fe (ppm)	23.14	36.58	2.20 -	143.00
DTPA-extractable Mn (ppm)	11.70	10.31	0.58 -	32.40
DTPA-extractable Zn (ppm)	1.23	1.58	0.02 -	6.62
DTPA-extractable Cu (ppm)	1.48	1.34	0.60 -	4.42
DTPA-extractable Ni (ppm)	0.83	1.01	0.24 -	4.58
DTPA-extractable Pb (ppm)	0.74	0.62	0.40 -	2.36
DTPA-extractable Cd (ppm)	0.12	0.18	0.05 -	0.21
Organic matter (%)	2.12	1.87	0.10 -	5.00

1/ Exchangeable = Extractable - Soluble (Richards 1969)
2/ Ca:Mg = Exchangeable Ca/Exchangeable Mg

The minimum detection level was assigned to any sample with an undetectable quantity for a given parameter. Except for the DTPA extractions, each mean and standard deviation is based on 22 samples. DTPA analyses were run on 17 of 22 samples. Since only one sample contained a detectable quantity of soluble carbonate (CO_3), and none of the samples contained detectable levels of soluble selenium (Se) or NH_4OAc-extractable Cd, these parameters were excluded from the table.

A comparison of Table 4 with the MDSL criteria indicated that the growth media exceeded the suspect levels for pH, EC, SAR, Mo and Ni. A gray calcareous mudstone (sample 17), with a pH of 9.4, was the only material to exceed the suspect pH level. Since the MDSL criterion for pH does not specify a limiting value in the acidic range, USBR criteria were used to evaluate the acidic media. Materials with pH values of less than 5.0 are rated as poor plant growth media by these criteria (USBR 1981). Four overburden samples and one spoil material had pH values of less than 5.0. The acidic overburden included a Bear Paw Shale material (sample 15), a gray fossiliferous siltstone (sample 18), a gray fossiliferous shale (sample 19) and a Fort Union interbedded sandstone and shale (sample 20). The acidic mine spoil (sample 22) was a yellowish-brown material containing coal and gypsum fragments. The acidic media were also high in soluble salts.

Four of the five acidic samples had conductance values greater than 4 mmhos/cm. The acidity and salinity of sample 18 were especially pronounced. This siltstone material had a pH of 3.9 and a conductance of 23.9 mmhos/cm. The salt crust which formed on its surface is shown in Figure 3. The only saline material that was not also acidic was a soil material weathered from Bear Paw Shale (see Figure 2). By contrast, the unweathered Bear Paw Shale (sample 15) was the only acidic medium with low conductance (0.29 mmhos/cm). This variability for Bear Paw Shale is well within the range reported by Tourtelot (1962) for the Pierre Shale and its geologic equivalents. The acidic and saline materials were rated as unsuitable growth media.

Figure 3. The salt crust which formed on the surface of an acidic, saline and sodic material geologically identified as siltstone (sample 18).

The MDSL level for SAR was exceeded in three of the samples: the saline soil derived from Bear Paw Shale (sample 2), a Fort Union mudstone (sample 17), and a gray fossiliferous siltstone (sample 18). Dominance of the sodium ion on the exchange complex of these materials causes dispersion of colloids resulting in low permeability and increased potential for surface runoff and erosion (Richards

1969). The salinity of sample 2, high pH of sample 17 and combined acidity and salinity of sample 18 would complicate reclamation efforts if significant amounts of these sodic overburden materials were placed in the root zone after mining.

Barrett and others (1980) recommended adequacy levels of P and K for post-mine establishment of native and improved range grasses. These levels were set at 7 ppm P ($NaHCO_3$ extraction) and 60 ppm K (NH_4OAc extraction). By these criteria, 17 of the 22 samples (77%) were P deficient. Only sample 20 was deficient in K.

Criteria are lacking for individual assessment of water soluble levels of sulfate (SO_4), nitrate (NO_3), bicarbonate (HCO_3), chloride (Cl) and CO_3 for reclamation planning. Since soil colloids carry a net negative charge, colloidal surfaces generally repel these anions. Anion concentrations, together with moisture content, control the salt concentration of the soil solution (Nye and Tinker 1977). The combined influence of soluble anions can, therefore, be estimated by measuring the conductivity of water extracts (Richards 1969). From the data in Table 4 it is evident that SO_4 was the dominant soluble anion in the growth media, followed by NO_3 and Cl. Sample 17 was the only material with a detectable concentration of soluble CO_3 (40 mg/l).

Criteria are also lacking for evaluation of organic matter content of growth media for reclamation planning. Barrett and others (1980), however, suggested the 2 percent level as the point above which N fertilization is not required for establishment of forage grasses. By this criterion, N fertilization would be required for 13

(59%) of the samples. The relatively high organic matter readings for two overburden materials (samples 18,20) and one mine spoil (sample 22) could have been caused by coal fragments in these samples.

Complete results of the trace metal analyses are given in Appendix II, Table 10. Of the trace metals analyzed by methods comparable to MDSL procedures, only Ni and Mo exceeded suspect levels. The 1 ppm suspect Ni level was exceeded in six (35%) of the samples analyzed by DTPA extraction. Five of these samples were soil materials; a gray siltstone interburden (sample 16) was the only geologic material high in Ni. Molybdenum levels exceeded the 0.3 ppm suspect concentration in nine (41%) of the samples. These included four soil samples, three geologic materials and both of the mine spoils. According to MDSL criteria, none of the samples contained suspect levels of Cu, Zn, Mn, Pb, Cd, Se or B.

Guidelines for adequate levels of plant available Zn, Fe, Cu and Mn were suggested by Follett and Lindsay (1970). They are 1.0 ppm for Zn and Mn, 4.5 ppm for Fe and 0.2 ppm for Cu. According to these guidelines, potential Zn deficiencies were detected in eight soil materials and one mine spoil sample; two soil samples were Mn deficient; three soil samples were low in Fe. No Cu deficiencies were detected.

Although criteria for evaluating exchangeable Ca:Mg ratios are not well-developed, Barrett and others (1980) consider the parameter important from a plant nutrition standpoint. Reduced Ca uptake caused by low Ca:Mg ratios in the growth medium could reduce plant production (Barrett et al. 1980). Bear and Troth (1948) recommended an optimum ratio of 6.5:1 for alfalfa production. Halstead and others (1958) observed that a range of ratios from 0.6:1 to 13.5:1 had no effect on alfalfa yield. In the same study, however, a $MgCO_3$ liming treatment decreased levels of exchangeable Ca in the soil and reduced Ca levels in alfalfa tissues. The $MgCO_3$ treatment also reduced P uptake by alfalfa. Two overburden materials (samples 18,19) and one spoil material (sample 22) had exchangeable Ca:Mg ratios of less than one.

Using four sets of criteria, evaluation of the physical and chemical analysis results identified potential plant growth problems in 95 percent of the samples. Phosphorus deficiency and low organic matter content were the two most common problems. These two factors combined rendered 20 of the samples inadequate as plant growth media. Although the suspect level for Mo was exceeded in 41 percent of the samples, concentrations were well below levels toxic to plants (Hornick et al. 1977). Inhibitory clay textures and high Ni concentrations each occurred in over a third of the samples. Although few Fe, Mn or Cu deficiencies were detected, nine of the growth media (41%) were low in Zn. Inhibitory pH and salinity levels each occurred in 23 percent of the samples. Although only three samples were sodic, their SAR values were extremely high, averaging 26.2. Potassium levels were adequate in all but a single sample. The only material without growth-limiting properties was sample 12. This A horizon material with fine granular structure contained adequate P and ranked highest in organic matter. It should be stressed again that the criteria used for this evaluation may be somewhat arbitrary. Nutrient interactions and growth media characteristics could change the level at which an element becomes growth-limiting, and nutrient requirements for agronomic crops may be different for perennial native species.

Greenhouse Analysis: yield relationships

Figure 4 shows the layout of the greenhouse study as it appeared just prior to harvesting. The larger green containers are Jenny pot-culture replications; the smaller white containers are replications of the Neubauer seedling method. The suspended plastic container and the balance used for watering are seen in the right of the photograph.

Figure 4. The greenhouse study just prior to harvesting.

A complete list of the yield and elemental uptake data for the greenhouse methods is given in Appendix III, Tables 11 and 12.

Analysis of variance for the yield data (see Appendix IV, Table 13) indicated highly significant yield differences ($p<0.01$) among the growth media, highly significant differences between the potting methods and a significant interaction between potting method and growth medium. The interaction implies that the greenhouse methods gave different yield-based assessments of the growth media. This difference is shown by the statistical figures and yield-based rankings of the growth media given in Table 5.

Table 5. Jenny and Neubauer yield-based rankings of the 22 growth media.

Jenny Yield[*]	Sample No.	Sample No.	Neubauer Yield[*]
1.731	12	12	0.462
0.942	10	10	0.461
0.742	14	6	0.436
0.648	8	17	0.429
0.642	5	8	0.407
0.432	6	16	0.396
0.411	7	11	0.380
0.298	2	22	0.373
0.289	22	14	0.365
0.264	19	13	0.341
0.256	13	7	0.338
0.198	3	2	0.326
0.175	11	5	0.326
0.135	15	9	0.318
0.120	4	3	0.305
0.119	9	18	0.305
0.108	21	21	0.297
0.092	1	1	0.283
0.092	16	15	0.268
0.079	17	4	0.264
0.028	18	19	0.250
0.000	20	20	0.027
Mean = 0.353 S.D. = 0.396 L.S.D. = 0.078[**]			Mean = 0.344 S.D. = 0.093 L.S.D. = 0.027[**]

[*] Means of 10 replications in g/pot

[**] Significant at the 99 percent level

Although the difference between Jenny and Neubauer mean shoot yield was only 0.081 g per container, the standard deviation in Jenny pot-culture yield was 4.26 times larger than the same statistic for the Neubauer yield. The greenhouse methods gave identical yield-based rankings to only 5 (23%) of the growth media. A Spearman's rank order correlation coefficient (r_s) was calculated for the Jenny and Neubauer yield-based rankings. This test statistic gives the degree of association or similarity between the two rankings in Table 5. The analysis resulted in a coefficient of 0.46, which indicated a poor degree of association. The differences between the two methods in yield variability and the disparity in the two yield-based rankings were expected because of three fundamental differences in the greenhouse methods: (1) the sand dilution of each growth medium by the Neubauer method, (2) the different planting densities of the methods, (3) the difference in the amount of sample used in the containers.

In the Neubauer method, the mixing of each 100 g growth media sample with 50 g of acid-washed sand effectively diluted the chemical concentration of each sample and made the texture more coarse. Therefore, plants grown by the Neubauer method responded to a set of physical and chemical conditions which were quite different from properties of the same medium prepared by the Jenny method. Dollhopf and others (1978) reported a near linear reduction in potential toxicity of overburden strata when problem overburden was mixed with more suitable materials in the dragline spoiling process. The effect of a similar dilution in the Neubauer containers is seen in figure 5.

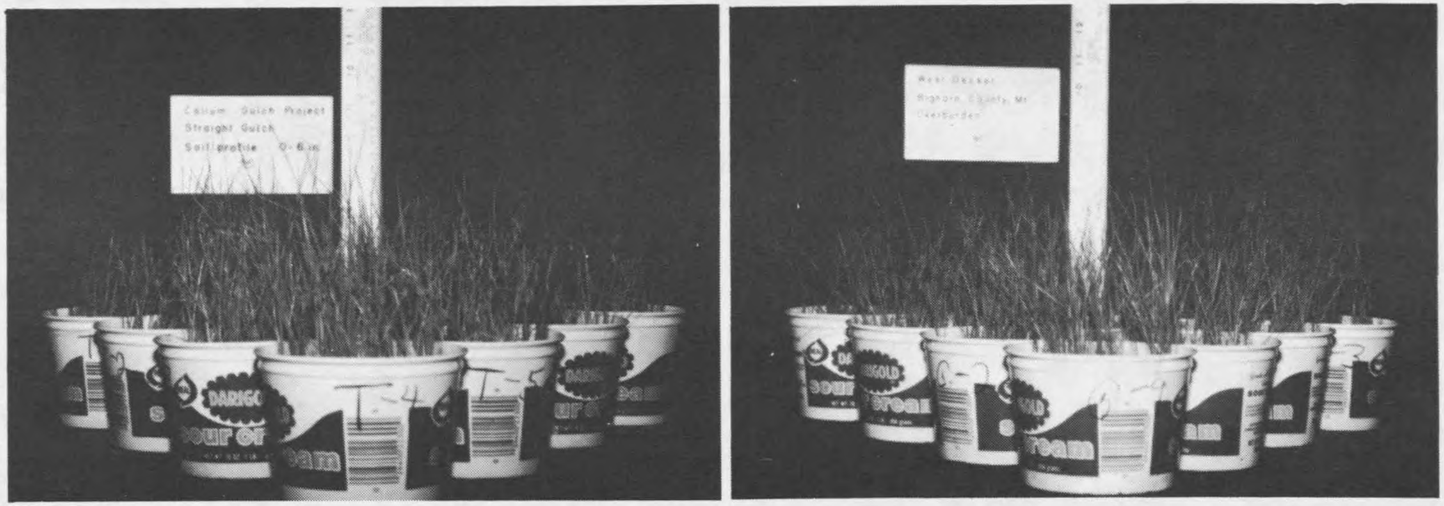

Figure 5. Neubauer containers showing the similarity in growth response between the most productive sample (left) and a sodic overburden (right).

Improved conditions for seedlings growing in Neubauer containers can be seen by comparing the Neubauer responses to samples 12 and 17. Improved growth conditions with the sand dilution resulted in a smaller difference between mean yield in the most productive medium (sample 12) and mean yield in a sodic overburden (sample 17). Figure 5 shows the similarity in Neubauer shoot growth between these materials. The Neubauer shoot yield means for samples 12 and 17 differed by only 0.033 g per container. This resulted in a higher ranking for sample 17 by the Neubauer method. In the undiluted Jenny pot-cultures, mean yield in the sodic overburden was 1.652 g per pot less than production in sample 12 and its yield-based ranking among the growth media was much lower. The sand dilution served to reduce the variation in Neubauer yield by reducing any toxic or inhibitory property of the growth medium.

Neubauer yield differences were also reduced by larger seedling numbers in Neubauer containers. The extreme acidity and salinity of sample 20 prevented plant growth in Jenny pot-cultures. Although the Neubauer method also ranked this material as the poorest growth medium, an average of 40 plants per container were able to emerge. The combined acidity, salinity and sodicity of sample 18 restricted seedling emergence in Jenny pot-cultures to two plants per container. Neubauer replications of the same sample averaged 99 seedlings per container. The yield-based ranking for sample 18 was higher by the Neubauer method partly because of its higher planting density.

The lower standard deviation in Neubauer yield could also be partly explained by the the lower nutrient capacity of the method's smaller sample weight. The Neubauer method was developed with the assumption that a dense stand of seedlings extracting nutrients from a small amount of soil would rapidly exhaust the nutrient supply. Under these conditions, the capacity of the solid phase to replenish the soil solution becomes a growth-limiting factor. The lower replenishing capacity of the Neubauer method's 100 g sample weight would have restricted plant growth in fertile media more than the 1 kg Jenny pot-cultures which provided plants with a larger solid phase nutrient pool.

The advantage of a larger sample weight was shown by a greater yield response of seedlings grown in the most productive medium (sample 12). The mean shoot yield for this sample in Jenny pot-cultures was 1.38 g per pot greater than the overall mean yield. The shoot yield increase for sample 12 was 0.80 grams per container by the Neubauer method. The advantage of a larger nutrient pool was also expressed by the difference in Jenny and Neubauer seedling height in sample 12. Figure 6 shows a Jenny pot-culture of sample 12 after 30 days of growth. Seedling height in this sample averaged 18 cm after 30 days; seedling height in Neubauer replications of the same sample (see Figure 5) averaged 12.1 cm after 45 days. The higher nutrient capacity of fertile growth media in Jenny pot-cultures allowed larger shoot yield increases than the same materials in the smaller Neubauer containers.

The combined influences of the larger sample weight in Jenny pot-cultures, the sand dilution factor and the greater planting density of the Neubauer method were possible causes of the significant interaction between growth medium and potting technique observed in the analysis of variance. They could also have caused the difference between the yield-based growth media rankings listed in Table 5.

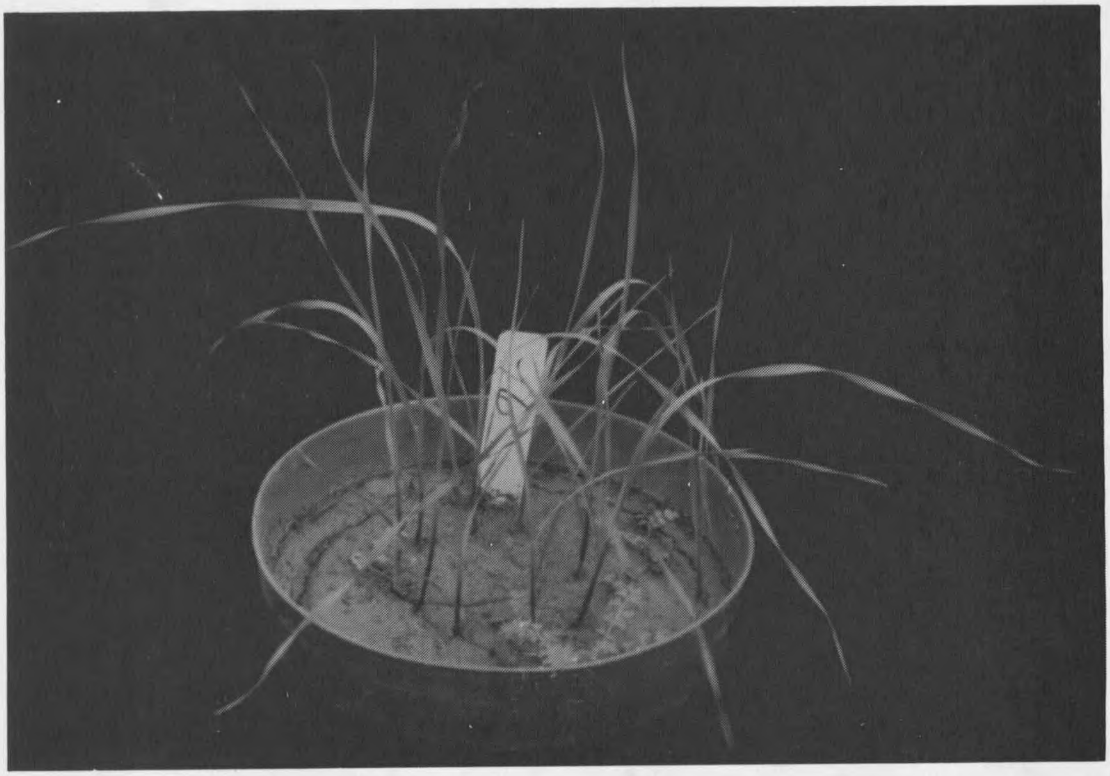

Figure 6. Seedling growth in a Jenny pot-culture of sample 12 after 30 days.

To identify additional factors which influenced shoot yield response and to determine whether they operated for both of the greenhouse methods, Jenny and Neubauer yield responses were correlated with growth media parameters measured in the laboratory. A complete list of the variables used in the regression analysis is contained in Table 6.

Table 6. Variables used in the regression analysis.

Variable Number	Variable Name	Units
V01	Sample number	a number (1-22)
V02	Jenny shoot yield	g/pot
V03	Neubauer shoot yield	g/pot
V04	pH	-log {H+}
V05	EC	mmhos/cm
V06	CEC	me/100g
V07	SAR	a ratio
V08	Exchangeable Ca	me/100g
V09	Exchangeable Mg	me/100g
V10	Exchangeable Na	me/100g
V11	Exchangeable K	me/100g
V12	Ca:Mg	a ratio
V13	Soluble SO_4	mg/l
V14	Soluble Cl	mg/l
V15	Soluble HCO_3	mg/l
V16	Boron	ppm
V17	NH_4OAc-extractable Zn	ppm
V18	NH_4OAc-extractable Fe	ppm
V19	NH_4OAc-extractable Cu	ppm
V20	NH_4OAc-extractable Ni	ppm
V21	NH_4OAc-extractable Mn	ppm
V22	DTPA-extractable Zn	ppm
V23	DTPA-extractable Cu	ppm
V24	DTPA-extractable Pb	ppm
V25	DTPA-extractable Ni	ppm
V26	DTPA-extractable Fe	ppm
V27	DTPA-extractable Mn	ppm
V28	DTPA-extractable Cd	ppm
V29	Molybdenum	ppm
V30	Phosphorus	ppm
V31	Organic matter	percent
V32	Moisture at saturatrion	percent
V33	Moisture at 1/3 bar	percent
V34	Moisture at 15 bar	percent
V35	Sand content	percent
V36	Silt content	percent
V37	Clay content	percent

Five growth media parameters were excluded from this list of independent variables. Hot water soluble Se and NH_4OAc-extractable Cd were excluded because they were not detected in any of the samples. Soluble CO_3 was excluded because it was detected in only one sample. Soluble NO_3 and NH_4OAc-extractable Pb were excluded because detectable levels could be measured in only 7 of 22 samples. Multiple stepwise linear regression analysis was used with Jenny and Neubauer shoot yield response as the dependent variables and measured growth media parameters as independent variables. Each of the regressions included 22 cases; each case being a trial on a single growth medium. Yield response values for each case were means of ten replications. Because the regression program would exclude any case without a yield response, the zero response of Jenny pot-cultures to sample 20 was substituted with a value of 0.001 g per container. By this substitution, sample 20 would be included as a case in the regression analysis and its status as the lowest yielding medium would be maintained.

Table 7 contains the variables identified by the regression analysis as having important influences on yield in the greenhouse methods. Table 7 also lists the statistical figures associated with each variable. The step number, constant and beta values from the table can be used to construct the regression equation for shoot yield in each greenhouse method. For example, the equation for shoot yield in the Jenny pot-cultures would read:

$$Y = .435 - 1.305X_1 + .581X_2 + .024X_3 - .023X_4 - .204X_5$$

where:

Y = shoot yield in grams per pot

X_1 = value of V29

X_2 = value of V11

X_3 = value of V30

X_4 = value of V09

X_5 = value of V25

The equation for Neubauer yield would be constructed similarly.

Table 7. Results of the regression analysis with Jenny and Neubauer shoot yield as the dependent variables.

Dependent Variable	Step into Equation	Variable No.	Constant	Beta	Simple R	R^2	F-sig. Level
Jenny Yield	1	29		-1.305	-.46	.22	.05
	2	11		.581	.37	.44	.005
	3	30	.435	.024	.10	.62	.005
	4	9		-.023	-.45	.71	.005
	5	25		-.204	.05	.81	.005
Neubauer Yield	1	4		.029	.58	.36	.005
	2	31	.148	.152	.12	.46	.005
	3	9		-.422	-.49	.52	.005

A maximum of five variables were allowed to enter a regression equation. It was felt that this limitation would allow for identification of the most important relationships. The regression equation for Neubauer yield, however, identified only three growth media parameters as being yield-influencing factors. This result indicated that Neubauer yield response had a weaker functional relationship with the growth media parameters. This was also illustrated by the R^2 values for the two equations. A value of .52 for the Neubauer equation, compared to .81 for the Jenny equation, indicated that a smaller portion of Neubauer yield variation was explained by the combined linear influence of the independent variables. Simple correlations (Simple R), however, for each of the variables in the Neubauer equation indicated relationships with shoot yield.

A correlation coefficient of .58 indicated a positive relationship between Neubauer yield and pH. Using the Neubauer method in a study of trace element uptake, Prabhakarannair and Cottenie (1969) reported that the dense root network effectively lowered the pH of the soil and increased the solubility and uptake of Mn, Cu, Zn, Fe and aluminum (Al). A decrease in extractable amounts of soil trace elements after a 30-day growth period was attributed to depletion by the dense stand of seedlings. Micronutrient depletion would be less rapid in growth media having high pH values. Most of the micronutrient reserve would initially be in slightly soluble oxide and hydroxide forms. Trace metal uptake could have occurred over a longer portion of the growth period for seedlings growing in more alkaline media as initially unavailable forms became more soluble with the declining pH in the rhizosphere. A sustained supply of micronutrients could have been responsible for the positive correlation between pH and yield in the Neubauer containers.

Neubauer yield response was also positively correlated with organic matter content, although the degree of correspondence was less than that observed with pH. The Neubauer method was described by Fried and Broeshart (1967) as a severe test of the soil's capacity to replenish a rapidly depleted soil solution. The reactive surface of organic matter, formed by COOH and OH groups, adds significantly to the cation exchange capacity of soils. The exchange capacity of organic matter and its value as a source of native N, P and sulfur (S) would serve to buffer a rapid depletion of the soil solution. These contributions of soil organic matter to soil fertility could possibly explain the positive correlation with shoot yield.

Exchangeable Mg was the only independent variable to enter both of the regression equations. Simple correlations indicated a negative relationship with yield in each case. This result is unusual because of the role of Mg as an essential fixed element in chlorophyll and its dominance over all other elements in enzyme activation (Epstein 1972). The literature does, however, contain references to ion "antagonisms" which are deficiencies of one element caused by excessive absorption of another. A study by Walker and others (1955) used the Jenny pot-culture to investigate Ca deficiencies caused by high Mg levels in serpentine soils. Marked yield decreases and acute Ca deficiency symptoms were observed for plants grown in soils with low Ca:Mg ratios. A study by Epstein (1961) concluded that Mg was ineffective, compared to Ca, in reversing the inhibition of K ion transport by Na ions. This could possibly explain the K deficiency observed by Ulrich and Ohki (1966) with Mg fertilization. Inhibition of K absorption by

Na ions when Mg levels are high could explain the negative correlation between yield and exchangeable Mg in both regression equations.

The entry of extractable (Mo) into the regression equation for the Jenny method was a second unusual result. As indicated by the R^2 value, the negative influence of Mo accounted for 22 percent of the observed variation in shoot yield. The literature does not support the notion that the range of extractable Mo in the growth media (0.06 - 0.66 ppm) could have a negative influence on plant growth. A greenhouse study conducted by Hornick and others (1977) was unable to detect significant effects of Mo treatments (0, 20 and 40 ppm) on growth of five crop and pasture species. Gough and others (1979) could report no instances of Mo toxicity to plants under field conditions. Allaway (1977) reported that plant growth symptoms are of little value for detecting high Mo levels of up to several hundred parts per million. This evidence suggests that Mo concentration does not directly affect plant yield.

An alternative explanation for the occurrence of Mo in the equation could be its intercorrelation with other independent variables. Intercorrelation among independent variables is a common problem in multiple regression analysis. It exists when the independent variables are correlated among themselves or when they are correlated with other factors, not included in the analysis, that do affect the dependent variable (Neter and Wasserman 1974). An intercorrelation could not be found between extractable Mo and the other independent variables in this study. Therefore, the occurrence of Mo in the equation could possibly be explained by its intercorrelation with an unmeasured variable affecting yield. Further investigation into Mo availability and its relation to western wheatgrass yield is needed to properly address this problem.

The entry of extractable P and exchangeable K into the regression equation for Jenny pot-culture yield was expected because of the primary nutrient status of these elements. The inclusion of P and K and their positive correlations with yield legitimize the the pot-culture method as a diagnostic technique for reclamation planning. Despite modifications of the original procedure and expansion of its soil testing application to include spoil and overburden screening, the method gave evidence of a functional relationship between test-plant yield and the primary nutrient status of the growth media.

The fifth variable to enter the Jenny regression equation was DTPA-extractable nickel. Nickel is not an essential nutrient and can be toxic to plants at high concentrations. Although DTPA Ni was included in the equation, the simple correlation coefficient ($R = .05$) indicated a relatively weak relationship with yield in Jenny pot-cultures.

The overall R^2 value for the Jenny equation was .81 compared to a value of .52 for the Neubauer equation. This comparison indicated that a larger portion of Jenny pot-culture yield could be explained by the influence of the growth media parameters measured in the laboratory. The entry of only three variables into the Neubauer equation, compared to five variables in the Jenny equation, further demonstrated that Neubauer yield response was not as strongly influenced by the growth media parameters measured in this study.

Greenhouse Analysis: elemental uptake relationships

Plant tissue concentrations of 13 elements were determined for vegetation grown by both of the greenhouse methods. Table 8 contains Jenny and Neubauer means, standard deviations and ranges for each of these elements. An analysis of variance table was computed for each element to determine if vegetation grown by the Jenny and Neubauer methods differed in elemental concentrations (see Appendix V, Tables 14-26). Results indicated that vegetation produced by the Jenny method contained significantly ($p<.01$) higher concentrations of N, Mo, Zn, Cu and Cd. Vegetation produced by the Neubauer method contained significantly ($p<.01$) higher concentrations of P, Ca and Mg. There were no significant differences between the methods for plant concentrations of K, Mn, Fe and Pb.

Table 8. Summary of data for elemental tissue concentrations in western wheatgrass grown by the Jenny and Neubauer methods.

	Jenny		Neubauer		Jenny Range		Neubauer Range	
Parameter	Mean	S.D.	Mean	S.D.	Min. -	Max.	Min. -	Max.
N (%)	2.0	0.81	1.3	0.56	0.86 -	3.63	0.97 -	3.35
P (%)	0.1	0.08	0.2	0.05	0.03 -	0.33	0.14 -	0.34
K (%)	1.9	0.81	1.9	0.38	0.56 -	3.20	1.34 -	2.98
Ca (%)	0.2	0.08	0.3	0.10	0.08 -	0.40	0.11 -	0.48
Mg (%)	0.2	0.05	0.3	0.13	0.12 -	0.32	0.15 -	0.66
Mn (ppm)	62.8	39.40	70.6	49.60	13.60 -	167.60	25.00 -	251.00
Zn (ppm)	26.6	10.50	20.0	6.80	7.80 -	46.00	10.10 -	37.50
Fe (ppm)	95.3	51.50	72.4	15.40	39.00 -	172.00	49.00 -	101.00
Mo (ppm)	0.4	0.19	1.3	0.92	0.21 -	0.92	0.40 -	3.61
Cd (ppm)	0.2	0.03	0.1	0.02	0.13 -	0.23	0.03 -	0.11
Ni (ppm)	1.6	1.98	0.9	0.78	0.28 -	7.86	0.33 -	4.13
Pb (ppm)	0.7	0.21	0.8	0.25	0.36 -	1.00	0.43 -	1.52
Cu (ppm)	11.2	1.95	5.4	1.61	9.20 -	14.20	3.30 -	9.50

As with the yield differences, elemental uptake variability can be attributed to fundamental differences in the methods. Bates (1971) included tissue age and physiological maturity as critical factors influencing nutrient concentrations in plants. At the time of harvesting, the age of the plants grown by the Jenny and Neubauer methods differed by 15 days. This factor could account for some of the differences in elemental concentrations observed for the two methods. Plants grown concurrently in media having different nutrient concentrations may vary in physiological maturity (Munson and Nelson 1973).

The initial concentrations of each growth medium were reduced with the addition of sand to the Neubauer containers. The sand dilution factor could also account for some of the observed differences in elemental uptake. Plant density also affects the physiological growth stage of plants since competition will affect individual plant size (Nye and Tinker 1977).

Seedlings in Neubauer containers were limited to growth of two to three leaves per plant in the most productive medium. Plants in Jenny pot-cultures of the same sample produced five to six leaves and were tillering from short rhizomes. Such differences in physiological maturity could possibly explain the differences in elemental uptake observed in the analysis of variance.

SUMMARY AND CONCLUSIONS

Greenhouse methods have been used to identify growth-limiting properties of soils and geologic materials for reclamation planning. Modifications of the Jenny pot-culture have often been used for this purpose. The large amounts of sample and lengthy growth periods required for these modifications have made greenhouse testing an expensive approach to soil and overburden screening. The smaller sample weight and shorter growth period of the Neubauer seedling method would reduce the cost of greenhouse testing if shoot yield by the method could be used to identify plant growth problems. In this study, shoot yield by the Jenny pot-culture method was compared to Neubauer seedling yield to determine whether the Neubauer method could be used as a diagnostic tool to assess growth media suitability for reclamation planning.

The comparison was run on 22 growth media samples which included soils, geologic materials and mine spoils. Physical and chemical parameters were measured for each sample using conventional laboratory analysis methods. The greenhouse methods were run concurrently using western wheatgrass (Agropyron smithii var. Rosanna) as the test-plant. Shoot yield and tissue concentrations of 13 elements served as response variables. Analysis of variance for each response variable was computed to observe the variability attributed to growth medium and potting technique. A Spearman's rank order correlation coefficient was computed to determine the degree of association between the yield-based rankings provided by the two potting methods. Multiple stepwise linear regression analysis was implemented with Jenny and Neubauer yield response as the dependent variables and growth media analysis data as independent variables. The regression analysis identified yield-influencing growth media parameters for each greenhouse method. It was also used to compare the degree of correspondence between yield by each method and the measured growth media characteristics.

Analysis of variance indicated that shoot yields for the Jenny and Neubauer methods were significantly different. A significant interaction between potting technique and growth medium indicated that the Jenny and Neubauer methods gave different yield-based rankings of the growth media being tested. A Spearman's rank order correlation coefficient of 0.46 indicated a poor degree of association between the Jenny and Neubauer yield-based rankings of the growth media. Analysis of variance for the elemental tissue concentrations indicated that vegetation produced by the two methods differed significantly for 9 of the 13 elements measured.

The observed differences in shoot yield and elemental uptake could be attributed to intrinsic differences in the two potting techniques. The sand dilution of each growth medium by the Neubauer method, the higher seedling density in Neubauer containers and the lower nutrient capacity of the Neubauer method's smaller sample weight are possible explanations for the analysis of variance results. The sand dilution effectively homogenized the variability among the growth media by both reducing potentially toxic or inhibitory properties and lowering essential nutrient concentrations in more suitable media. This leveling effect of the sand dilution could explain why the Neubauer method ranked the growth media differently than the Jenny pot-culture. The higher planting density combined with the smaller sample weight in Neubauer containers produced a seedling-to-soil ratio that was much larger for the Neubauer method than for the Jenny pot-culture. As a result, the Neubauer method produced more seedlings per container for each growth medium. However, yield increases were restricted in the more suitable media because plants competed more intensively for nutrients from a smaller nutrient pool. The combination of higher seedling numbers in relatively poor media and restricted production in more fertile media could explain the lower standard deviation in Neubauer yield.

Multiple regression analysis produced a regression equation for yield by each greenhouse method. The equation for the Jenny pot-culture identified more growth media parameters and produced a higher R^2 value than the equation for Neubauer yield. This indicated that yield by the Jenny method had a stronger functional relationship with growth media parameters commonly measured to assess soil and overburden suitability for reclamation planning. Because of the weaker functional relationship between Neubauer shoot yield response and the growth media properties, it must be concluded that the Neubauer method is less adequate as a diagnostic tool. The method does, however, illustrate the advantage of diluting a potentially toxic or inhibitory growth medium with a more suitable material.

Despite the smaller sample weight and shorter growth period of the Neubauer method, preparation of individual containers is a time-consuming task, especially if extensive replication is required. The daily watering routine is also time-consuming. Although the Jenny pot-cultures require larger sample weights and a longer trial period, container preparation and the watering procedure are simpler. The possibilities of using a smaller container and shortening the growth period could be investigated in an effort to reduce costs.

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LITERATURE CITED

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APPENDICES

APPENDIX I

GROWTH MEDIA DESCRIPTIONS

Growth Media Descriptions

Soils

Sample Number	Description
1	Classification: Ustic Camborthid, fine-loamy, mixed Parent Material: Bear Paw Shale B21 8-25 cm. Olive brown (2.5Y 4/3) clay; moderate very fine platy structure; loose (dry), very friable (moist), sticky and plastic (wet); slightly acid.
2	Classification: Ustic Torriorthent, fine-loamy, mixed Parent Material: Bear Paw Shale C3 5-14 cm. Brownish black (2.5Y 3/2) clay; moderate fine platy structure; loose (dry), very friable (moist), sticky and plastic (wet); mildly alkaline.
3	Classification: Typic Argiboroll, fine-silty, mixed (Farland series) Parent Material: Calcareous Shale A1 0-5 cm. Brownish black (10YR 3/2) clay loam; strong coarse platy breaking to very fine platy structure; slightly hard (dry), friable (moist), sticky and plastic (wet); mildly alkaline.
4	Classification: Typic Argiboroll, fine-silty, mixed (Farland series) Parent Material: Calcareous Shale C1 46-63 cm. Olive brown (2.5Y 4/4) loam; moderate medium subangular blocky structure, hard (dry), very friable (moist), slightly sticky and slightly plastic (wet); moderately alkaline.

Growth Media Descriptions

Sample Number	Description
5	Classification: Ustic Torriorthent, clayey, montmorillonitic (Midway Series) Parent Material: Calcareous Shale C2 18-76 cm. Gray (10Y 6/1) clay; moderate fine platy structure; soft (dry), friable (moist), sticky and plastic (wet); mildly alkaline.
6	Classification: Entic Haploboroll, loamy-skeletal, mixed (Wilaux Series) Parent Material: Clinker A1 0-7 cm. Dark reddish brown (5YR 3/3) loam; weak medium granular structure; soft (dry), very friable (moist), non-sticky and non-plastic (wet); moderately alkaline.
7	Classification: Typic Haplaquept, fine, montmorillonitic (McKenzie Series) Parent Material: Lake Sediments B2 8-46 cm. Black (5Y 2/1) clay; strong coarse prismatic structure; very hard (dry), very firm (moist), very sticky and very platic (wet); neutral.
8	Classification: Borollic camborthid, fine-loamy, mixed Parent Material: Alluvium B2 60+ cm. Brown (10YR 4/4) loam; moderate medium platy structure; slightly hard (dry), friable (moist), sticky and slightly plastic (wet); moderately alkaline.

Growth Media Descriptions

Sample Number	Description
9	Classification: Entic Haploboroll, loamy-skeletal, mixed Parent Material: Alluvium C1 61-81 cm. Brown (7.5YR 4/4) sandy loam; single-grained structure: loose (dry), friable (moist): non-sticky and non-plastic (wet); strongly alkaline.
10	Classification: Borollic Haplargid, fine-silty, montmorillonitic A1 0-8 cm. Brown (10YR 4/4) loam; moderate medium platy structure; slightly hard (dry), firm (moist), slightly sticky and non-plastic (wet); neutral.
11	Classification: Borollic Haplargid, fine-silty, montmorillonitic Bt2 8+ cm. Dark brown (10Y$ 3/3) loam; moderate medium subangular blocky structure; hard (dry), very firm (moist), sticky and slightly plastic (wet); moderately alkaline.
12	Classification: Typic Torrifluvent, fine-loamy, mixed Parent Material: Alluvium A1 0-15 cm. Dark brown (10YR 3/4) loam; moderate fine granular structure; soft (dry), very friable (moist), slightly sticky and slightly plastic (wet); moderately alkaline.
13	Classification: Unknown Bt 18-36 cm. Dark brown (10YR 3/3) clay loam; strong coarse blocky structure; hard (dry), very firm (moist), sticky and plastic (wet); moderately alkaline.

Growth Media Descriptions

Sample Number	Description
14	Classification: Unknown C Dark grayish yellow (2.5Y 4/2) loam; massive structure; soft (dry), very friable (moist), sticky and plastic (wet); moderately alkaline.

Geologic Overburden

Sample Number	Description
15	Gray to black, fissle, acid shale; Bear Paw Formation.
16	Blue-gray to gray calcareous siltstone interburden; Fort Union Formation.
17	Light gray to gray calcareous mudstone; Fort Union Formation.
18	Light gray, thin-bedded, fossiliferous siltstone.
19	Gray to black, moderately fissle shale.
20	Brownish gray to black, interbedded sandstone and shale; Fort Union Formation.

Mine Spoils

Sample Number	Description
21	Yellowish brown, calcareous spoil.
22	Grayish brown to black, acidic spoil.

APPENDIX II

LABORATORY CHARACTERIZATION DATA

Table 9. Physical Laboratory Data

Sample No.	Percent Fine Earth Fraction Sand .05-2mm	Silt .002-.05mm	Clay <.002mm	Percent Water Sat.	1/3 bar	15 bar
1	15.9	32.1	52.0	68.2	31.0	24.6
2	10.2	27.8	62.0	170.2	52.9	31.7
3	21.5	40.5	38.0	61.3	26.6	19.1
4	43.5	32.5	24.0	44.6	17.5	10.8
5	10.0	23.1	66.9	68.6	27.7	21.4
6	41.1	42.0	16.9	52.1	29.0	13.9
7	19.1	30.0	50.9	69.5	32.6	22.4
8	41.1	38.0	20.9	43.7	16.6	11.4
9	65.1	22.0	12.9	33.7	16.3	9.3
10	40.2	44.8	15.0	41.7	23.9	9.8
11	38.2	38.8	23.0	40.2	17.2	10.9
12	44.2	34.8	21.0	48.8	19.3	13.5
13	28.2	34.8	37.0	51.2	22.3	16.7
14	38.2	36.8	25.0	37.7	20.7	9.6
15	22.0	30.0	48.0	74.5	31.0	25.3
16	3.9	70.1	26.0	34.6	19.6	12.5
17	28.8	49.2	22.0	227.4	51.7	38.5
18	16.2	52.8	31.0	40.7	19.5	17.3
19	11.1	32.0	56.9	83.0	24.9	17.9
20	23.9	34.4	41.7	50.9	27.5	21.4
21	39.5	36.5	24.0	41.5	19.3	9.5
22	27.5	28.5	44.0	69.5	26.3	20.4

Table 10. Chemical laboratory data.

Sample Number	pH (1)	EC (mmhos/cm) (1)	SAR (2)	Ca:Mg (3)	CEC (4) (me/100g)	Organic Matter (%)	Extractable Bases (5) (ppm)			
							Ca	Mg	Na	K
1	6.3	0.1	0.60	5.30	34.9	0.7	8480.0	968.0	126.4	192.0
2	7.6	7.9	27.70	2.71	30.7	0.8	8968.0	2120.0	11432.0	880.0
3	7.8	0.2	0.09	2.42	26.1	3.2	6524.0	1632.0	44.8	504.0
4	8.3	0.2	0.21	6.21	13.1	0.7	15936.0	1560.0	48.8	180.0
5	7.7	3.5	3.29	6.43	14.8	0.5	18384.0	1912.0	673.6	400.0
6	7.9	0.4	0.09	17.16	21.4	5.0	14492.0	512.0	43.2	480.0
7	7.4	0.2	0.23	1.65	28.7	3.4	5880.0	2172.0	76.0	1316.0
8	8.0	0.5	0.04	2.23	13.3	2.6	3652.0	1000.0	39.2	504.0
9	8.6	0.5	1.94	1.03	13.3	1.0	5300.0	3128.0	246.4	516.0
10	6.9	0.3	0.15	3.66	12.1	4.2	2576.0	436.0	40.8	492.0
11	8.3	0.3	0.87	3.21	12.6	1.9	5228.0	988.0	115.2	316.0
12	8.0	1.0	0.04	10.04	20.5	5.0	9121.0	560.0	41.2	740.0
13	8.0	0.2	0.15	2.90	21.7	1.3	6772.0	1416.0	50.4	284.0
14	7.9	2.0	0.12	198.55	10.2	0.6	36000.0	120.0	64.0	344.0
15	3.9	0.3	0.64	1.75	38.1	0.3	4480.0	1492.0	128.0	464.0
16	8.2	1.5	1.98	9.98	3.5	0.5	11144.0	720.0	152.0	192.0
17	9.4	0.6	34.70	5.07	18.2	1.0	7220.0	868.0	4575.2	340.0
18	3.9	23.9	16.30	0.96	24.5	4.8	3724.0	3892.0	4955.2	144.0
19	4.1	5.9	5.27	0.54	14.9	0.3	2052.0	2692.0	1641.6	208.0
20	2.9	8.4	0.04	1.18	27.3	4.7	3688.0	2640.0	46.4	92.0
21	7.9	1.7	0.24	7.17	6.4	0.1	12896.0	1088.0	55.2	160.0
22	3.9	4.7	2.72	0.86	27.7	4.7	3296.0	2564.0	592.0	376.0

(1) saturated paste extract

(2) Sodium Adsorption Ratio = $\dfrac{Na}{\left(\dfrac{Ca+Mg}{2}\right)^{\frac{1}{2}}}$

(3) Ca:Mg = $\dfrac{\text{Exchangeable Ca}}{\text{Exchangeable Mg}}$

(4) NaOAc saturation

(5) $1\underline{N}$ NH_4OAc extraction

Table 10. Chemical laboratory data (continued).

Sample Number	Soluble Bases (1) (mg/l) Ca	Mg	Na	K	Exchangeable Bases (6) (me/100g) Ca	Mg	Na	K	Soluble Anions (1) (mg/l) SO_4	NO_3	CO_3	HCO_3	Cl
1	4.9	1.0	5.6	6.4	42.3	8.0	0.5	1.5	7	< 0.2	0.0	6.1	17.3
2	356.7	148.7	2467.0	42.6	41.7	15.4	31.5	2.0	6242	27.5	0.0	42.7	62.0
3	19.3	7.0	1.8	5.6	32.5	13.4	0.2	1.3	20	< 0.2	0.0	72.4	5.3
4	20.3	14.0	4.9	2.9	79.5	12.8	0.2	0.5	12	< 0.2	0.0	131.1	1.8
5	492.5	303.4	376.7	21.7	90.0	14.0	1.8	1.0	2926	< 0.2	0.0	54.9	40.8
6	71.0	7.0	2.9	7.5	72.1	4.2	0.2	1.2	96	< 0.2	0.0	183.0	1.8
7	10.2	6.3	3.8	14.2	29.3	17.8	0.3	3.3	34	< 0.2	0.0	30.5	12.4
8	53.3	29.3	1.6	17.3	18.1	8.1	0.2	1.3	131	< 0.2	0.0	213.5	3.6
9	3.6	34.0	54.4	17.3	26.4	25.6	1.0	1.3	155	< 0.2	0.0	216.5	3.6
10	30.0	14.0	4.0	22.6	12.8	3.5	0.2	1.2	138	< 0.2	0.0	76.3	10.6
11	28.0	16.0	23.4	3.9	26.4	8.1	0.5	0.8	185	< 0.2	0.0	186.1	17.3
12	132.0	29.7	2.1	48.0	45.2	4.5	0.2	1.8	197	291.0	0.0	170.8	49.6
13	19.7	8.0	3.1	0.9	33.7	11.6	0.2	1.8	24	< 0.2	0.0	38.1	23.6
14	476.7	21.7	9.7	21.9	178.7	0.9	0.3	0.9	1567	19.2	0.0	103.7	8.9
15	21.0	6.0	13.0	12.0	21.3	12.2	0.5	1.2	130	< 0.2	0.0	0.1	1.8
16	93.0	100.7	115.7	36.2	55.4	5.6	0.5	0.5	843	< 0.2	0.0	161.1	10.6
17	0.9	0.4	161.3	3.0	36.0	7.1	18.3	0.9	519	< 0.2	40.0	292.8	3.5
18	348.3	4000.0	4933.0	24.9	17.8	18.6	12.8	0.3	29508	823.8	0.0	0.1	616.8
19	208.2	680.0	698.3	16.1	9.4	17.5	4.6	0.5	5342	8.0	0.0	0.1	126.7
20	266.0	1608.0	8.7	2.1	17.7	15.0	0.2	0.2	9571	< 0.2	0.0	0.1	0.1
21	240.0	149.0	19.3	11.3	63.8	8.9	0.2	0.4	1342	1.7	0.0	88.5	7.1
22	368.3	620.0	368.3	35.3	15.2	17.6	1.5	0.9	4823	106.5	0.0	0.1	37.9

(1) saturated paste extract

(6) Exchangeable = extractable minus soluble

Table 10. Chemical laboratory data (continued).

Sample Number	Soluble Boron (7) (ppm)	Extractable Phosphorous (8) (ppm)	Soluble Selenium (7) (ppm)	Trace Metal Analyses (9) (ppm)						
				Mn	Zn	Fe	Cd	Ni	Pb	Cu
1	1.73	1.2	<0.015	14.3	1.92	143.0	0.20	1.78	0.54	4.42
2	4.40	2.3	<0.015	9.4	1.22	12.9	0.21	1.40	1.36	3.79
3	7.99	0.8	<0.015	32.4	0.85	23.0	0.16	1.88	1.10	2.09
4	0.95	0.1	<0.015	4.2	0.20	4.1	0.06	0.46	0.52	1.01
5	2.55	2.6	<0.015	0.6	0.72	18.5	0.09	0.32	1.20	2.18
6	0.90	1.2	<0.015	3.5	0.48	3.9	0.11	0.44	0.56	0.64
7	2.29	0.4	<0.015	29.7	2.02	86.5	0.20	4.58	1.70	2.93
8	0.28	1.5	<0.015	9.2	0.59	6.1	0.08	0.62	0.72	0.92
9	0.05	0.1	<0.015	0.8	0.36	5.5	0.05	0.24	0.40	0.80
10	3.07	1.5	<0.015	17.0	1.76	37.0	0.12	0.80	0.38	1.46
11	0.05	0.4	<0.015	8.6	6.62	10.8	0.10	0.92	0.52	1.13
12	2.46	9.2	<0.015	5.4	3.10	11.4	0.16	0.82	1.04	1.15
13	2.37	2.3	<0.015	24.1	0.19	7.6	0.10	1.40	1.04	1.80
14	0.36	8.1	<0.015	1.3	0.30	2.2	0.08	0.40	0.54	0.60
15	1.98	7.7	<0.015	----	----	----	----	----	----	----
16	0.05	0.1	<0.015	24.6	2.59	86.3	0.12	1.02	2.36	3.84
17	0.05	0.4	<0.015	9.9	3.20	39.8	0.13	0.78	1.18	2.58
18	0.64	7.7	<0.015	----	----	----	----	----	----	----
19	0.40	3.4	<0.015	----	----	----	----	----	----	----
20	2.35	4.8	<0.015	----	----	----	----	----	----	----
21	0.05	24.2	<0.015	4.3	0.91	10.5	0.08	0.38	1.14	1.16
22	3.79	1.2	<0.015	----	----	----	----	----	----	----

(7) Hot water solution

(8) $NaHCO_3$ extraction

(9) DTPA/TEA extraction

Table 10. Chemical laboratory data (continued).

Sample Number	Trace Metal Analyses (5) (ppm)							
	Mn	Zn	Fe	Cd	Ni	Pb	Cu	Mo (10)
1	17.6	3.3	1.2	<0.2	2.2	<0.4	0.6	0.51
2	3.0	0.9	1.6	<0.2	1.3	0.7	0.3	0.51
3	13.8	25.6	1.1	<0.2	1.3	<0.4	1.6	0.17
4	5.6	1.5	1.7	<0.2	1.0	<0.4	1.4	0.09
5	1.2	1.4	1.4	<0.2	1.0	<0.4	0.1	0.14
6	2.3	1.0	2.3	<0.2	0.6	<0.4	0.1	0.21
7	5.8	2.6	1.4	<0.2	0.6	1.6	0.1	0.43
8	4.3	1.3	1.3	<0.2	1.1	<0.4	0.1	0.11
9	3.8	1.5	0.9	<0.2	0.4	<0.4	0.1	0.35
10	8.9	1.9	1.3	<0.2	0.2	<0.4	0.1	0.20
11	4.4	1.8	1.0	<0.2	0.2	<0.4	0.1	0.17
12	5.0	1.6	2.4	<0.2	0.2	1.0	0.9	0.07
13	10.6	1.0	1.0	<0.2	0.2	<0.4	0.6	0.26
14	8.0	3.4	2.0	<0.2	1.6	1.5	1.4	0.06
15	38.6	3.1	0.7	<0.2	9.9	<0.4	4.5	0.66
16	70.4	4.0	1.2	<0.2	1.9	0.6	3.1	0.43
17	36.6	5.4	1.0	<0.2	1.4	<0.4	9.7	0.28
18	4.7	5.6	4.0	<0.2	2.2	<0.4	1.0	0.19
19	5.4	5.6	0.8	<0.2	1.8	<0.4	5.4	0.13
20	12.0	8.7	1.7	<0.2	4.6	1.0	1.4	0.31
21	29.8	2.6	1.1	<0.2	0.8	<0.4	0.6	0.60
22	9.6	4.8	1.6	<0.2	1.4	<0.4	0.1	0.31

(5) 1 N NH_4OAc extraction

(10) Tamm's Reagent

APPENDIX III

VEGETATION ANALYSIS DATA

Table 11. Vegetation analysis data for the Jenny pot-culture method.

Sample Number	Shoot Yield (1) (g/pot)	Macronutrient Content (%)					Trace Element Concentration (ppm)							
		N	P	K	Ca	Mg	Mn	Zn	Fe	Mo	Cd	Ni	Pb	Cu
1	0.092	1.00	0.13	0.95	0.201	0.128	106.0	15.8	132	--	--	--	--	--
2	0.298	3.63	0.33	3.03	0.185	0.229	57.5	44.8	72	0.21	0.21	1.98	0.58	13.0
3	0.198	3.23	0.11	2.18	0.160	0.116	46.0	46.0	80	0.23	0.23	2.55	0.67	10.2
4	0.120	1.98	0.07	1.14	0.328	0.234	129.0	16.8	86	--	--	--	--	--
5	0.602	1.19	0.25	1.74	0.187	0.188	13.6	17.0	44	0.57	0.18	0.76	0.87	10.1
6	0.432	2.68	0.15	2.39	0.220	0.160	61.0	22.2	57	0.28	0.15	0.98	1.00	9.8
7	0.411	1.83	0.13	2.53	0.204	0.161	26.5	31.3	94	0.45	0.19	0.82	0.90	9.5
8	0.648	1.83	0.19	2.54	0.267	0.189	41.8	18.9	63	0.47	0.16	0.39	0.36	9.5
9	0.119	0.86	0.08	0.88	0.079	0.280	45.1	7.8	65	--	--	--	--	--
10	0.942	1.89	0.21	2.83	0.235	0.185	33.0	34.7	67	0.27	0.15	1.05	0.37	9.8
11	0.175	2.56	0.09	1.43	0.300	0.220	73.2	25.2	80	0.55	0.13	1.26	0.48	9.2
12	1.731	2.46	0.31	3.20	0.404	0.204	28.0	41.0	96	0.92	0.14	0.28	0.77	13.6
13	0.256	2.45	0.16	2.33	0.312	0.174	58.7	24.7	58	0.54	0.18	0.86	0.64	13.7
14	0.742	1.76	0.13	2.47	0.366	0.143	37.9	21.1	65	0.51	0.14	0.84	0.52	14.2
15	0.135	1.62	0.06	1.24	0.182	0.197	70.9	18.9	126	0.39	0.20	7.86	0.91	10.1
16	0.092	1.82	0.08	1.13	0.199	0.268	167.6	24.8	165	--	--	--	--	--
17	0.079	3.49	0.03	0.56	0.142	0.184	47.8	32.9	250	--	--	--	--	--
18	0.028	--	--	--	--	--	--	--	--	--	--	--	--	--
19	0.264	1.21	0.24	1.47	0.098	0.267	29.4	28.6	39	0.51	0.22	0.99	0.69	13.3
20	0.00	--	--	--	--	--	--	--	--	--	--	--	--	--
21	0.108	1.29	0.04	1.25	0.237	0.258	119.5	20.4	96	--	--	--	--	--
22	0.289	2.61	0.10	2.66	0.160	0.316	63.4	39.9	172	--	--	--	--	--

(1) Means of 10 replications

Table 12. Vegetation analysis data for the Neubauer Seedling method.

Sample Number	Shoot Yield (1) (g/pot)	Macronutrient Content (%)						Trace Element Concentration (ppm)							
		N	P	K	Ca	Mg	Mn	Zn	Fe	Mo	Cd	Ni	Pb	Cu
1	0.283	1.00	0.16	1.73	0.310	0.180	67.0	21.9	63	0.40	0.05	1.09	1.52	5.3
2	0.326	1.36	0.26	2.50	0.143	0.253	37.9	22.8	88	1.02	0.08	0.79	0.98	6.4
3	0.305	1.16	0.16	1.73	0.299	0.217	83.6	14.7	67	1.15	0.06	0.65	0.74	4.0
4	0.264	1.14	0.18	1.38	0.352	0.293	74.5	13.7	69	1.39	0.09	0.59	0.90	4.1
5	0.326	1.17	0.25	1.58	0.308	0.275	49.0	10.1	93	0.48	0.05	0.84	0.90	5.2
6	0.436	1.15	0.18	1.55	0.342	0.178	70.0	12.0	52	3.41	0.03	0.37	0.50	3.8
7	0.338	1.09	0.17	2.02	0.233	0.209	41.2	13.5	69	1.04	0.05	0.71	0.71	3.5
8	0.407	1.15	0.17	2.13	0.293	0.171	93.1	16.1	59	2.90	0.09	0.85	0.91	5.1
9	0.318	1.07	0.16	1.86	0.112	0.298	33.9	17.9	65	1.79	0.09	0.46	1.03	3.7
10	0.461	1.36	0.17	2.09	0.350	0.212	251.0	17.8	101	3.61	0.04	0.33	0.91	3.3
11	0.380	0.97	0.14	1.61	0.318	0.217	54.1	14.0	81	1.88	0.08	0.74	1.16	6.6
12	0.462	1.26	0.34	2.98	0.360	0.284	62.6	22.7	99	1.51	0.06	0.47	0.65	5.0
13	0.341	1.12	0.18	1.34	0.376	0.319	54.7	17.3	49	1.06	0.03	0.34	0.88	5.2
14	0.365	1.30	0.19	1.88	0.479	0.155	71.3	27.7	60	0.76	0.04	0.84	0.92	5.0
15	0.268	1.00	0.17	1.75	0.205	0.223	47.2	20.5	98	0.53	0.11	4.13	1.07	5.2
16	0.396	1.32	0.16	2.09	0.236	0.316	155.6	23.0	76	0.70	0.06	0.87	0.73	6.1
17	0.429	1.31	0.15	1.88	0.148	0.227	25.0	22.1	71	1.03	0.06	0.70	0.71	4.0
18	0.305	2.66	0.17	1.68	0.115	0.598	34.9	33.6	70	0.93	0.09	1.03	0.63	9.5
19	0.250	1.25	0.25	2.16	0.185	0.660	52.3	37.5	67	1.10	0.09	0.95	0.43	8.2
20	0.027	3.35	--	--	--	--	--	--	--	--	--	--	--	--
21	0.297	1.06	0.16	1.47	0.328	0.328	66.3	20.5	57	0.59	0.11	0.99	1.19	7.5
22	0.373	1.26	0.14	1.87	0.200	0.372	58.4	21.6	67	0.79	0.08	0.86	0.82	6.1

(1) Means of 10 replications

APPENDIX IV

ANALYSIS OF VARIANCE TABLES

Table 13. Analysis of variance for shoot yield of western wheatgrass.

Source	df	Mean Square
blocks	9	
potting method	1	0.0501**
growth medium	20	0.9675**
potting method X growth medium	20	0.6567**
Error	369	0.0032

** $p<0.01$

Table 14. Analysis of variance for plant concentrations of nitrogen.

Source	df	Mean Square
potting method	1	8.00**
growth medium	19	0.369
Error	19	0.290

**$p<0.01$

Table 15. Analysis of variance for plant concentrations of phosphorus.

Source	df	Mean Square
potting method	1	0.021**
growth medium	19	0.008*
Error	19	0.002

* $p<0.05$
** $p<0.01$

Table 16. Analysis of variance for plant concentrations of potassium.

Source	df	Mean Square
potting method	1	0.003
growth medium	19	0.551
Error	19	0.245

Table 17. Analysis of variance for plant concetrations of calcium.

Source	df	Mean Square
potting method	1	0.030**
growth medium	19	0.014**
Error	19	0.001

** $p<0.01$

Table 18. Analysis of variance for plant concentrations of magnesium.

Source	df	Mean Square
potting method	1	0.041**
growth medium	19	0.011
Error	19	0.003

** $p<0.01$

Table 19. Analysis of variance for plant concentrations of manganese.

Source	df	Mean square
potting method	1	935.1
growth medium	19	2399.3
Error	19	1673.2

Table 20. Analysis of variance for plant concentrations of zinc.

Source	df	Mean Square
potting method	1	528.5**
growth medium	19	85.4
Error	19	63.5

$^{**}p<0.01$

Table 21. Analysis of variance for plant concentrations of iron.

Source	df	Mean Square
potting method	1	5198.4
growth medium	19	1493.7
Error	19	1407.7

Table 22. Analysis of variance for plant concentrations of molybdenum.

Source	df	Mean Square
potting method	1	8.14**
growth medium	12	0.532
Error	12	0.635

** $p<0.01$

Table 23. Analysis of variance for plant concentrations of cadmium.

Source	df	Mean Square
potting method	1	0.080**
growth medium	12	0.002
Error	12	0.001

** $p<0.01$

Table 24. Analysis of variance for plant concentrations of nickel.

Source	df	Mean Square
potting method	1	2.85*
growth medium	12	4.27*
Error	12	0.622

* $p<0.05$

Table 25. Analysis of variance for plant concentrations of lead.

Source	df	Mean square
potting method	1	0.15
growth medium	12	0.025
Error	12	0.063

Table 26. Analysis of variance for plant concentrations of copper.

Source	df	Mean Square
potting method	1	243.10¤¤
growth medium	12	3.96
Error	12	1.71

¤¤ $p<0.01$

Byron, T. M.
A Comparison of greenhouse methods as diagnostic tools..

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