RECLAMATION APPROACHES AND TECHNIQUES FOR SODIC, LOW pH SPOIL IN ABANDONED BENTONITE MINES[1]

by

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Abstract. The chemical and physical parameters of overburden (spoil) and pit bottom materials in abandoned bentonite mined lands in Crook County, Wyoming, were characterized by geologic unit in order to classify materials for defining site specific treatments during reclamation. Key characterization parameters were found to be saturation percentage, exchangeable sodium percentage, electrical conductivity and pH. These parameters were used to develop proposals for amendment types and rates, physical manipulations of spoil and pit bottom materials, and revegetation species as part of the reclamation plan.

Additional key words: exchangeable sodium percentage, abandoned mined lands, acidic material, clay.

Scope and Purpose of the Project

Harza Engineering Company and major subcontractors are working under contract with the Wyoming Department of Environmental Quality--Abandoned Mine Land program to, in part, perform the following functions relating to abandoned bentonite mines in northeastern Wyoming:

1) Perform an investigation of existing site conditions;

2) develop and recommend reclamation procedure and techniques based upon site investigations and existing research applicable to bentonite mine reclamation;

3) prepare plans and specifications for construction/reclamation work; and

4) supervise and manage construction/reclamation activities.

The investigation and design phase have been completed and limited construction activities have been accomplished.

The purpose of the investigative phase was to perform field investigations only to the extent necessary to make informed recommendations as to appropriate reclamation procedures and techniques.

Project Area Description

The project area is located along the northwestern and northeastern flanks of the Bearlodge Mountains (Wyoming Black Hills) in Crook County, Wyoming. The disturbance area is located within a shrub-grassland vegetative type with Ponderosa pine-scrub oak often found on lands immediately adjacent to disturbances. Average rainfall is 15.4 inches/annually with the bulk of this falling between March 1 and June 30.

Approximately 1,650 acres of land is to be reclaimed as part of this project (AML 11A). Bentonite was mined along the outcrop of mineral bearing formations and consequently mined pits are distributed throughout an approximate 450 square mile area.

Properties of Bentonite

Bentonite is a montmorillinitic clay formed by the alteration of volcanic ash. Bentonite was deposited in a marine environment during Cretaceous time and is found in bed deposits. In the northern Black Hills district, beds range from one inch to over seven feet in thickness. Several beds have been mined commercially in the past, Knechtel and Patterson (1962).

As a montmorillinitic clay, bentonite has a 2:1 matrix consisting of two ionic layers of Si^{+4}, tetrahedrally coordinated with ions of O^{-2} and separated by a layer of Al^{+3} and other metallic ions. Water is readily absorbed between the 2:1 matrix sheets of montmorillinite which results in swelling of the bentonite. High quality bentonite for use in drilling muds typically has very high saturation percentages (ranging as high a 300% or more by volume), high exchangeable Na^{+1} with correspondingly low exchangeable Ca^{+2} and Mg^{+2}.

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Knechtel and Patterson (1955) found bentonite with 36% and 89% of the total cation exchange capacity saturated by Na^+ in the principal commercial bentonite bed of the northern Black Hills. Knechtel and Patterson (1962), Rubey (1929) and Grim (1953) have dealt extensively with the description and properties of montmorillinitic clays. When water contacts bentonite, the clay swells to form an almost impervious seal to water infiltration. Darcy permeabilities of less than 10^{-7} cm/sec are typical of inplace clays. (Personal communication, R. K. Brown, 1986).

Unfortunately, those factors which constitute high quality bentonite, inhibit plant growth principally by limiting water availability to plants.

Geologic Setting

The geologic materials upon which this investigation was conducted are included in three upper Cretaceous formations: the Newcastle Sandstone; the Mowry shale; and the Belle Fourche shale. The stratigraphic relationships of these formations are illustrated in Figure I, taken from Knechtel and Patterson, (1955).

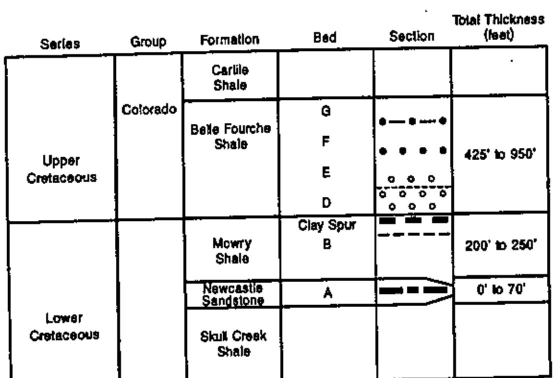

Figure I Typical Stratigraphic Column

As the stratigraphic column illustrates, numerous bentonite beds occur within these formations. However, within the geographic area of this investigation only four of these beds are of historic commercial value. Only two of these beds have been mined extensively.

The Newcastle sandstone formation contains the lowest commercial bed stratigraphically. The "A" bed occurs at the approximate midpoint of the formation. Mining within this bed accounts for approximately 11% of the area studied in this investigation. The formation as a whole consists of interbedded sandstone and sandy shales with lesser amounts of siltstone, carbonaceous shale, coal and bentonite. The materials found under the bentonite bed, which form the pit floor in mined out areas, are similar to those which overlie the bed and differ primarily only in the amount of hard platey carbonaceous shales present.

The Mowry shale formation, which lies immediately above the Newcastle Sandstone formation, contains numerous beds of bentonite including the "B" bed and "C", or Clay Spur bed. Of these, only the Clay Spur bed is of economic importance within the study area. The Clay Spur bed, which is by far the most historically important of the bentonite beds which have been mined in the study area, accounts for more than 87% of the area studied. This bed forms the stratigraphic contact between the overlying Belle Fourche shale and the underlying Mowry shale. The Mowry shale, which is exposed over relatively large areas of the study area, forms the pit bottom of all Clay Spur bed pits which have not been backfilled. It consists of dark gray siliceous shales which weather to hard, brittle, silver gray chips (Robinson, 1964; Knechtel & Patterson, 1962).

The Belle Fourche shale formation immediately overlies the Mowry shale formation and, like that formation, contains numerous bentonite beds. Of these beds, only two, the "E" and "F" beds, have seen any historical commercial development. Together, these two beds account for 2% of the area studied in this investigation. Because of its location above the Clay Spur bed, the lower member of the Belle Fourche shale constitutes the majority of the mine spoil within the study area. Within 40 to 50 feet above the Clay Spur bed, this material is composed of relatively soft gray-black shales containing many ovoid manganiferous siderite concretions. This shale weathers almost black in contrast to the Mowry shale (Robinson et al, 1964; Knechtel & Patterson, 1962). The "E" bed lies at or near the top of this siderite zone. As a result, the pit bottom of this bed contains abundant siderite concretions while the mine spoil derived from the overlying material is relatively free of this material. The "F" bed lies at the base of the upper member of the formation which constitutes all of the spoil material removed from mine sites on the bed. This material is almost entirely composed of soft dark-gray shale containing locally abundant calcarious concretions (Knechtel & Patterson, 1962).

Initial Field Observations

Preliminary site visits to all sites were conducted. During this time, observations were made concerning the physical characteristics of the inplace overburden, minespoil and pit bottom materials at each site. Additionally, the type and condition of the vegetative cover, both within disturbance areas and in adjacent undisturbed range, were also noted. Preliminary conclusions were then drawn from these observations as to the potential of the geologic materials in each of the three formations for use as plant growth media. One observation was that, of the three formations, the materials found in the Newcastle formation appeared best for direct use as plant growth media. This conclusion was based upon the natural revegetation success which was observed within disturbance areas in this formation, and field textural comparisons. Generally, these materials do not crust severely, and are either a silty clay or clay loam.

The material found in the lower member of the Belle Fourche shale formation material was felt to be the least desirable for use as a plant growth media. This conclusion was drawn from the almost total lack of natural revegetation within disturbance areas and the low productivity and plant density on adjacent undisturbed range. These materials were observed to have high clay contents, to crust severely and to be relatively impermeable to surface water infiltration.

Table I.--Overburden Analytical Methods

Parameter	Method
pH, saturated paste	(1) Method 21a
Conductivity, saturation paste extract (EC)	(1) Method 3a, 4b
Saturation percentage	(1) Method 2, 3a
Sodium Adsorbtion Ratio (SAR) (includes soluble Ca, Mg, Na)	(1) Method 20b 2, 3a
Particle size (% sand, silt, clay)	(3) Method 43-5
Particle size (% very fine sand)	140/270 mesh
Particle size (pipette method)	(3) Method 43-4
Texture	(3)
Acid base potential	(2) pp 43-51
Cation Exchange Capacity (CEC)	(3) Method 57-2
Exchangeable cations	(3) Method 59-4
Exchangeable Sodium Percentage (ESP)	(1) Method 20a
Lime, as $CaCO_3$	(1) Method 23c

(1) U.S. Salinity Laboratory. 1954. Diagnosis and improvement of saline and alkali soils. U.S.D.A. Agriculture Handbook No.60, Washington, D.C.
(2) Smith, R.M., W.E. Grube, T. Arkle, A. Sobek. Mine spoil potentials for soil and water quality. Envir. Prot. Agency - 670/2-74-070 Cincinnati, Ohio
(3) Black, C.A. 1965. Methods of soil analysis, part 1. Amer. Soc. of Agronomy

Mowry shale formation pit bottom materials were found to support vegetation in moderate but significant amounts in those areas where weathered shale material had been deposited by water or wind. Adjacent, undisturbed soils formed from weathered Mowry shale supported significant stands of grasses, scrub oak and ponderosa pine. However, plant growth was very limited on unweathered pit bottoms. Therefore, it was concluded that Mowry shale formation would be an acceptable plant growth medium when weathered or mechanically broken.

Preliminary observations and conclusions concerning the revegetation potential of Mowry and Belle Fourche shales were substantiated, in part, by productivity information found in the Crook County, Wyoming Soil Survey (Elwonger, 1983). The Grummit soil formed from weathered Mowry shale showed significantly higher productivity and greater permeabilities than Louvier soil formed from Belle Fourche shale. Available waterholding capacity was also significantly less for Grummit soil than Louvier soil.

Geologic Sampling Program

Following the initial field observations, a sampling and testing program was developed to aid in the further characterization of the geologic materials which were available for use as potential plant growth media. The goals of this program were:

1) To characterize and quantify the physical and chemical properties of the available mine spoil, in-place overburden and pit floor materials;

2) To determine the suitability of each material for use as plant growth media either directly or through the use of chemical and organic amendments and physical manipulations; and

3) To determine, to the extent possible, the location and areal and volumetric extent of all suitable or potentially suitable material for use as a plant growth media.

The sampling approach which was developed was based upon assumptions that:

a) Similar materials within mine pits would be treated as sampling units, i.e. undisturbed overburden, spoil and pit bottom. It was assumed that each of these materials would have a fairly uniform range of chemical and physical characteristics for each of the mine sites in which it was found. As an example, it was assumed that all pit bottom

Table II.--Comparison Of Key Physical And Chemical Parameters For Mowry And Belle Fourche Shale

	(Mowry Shale)				(Belle Fourche Shale)		
	n=24 x	Sx	Range	n=80	x	Sx	Range
EC, mmhos/cm3	8.24	4.01	1.12- 13.60		7.26	3.03	.79- 18.15
SAR (ratio)	25.42	11.70	1.37- 47.80		17.07	8.68	1.05- 34.60
ESP, (ratio)	8.24	4.01	5.41- 37.60		13.29	8.20	1.44- 47.20
pH, units	4.70	0.93	3.90- 7.30		6.20	1.23	3.70- 8.50
Saturation Percentage	69.75	20.48	45.80-133.00		103.65	59.29	43.00-370.00

materials for Clay Spur bed mine sites would be Mowry shale and would have relatively similar physical and chemical properties.

b) Taking a large number of samples within each sampling unit over a localized area would yield a range of test results which would fully characterize that area and, which could be used to develop prototype profiles of the sampling units that could be applied to other areas with only spot sampling needed to verify results.

Nine mine sites within the study area were selected for intensive sampling. Of these sites, six were selected as being representative of the Clay Spur bed mine sites and three were selected as being representative of the Newcastle Sandstone ("A" bed) mine sites.

Sampling Methodology

A reconnaissance team visited each of the sites selected for sampling and located the sample points. The number and location of the sample points were selected so as to be representative of the materials within each of the respective units in each of the mine sites. Total sampling depths were also determined at this time based upon anticipated depths of excavation during reclamation.

Sampling was performed using a truck mounted auger drill. At each sampling location samples were obtained for each apparent lithologic profile as determined by changes in color, texture and composition. The physical characteristics of each sample were noted and logged at the time of sampling. Characteristics noted were field texture, calcium carbonate ($CaCO_3$) content based upon reaction activity with hydrochloric acid, Munsel color rating, presence of moisture, relative hardness and material composition (sandstone, shale, etc.). Bagged sample were kept for each logged profile.

After samples were taken, profile logs were compared. Samples were selected for laboratory testing in order to represent the types of material and lithologic profiles found.

After all of the test results from the initial sampling and testing program were received, prototype physical and chemical profiles were developed for each sampling unit. Fifteen additional sampling sites were then selected throughout the remaining unsampled portion of the project area. These sample sites were selected so as to be representative of the unsampled area. Samples were taken and logged as previously described with bagged samples being kept for each logged profile. Sample logs were compared and representative samples were chosen for laboratory testing.

The results of these laboratory analyses were compared with the prototype profiles developed as a result of the initial intensive sampling and testing program. Similarities and differences between the prototype profiles and the additional laboratory results were noted.

Discussion of Physical and Chemical Characteristics of Mowry and Belle Fourche Shales

All samples were analyzed for the listed parameters, and using the procedures described in Table I. Comparison of the data allowed several generalizations to be made concerning the suitability of Mowry and Belle Fourche shales as plant growth medium.

Mowry Shale

Table II shows a summary of analytical results considered most important to plant growth for both Mowry and Belle Fourche shales. Mowry shale is generally acid in reaction, exhibiting consistently negative acid base potential especially below one foot in depth. Mowry shale is highly variable in respect to salinity and exchangeable sodium percentage but generally contains appreciable amounts of exchangeable sodium and soluble salts.

Particle size analysis consistently placed Mowry shale in the clay textural class (U.S.D.A. Handbook #18) with total clay content at approximately the same levels as those found in Belle Fourche shale. Saturation percentages were much less in Mowry shale, however, indicating that 1:1 matrix clays make up a much larger percentage of clay size particles in Mowry shale than in Belle Fourche shale.

Belle Fourche Shale

Belle Fourche shale exhibited more variability in acid reaction than Mowry shale. The mean pH for Belle Fourche shale was 6.2 as opposed to a mean value of 4.75 for Mowry shale. Acid base potential showed much variability with a range of from -17 to +96 $CaCO^3$/1,000 tons dry material.

Belle Fourche shale showed less variability with respect to sodium adsorbtion ratios (SAR) values than Mowry shale, but more variability for exchangeable sodium percentage (ESP) value with means for both parameters higher for Mowry shale.

Analytical tests consistently placed Belle Fourche shale in the clay textural class. Saturation percentage test results showed a much larger range of values for Belle Fourche shale than Mowry shale, with the mean value of Belle Fourche shale considerably less than for Mowry shale.

Selective use of the Mowry shale where possible in the reconstruction process was recommended because of its greater permeability to water due to its aggregation, apparent lower swelling clay content, and its potential for greater vegetative productivity.

Bentonite cleanings (low grade bentonite) and the zone of Belle Fourche shale material extending from the Clay Spur bed to the "D" bed were recommended for burial whenever possible. This material was also recommended for burial because of its relatively high swelling clay content and high ESP values.

Limitations of Analytical Procedures

Analytical procedures commonly used for characterization of agronomic and mine spoils where used in this investigation. It became apparent after review of analytical data that these tests have limitations when used to characterize fine textured, acid, and sodic geologic materials.

Observation of both native soils which developed from undisturbed Mowry shale and pit floor material exposed to weathering within abandoned mines indicates that Mowry shale weathers to a siliceous platey material which has significantly higher permeabilities than Belle Fourche shale. Observations concerning weathering characterizations are supported by Knechtel (1955) and Robinson (1956). Even though permeability estimates for the Grummit soil (weathered from Mowry shale) were at least twice that of the Louvier soil (weathered from Belle Fourche shale), laboratory data indicate that the Mowry shale would be expected to have lower permeability by virtue of its fine texture and high exchangeable sodium. The authors believe that this data does not accurately represent actual weathering conditions. The procedure used for preparation of the sample for determining particle size distribution includes both the crushing of material to a fine powder and chemical disaggregation prior to its analysis. Therefore, standard procedures probably significantly overestimate the effect of clay and silt particles on plant growth potential for the Mowry shale.

Standard laboratory technique may also result in the overestimation of the amounts of cations available to plants in the growth medium due to increased surface area exposed to reagents. Lime as percent $CaCO_3$ is a case in point. It is known that $CaCO_3$ is soluble at pH's below 7 and will not persist in soils below that pH (Tisdale and Nelson, 1975). However, laboratory analysis indicated detectable amounts of $CaCO_3$ in materials with pH's as low as 3.7.

SAR-ESP relationships may vary in fine textured, acid sodic conditions from those in saline-sodic soils.

The line which best fit available SAR and ESP data for Belle Fourche and Mowry shale was determined by the least squares method. Linear equations were calculated from 80 Belle Fourche and 24 Mowry shale samples. The data had reasonably good correlation with coefficients of determination of r^2=0.743 and r^2=0.724 respectively. The graphic relationships and equations for Belle Fourche and Mowry shales compared to the same relationship presented by the U.S. Soil Salinity Laboratory staff in the Agriculture Handbook #60 (U.S.D.A., 1954) are presented on Figures II and III respectively.

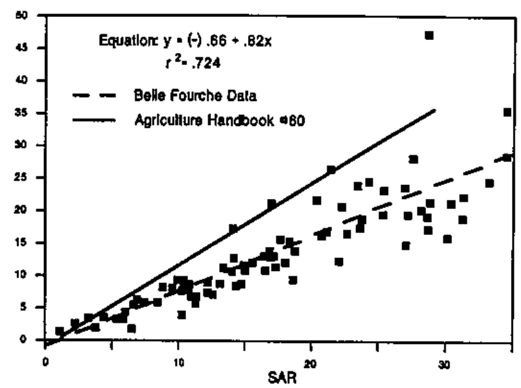

Figure II Belle Fourche Shale ESP - SAR Relationship

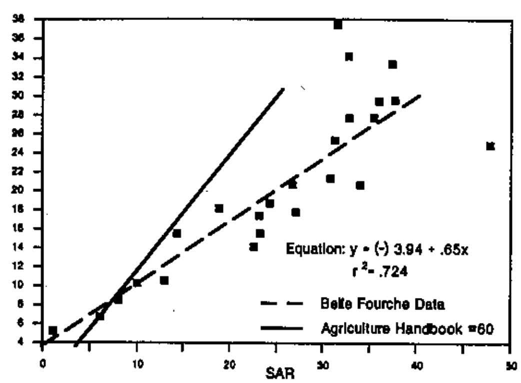

Figure III Mowry Shale ESP - SAR Relationship

The coefficient of determination (r^2) for the data points described by the paired coordinates of SAR and ESP analytical values were calculated for both Mowry and Belle Fourche shale. Calculated correlation coefficients were compared with the correlation coefficient found in the Agriculture Handbook #60 using Fisher's transformation.

No significant differences were found between calculated correlation coefficients for Mowry and Belle Fourche shale and that for the line presented in the Handbook #60. Unfortunately, the data used to calculate the Handbook #60 equation showing the SAR-ESP relationship was unavailable for review and analysis. Therefore, no statement can be made concerning statistical differences in the slope of the line. However, visual inspection of the graphic representations of both line indicates substantially different slopes between the Handbook #60 line and both Belle Fourche and Mowry shale. Use of the Agriculture Handbook #60 relationship to estimate ESP values from SAR values yields higher ESP values than use of equations developed from site specific data. Shay and Parady (1983) found that using SAR values to predict ESP consistently overpredicted ESP in coal overburden in southwest Wyoming.

Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) are calculations developed primarily for application in alkaline soils. The application of these criteria to acidic materials must be made cautiously since cation exchange reactions in acidic materials differ from that in alkaline materials. Aluminum, hydrogen and iron cations are more likely to dominate the soil exchange sites in low pH environments than sodium, calcium and magnesium. The assumption that acid bentonite spoils have significant amounts of metal and hydrogen ions attached to the soil colloid is partially substantiated by two samples of geologic materials analyzed for base saturation percentage. Analysis showed a 57% and 66% base saturation for Mowry and Belle Fourche shale respectively. Base saturation percentages considerably higher would normally be expected for sodic soils. (Buckman and Brady, 1969). Thus, a high ESP in acidic materials does not have the same implication to plant growth as it would in an alkaline environment. Unfortunately, little available research is available which describes soil chemical properties and reactions in an acid and sodic environment.

This study indicates that laboratory results should be viewed as indicators and applied with a knowledge of the limitations of analytical tests and the interactive processes within the material. Knowledge of the physical characteristics of the material under field conditions is also vital to interpreting the laboratory data.

Treatments and Amendments

The use of various treatments and amendments is proposed as a means of addressing specific physical and chemical properties of the spoil noted previously within the various geologic units to be used as plant growth medium. Since geologic units have been shown to have significantly different physical and chemical properties, methods for treating each geologic material differ. Table III summarizes the various treatments recommended and their purposes. The justification for each general treatment is listed below. All amendments will be incorporated to a minimum depth of 12 inches.

Woodchips

The incorporation of heavy applications of woodchips to the reclamation surface will increase water infiltration and increase the water holding capacity of the amended geologic material. Research performed by Schuman and Sedbrook (1984), Smith (1984) and Voorhees (1984) all found above ground biomass to increase with incorporation of woodchips. Woodchip addition physically modifies plant growth medium structure by allowing water penetration in and around the woodchips themselves. The infiltration of water has resulted in the leaching of soluble salts from the surface horizon of the reclaimed spoil (Smith, et al, 1985). Increased organic matter also increases soil cation exchange capacity. Based upon existing research a rate of from 18.2 to 36.4 dry tons woodchips per acre was recommended, depending on the geologic material being treated and water content of woodchips.

Woodchips are quite variable in moisture content with corresponding weight differences. Therefore, application rates are best presented as an application depth. A one inch depth of woodchips applied evenly over the reclamation surface will correspond to an application rate of 18.2 dry tons woodchips/acre based upon actual bulk density determinations from a woodchip pile near Hulett, Wyoming.

Calcium Amendments

As discussed previously, most geologic material available as a plant growth medium has relatively high exchangeable sodium percentages and is fine textured containing significant amounts of montmorillinitic clay, which results in a completely dispersed condition. Addition of a soluble calcium source will result in the replacement of exchangeable sodium on the soil complex with calcium when displaced sodium is leached from the soil. Reduction of exchangeable sodium in the soil will result in improved soil structure and permeability. The effects and treatment of sodic soils are dealt with extensively in the Agriculture Handbook #60 (1954). The addition of calcium amendments to geologic material on the surface of the recontoured pit is considered essential to successful revegetation. A goal of reduction of ESP to 10 or less was established as a compromise between cost and the fostering of soil conditions conducive to plant growth.

Various commercially available amendments were considered for use. Gypsum ($CaSO_4$ $2H_2O$) and limestone ($CaCO_3$) were selected as those recommended for use primarily because of their local availability and comparatively low cost. Gypsum was recommended for use on materials with a pH of 6 or greater. Limestone was recommended for materials with a pH of less than 6. Both gypsum and limestone are relatively insoluble in the soil environment (U.S.D.A., 1954). However, limestone solubilities increase substantially in low pH environments (Tisdale & Nelson, 1975). Since the use of woodchips as an amendment will effectively increase infiltration over the first years after treatment, it was felt that slow solubility of both gypsum and limestone is acceptable and even desirable from a long term viewpoint of sodium replacement and leaching.

As a secondary goal of the amendment program, limestone will modify pH values in materials with a pH of less than 6, resulting in a more favorable soil environment for plant establishment and productivity.

Table III.--Summary of Reclamation Techniques

Treatment	Purpose
Selective Use and Placement of Geologic Materials	Selection of geologic material with the best physical and chemical characteristics
Physical Treatments	
Deep Ripping (3 feet at 5 foot intervals)	Deep water percolation
Shallow Ripping (20 inches at 18 inch intervals)	Water infiltration, Amendment incorporation
Discing (12 inches deep)	Amendment incorporation, Seedbed preparation
Surface manipulations (pits, dozer basins, etc.)	Increase water infiltration
Amendments	
Woodchips (1 inch to 2 inch application)	Water infiltration, increased organic matter
Calcium source	
Gypsum	Reduction in ESP
Limestone	Reduction in ESP, Raise pH
Fertilizer	
Nitrogen	Plant nutrients
Phosphorus	Prevention of C:N imbalance
Microclimatic Alteration	
Topsoil	
Physical Treatments	Improve seedbed conditions
Amendments	
Mulch (hay or straw)	

Fertilizer

Nitrogen. Greenhouse studies performed by Dollhopf and Bauman (1981) found significantly increased plant yields for wheat grown on bentonite spoils and fertilized with variable amounts of nigrogen-phosphorus fertilizer up to a rate of 90 lbs. nitrogen per acre. Smith (1984) found that supplemental N-fertilization was required to optimize vegetation establishment on woodchip amended spoils. Based upon available research and personal communications (Schuman, 1985), a rate of 10 pounds available nitrogen per dry ton woodchips was selected as the optimum rate of nitrogen application. It was recommended that nitrogen be applied in the form of urea to minimize losses due to volatization.

Phosphorus. Phosphorus has been found deficient on mine spoils in the western U.S. (Power, 1978). It is known that phosphorus is limited in availability to plants at pH's below 5.5 and above 7 and that phosphorus is immobilized in fine textured soils more rapidly than in coarse textured soils. Lacking specific research evaluating variable rates of phosphorus fertilizer on bentonite spoils, a rate of 90 pounds per acre available phosphorus was recommended.

Physical Treatments

Physical treatments recommended included deep ripping of Mowry shale to a depth of three feet, shallow ripping of all geologic materials to 20 inches, discing of geologic material to a minimum depth of 12 inches and various surface manipulations such as pitting, dozer basins, or terracing in selected cases. Physical treatments were designed to increase infiltration, incorporate amendments and promote surface water retention.

The use of borrowed topsoil as a top dressing was recommended when available near reclamation sites (within 1/2 mile). The use of topsoil is expected to be particularly valuable in providing seedbed conditions conducive to seedling establishment during the first years.

Seeding and Mulching

Diverse seed mixes containing cool and warm season grasses, and shrubs were recommended for use on reclaimed lands. A total of six seed mixes will be used depending upon the type of geologic material being seeded and whether the seeded location is an upland or drainage channel site. It was recommended that all reclaimed areas be mulched with native hay or straw at a rate of two tons/acre and hay or straw crimped into the surface. Mulch will further improve microclimatic conditions in the seedbed by reducing surface temperatures and reducing evaporation from the reclaimed surface.

Costs of Treatments and Amendments

Table IV illustrates the range of costs for various geologic material based upon actual unit costs from similar reclamation efforts or engineering estimates. Only ranges can be supplied because of variables such as haul distance, costs of materials, and intensity of the application of the various treatments. The range of values are expected to represent the minimum and maximum costs of reclaiming lands using the treatments discussed. Costs do not include excavation and topsoil application.

Table IV.--Cost Summary for Reclamation Treatments by Formation(1)

Formation	Cost Range per Acre(2) in Dollars
Newcastle sandstone	1,690 - 2,340
Mowry shale	1,480 - 2,850
Belle Fourche shale	1,740 - 3,390

(1) All costs exclusive of excavation and borrowed topsoil costs

(2) All estimates in 1985 dollars

Conclusions

Geologic formations associated with bentonite mines in northeast Wyoming exhibit distinctly different physical and chemical properties. The characterization of these formations through geologic investigation and observation of outcrops of these same geologic formations in the vicinity of mined lands can provide a powerful tool in the characterization of spoil material available for use in reclamation. Although the identification of geologic formations with respect to potential as a plant growth medium has long been recognized as a useful tool in mined land reclamation, its application to mining situations in deep sedimentary deposits such as coal and uranium is often difficult or impossible because of mining method and cost considerations. Because bentonite is mined only in shallow pits, selective use of suitable geologic material on the reclamation surface is possible and will provide mine operators with additional materials suitable as plant growth medium.

Bentonite mined land reclamation in northeast Wyoming presents the reclamationist with a unique combination of chemical and physical soil problems. Bentonite spoil is generally acid in reaction, has high exchangeable sodium percentages, contains high concentrations of soluble salts and is fine textured. This unique combination of soil characteristics requires reevaluation of standard procedures used for characterization and treatment of sodic soils, including the sodium adsorbtion ratio-exchangeable sodium percentage relationship.

Since bentonite mine reclamation presents a combination of reclamation problems not normally encountered in a typical agronomic setting, the reclamation approach must be multifaceted and address each soil problem area in order to succeed.

The incorporation of woodchips as a physical and organic amendment, use of a calcium amendment to reduce exchangeable sodium and application of various physical manipulations to increase soil permeability is one such approach.

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