EVALUATION OF RECLAIMED ABANDONED BENTONITE MINE LANDS[1]

by

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Abstract: In 1985, the Abandoned Mined Land Division of the Wyoming Department of Environmental Quality began reclamation of 4,148 ha of abandoned bentonite mined lands. Calcium amendments and sawmill wood wastes were applied to the regraded spoils to enhance water infiltration, displacement of Na on the clay spoil, and leaching of the displaced Na and other soluble salts. Revegetation of these lands was generally successful, but after several years small areas (0.1-0.2 ha) began to show signs of vegetation stress or death. The purpose of this research was to determine the cause of vegetation die-back and to prescribe corrective treatment options. A randomized block design was imposed on study areas near Upton, Colony, and Greybull, Wyoming to characterize spoil chemical properties of "good," "moderate," and "dead" vegetation zones, which were subjectively delineated by visual vegetation cover and density differences. Spoil analyses indicated exchangeable-sodium (Na) concentrations were high and the "dead" vegetation zones exhibited exchangeable-sodium-percentages (ESP) above 50%, while surrounding "good" vegetation zones exhibited ESP values <10%. This coupled with low soluble-Na concentrations (<2 cmol/kg) suggests insufficient calcium (Ca) amendments were initially applied to ameliorate the sodic conditions of the spoil. The sampling design used to determine Ca amendment rates, which consisted of a composite of 5 spoil cores taken from each 0.8 ha area, was apparently insufficient to account for the highly heterogenous spoil material that occurred throughout these abandoned bentonite reclamation sites. To revegetate these small degraded sites, additional Ca amendment would be necessary and reseeding would be required. However, we recommend further monitoring of the affected sites to determine if unfavorable conditions continue to degrade the reclaimed landscape before any attempt is made to rehabilitate the affected sites. If the degraded sites are stable, further Remediation efforts are not warranted because small areas of little or no vegetation are common on native landscapes of these areas.

Additional Key Words: revegetation, sodicity, clay

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Introduction

Large-scale bentonite mining in the Northern Great Plains began in the 1940's (Davis 1965), prior to the enactment of legislation requiring reclamation of the mined lands. As a result thousands of hectares of rangeland were disturbed before reclamation laws were passed in the early 1970's in the region. The National Academy of Sciences (1974) reported that in 1973 in Montana, more land was disturbed and abandoned by bentonite mining than by coal mining. Lands disturbed by bentonite mining are the most difficult to reclaim because of the nature of the spoils (high clay, high salinity, and high sodicity) and the arid to semiarid climate of the region (Schuman et al. 1994). Neither natural revegetation or conventional early revegetation attempts resulted in successful plant reestablishment (Dollhopf and Bauman 1981, Sieg et al. 1983) until spoil amendment programs were developed that improved water relations and ameliorated the high clay and sodicity of the spoil (Smith et al. 1985, Dollhopf et al. 1988, Belden et al. 1990, Schuman and Belden 1990, Schuman and Meining 1993, Schuman 1995). Research found that amending bentonite spoil with sawmill wood wastes (sawdust, chips, and bark) would increase spoil permeability and allow leaching of soluble salts and dissolution of gypsum that would enable the exchange of calcium for the high levels of exchangeable Na associated with clay spoil material.

Under Title IV of the Surface Mining Control and Reclamation Act of 1977 (U.S. Congress 1977), and by amendment into the Wyoming Environmental Quality Act of 1973 in 1982, the Abandoned Mine Land Program (AML) of the Wyoming Department of Environmental Quality was formed to address the elimination of hazards to public health and safety and to correct environmental degradation of off-site areas resulting from mining activities abandoned prior to reclamation laws (Richmond 1995). Although this program was directed towards coal mine lands, states that could prove they had adequately addressed all abandoned coal mine lands were allowed to use this program to address non-coal issues.. In 1983, Wyoming was certified to have addressed all public health and safety concerns associated with abandoned coal mine lands and began to develop a program to address the large abandoned bentonite mine land concern in the state. Using recent research, Wyoming developed a prescription for rehabilitating abandoned bentonite mine lands. Amendment of abandoned bentonite mine spoil with sawmill wood wastes, fertilizer, and a Ca amendment were generally considered necessary to revegetate these lands. The Ca amendment levels in the reclamation program were established to reduce the ESP to 10% and sawmill wastes were applied at approximately 60 Mg/ha when spoil clay content exceeded 30%. Calcium amendment application rates were determined utilizing a regraded-spoil sampling procedure that consisted of taking 5 spoil cores, 30 cm deep, on each 0.8 ha plot. One spoil core would be taken from the center of each 1/4 section of the plot and one core would be taken directly in the center of the plot and all five composited to characterize the sodicity of the area. Areas that had an average exchangeable sodium percentage (ESP) of <10% did not receive any Ca amendment. These amendments, along with nitrogen (N) and phosphorus (P) fertilizer, were broadcast on the regraded spoil and incorporated to 30-45 cm. Details of the reclamation prescription used to reclaim abandoned bentonite mine spoils in Wyoming is described by Richmond (1995). From 1985 to 1995, the Wyoming AML Division has revegetated approximately 4200 ha of abandoned bentonite spoil using this technology (Richmond 1995). Several years into this rehabilitation program, small areas (<0.2 ha) of vegetation die-back began to appear in the revegetated landscapes. Concern over potential implications of die-back areas prompted the Wyoming AML Division to investigate the cause of vegetation failure on these small areas within revegetated lands.

Objectives of this research study were to determine the cause of the vegetation die-back areas of the rehabilitated abandoned mine lands, assess the spoil chemical characteristics of various sites representing different phases of die-back ("good," "moderate," and "dead"), and assess the need for remediation techniques.

Methods and Materials

Three areas in Wyoming where abandoned bentonite mine spoil materials had been reclaimed were assessed. These sites included Upton and Colony in northeastern Wyoming and Greybull in northcentral Wyoming.

Upton Sites: Sites were located approximately 7-10 km northwest of Upton in Weston County, Wyoming. Sites were mined in the 1950's and consisted of spoil materials with high soluble salts (>10 dS/m), high clay content (>55%) and ESP (>50%). Spoil material are predominately composed of Mowry and Belle Fourche shales and topography ranged from low hills to broad flats to badlands (Mapel and Pillmore 1964) with elevations from 1250-1450 m (Davis 1965). Average annual precipitation is 36.8 cm with an average frost free growing period of 119 days (NOAA 1995). Spoil amendments included wood waste applications from 22-67 Mg/ha depending on clay content of the spoil, with Ca amendments (gypsum or calcium carbonate) applied to reduce the ESP to 10%. Calcium carbonate was used as Ca amendment when pH of the spoil was acidic; which resulted from the oxidation of jarosite. Nitrogen and P fertilizer were applied at the rate of 5 kg N/Mg of wood wastes or 90 kg P/ha, respectively. The sites were chiseled or ripped to a depth of 45 cm followed by disking and incorporation of amendments to about 30 cm. At this site about 1/3 of the Ca-amendment was applied to the seedbed surface after disking. The regraded, amended area was drill seeded with a mixture of western wheatgrass (*Pascopyrum smithii*), slender wheatgrass (*Elymus trachycaulus*), thickspike wheatgrass (*E.* lanceolatus), streambank wheatgrass (*Agropyron riparium*), smooth brome grass (*Bromus inermis*), yellow sweetclover (*Melilotus officinalis*), and Gardner (*Atriplex gardneri*) and fourwing saltbush (*A. canescens*), at 30.1 kg PLS/ha (pure live seed).

Colony Sites: These study sites were located within 7-11 km south of Colony in Crook County, Wyoming. This area was mined from 1950 to 1970 and consisted of spoil material derived from the Belle Fourche shales and Newcastle Sandstone formations. Therefore, the clay content, salinity and ESP was considerably lower than that common to the Upton sites. ESP values were generally in the 25% range. Topography ranged from low hills to ridges, with elevations from 1010 to 1070 m (IMEC 1985). Average annual precipitation is 371 mm with a frost free growing period of 129 days (NOAA 1995). Amendments consisted of 45 Mg wood wastes per ha and a combination of 75% gypsum and 25% $CaCl_2$. In addition, $CaCO_3$ was applied when the spoil pH was acidic. All Ca amendments were applied to reduce the ESP to 10%. Other spoil amendments and incorporation methods were similar to those utilized at the Upton site. A mixture of western wheatgrass, slender wheatgrass, thickspike wheatgrass, streambank wheatgrass, Gardner saltbush, smooth brome grass, and yellow sweetclover were broadcast seeded with a pitter-seeder at 26.9 kg PLS/ha.

Greybull Sites: These study sites were located about 19 km northeast of Greybull in Big Horn County, Wyoming. The area was mined prior to 1973 and consisted of spoil material that was composed of about 30% clay with an ESP of 15%. Spoils are from the Frontier sandstone and Mowry shale formations. Topography consists of steep dips forming a series of hogbacks or cuestas (Rioux 1958), with elevations from 1285 to 1317 m (Centennial Engineering 1987). Average precipitation is 174 mm with a frost free growing period of 130 days. No sawmill wood wastes or fertilizers were utilized because of the more coarse spoil texture of this site. A combination of 25% $CaCl_2$ and 75% gypsum was applied to reduce the ESP to 10%. After amendment application, the regraded spoil was ripped to a depth of 20-36 cm and disked to a depth of 15 cm. A mixture of thickspike wheatgrass, streambank wheatgrass, Russian wildrye (*Elymus junceus*), Indian ricegrass (*Oryzopsis hymenoides*), crested wheatgrass (*Agropyron cristatum*), Gardner saltbush, greasewood (*Sarcobatus vermiculatus*) and white sweetclover (*Melilotus abla*) were broadcast seeded with a pitter-seeder at 22.3 kg PLS/ha.

A randomized complete block design was utilized for statistically evaluating spoil chemical characteristics across vegetation conditions. Three sampling sites were selected at both Upton and Colony and two sampling sites were selected at the Greybull location. Three vegetation conditions were delineated at each site. At the Upton and Colony sites, the center of the die-back area was designated as the "dead" vegetative condition. The transition area between "dead" and "good" condition areas was designated as the "moderate" condition (Fig. 1). At the Greybull sites, the "dead" areas were still observed; however, a shrub vegetation community represented the "good" condition at site G-1; whereas a grass and shrub community represented the "good" and "moderate" conditions at site G-2. Three transects were arranged parallel to one another that dissected the vegetative conditions (Fig. 1). Spoil cores were taken at six locations along each of the three transects with two spoil cores representing each of the three vegetative conditions. Spoil cores were segregated into three depth increments, 0-15, 15-30, and 30-60 cm. Spoil cores were collected in June or July 1997 using a truck mounted hydraulic soil sampler. Spoil analyses included: pH, EC, and water-soluble, extractable, and exchangeable-cations, and CEC. Spoil pH, EC, and soluble cations were determined on

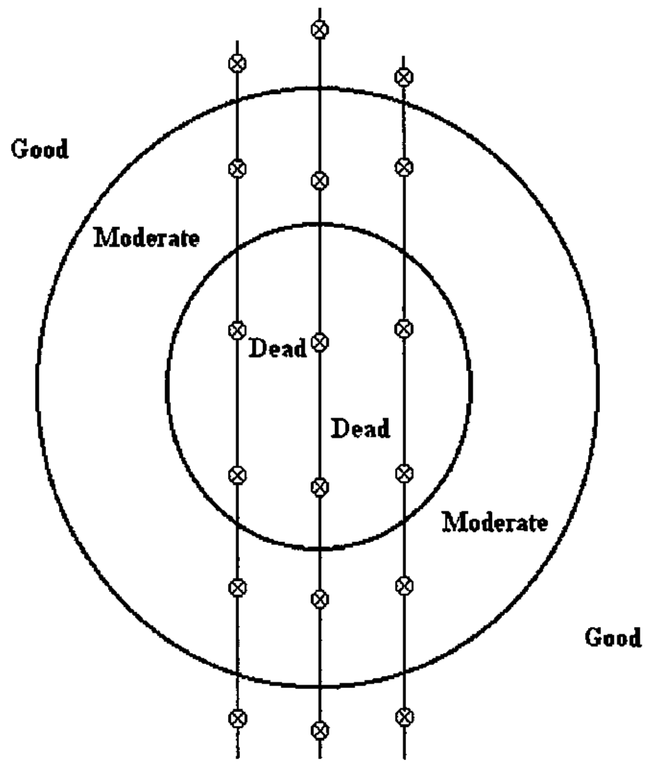

Figure 1. Field spoil sampling design.

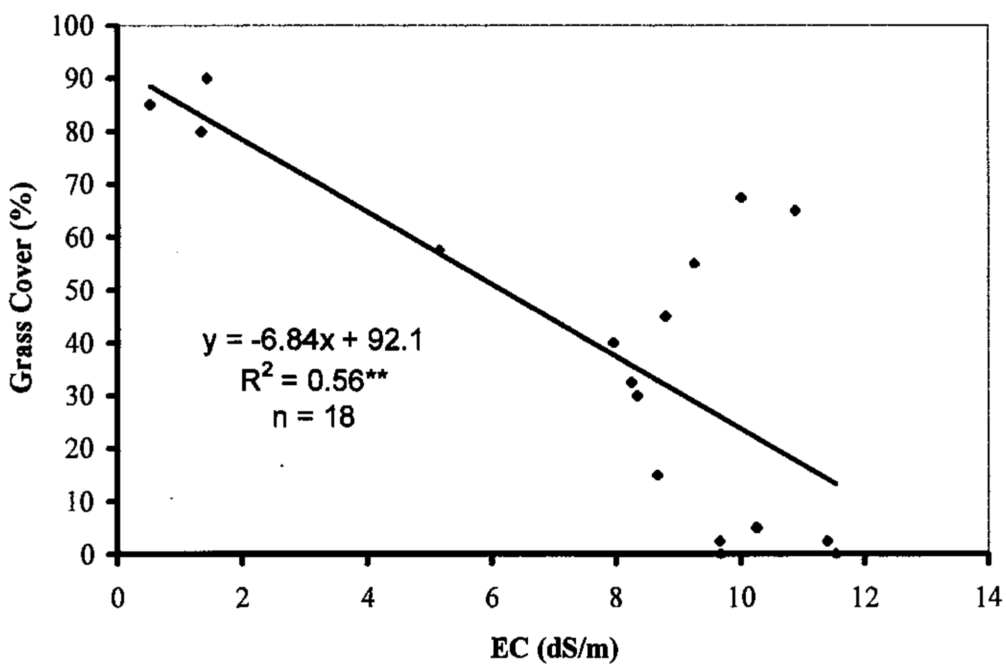

Figure 2. Relationship between grass cover and EC, Upton-1. (** P=0.05)

a 1:1 solid:water paste (U.S. Salinity Lab Staff 1954). Extractable cations were evaluated using a buffered 1 N ammonium acetate extraction procedure (U.S. Salinity Lab Staff 1954). CEC was determined using a Na-saturation procedure (U.S. Salinity Lab Staff 1954). Soluble and extractable cations and Na levels for CEC were determined using atomic absorption spectrophotometry (Rhoades 1982).

Aerial plant cover was estimated using a point frequency frame with ten pins approaching the ground at a 60° angle (Mueller-Dombois and Ellenberg 1974). Plant cover data was collected at four locations near each spoil core site.

Data analyses was completed using analysis of variance and regression analysis. Mean separations were tested using the Least Significant Difference method. All statistical analysis was evaluated at $P \leq 0.05$.

Results and Discussion

Upton Sites: The Upton sites generally exhibited the greatest degree of spoil salinity and sodicity; partly because spoil materials had inherently higher levels of these parameters.

Upton-1: Vegetation cover and vegetative condition were strongly influenced by site EC. The "good" vegetative condition sites had significantly lower EC (2.9 dS/m) than either the "moderate" (7.3 dS/m) or "dead" (9.9 dS/m) vegetative conditions. Condition of vegetation cover showed a significant relationship to EC of surface 15 cm of the spoil (Fig. 2). Exchangeable-Na and ESP were significantly lower on the "good" vegetation condition site than on the "moderate" or "dead" condition sites at all spoil depths (Table 1). Vegetation cover also exhibited a significant relationship to the 0-15 cm spoil ESP (Fig. 3). The observed relationship between plant growth and ESP, along with the fact that the soluble and exchangeable Ca in these spoils was extremely low, indicate that the Ca-amendment was inadequate to correct the sodic conditions of spoil on the "moderate" and "dead" condition sites.

Upton-2: Spoil EC was significantly lower on "good" condition sites for the 0-15 and 15-30 cm depths compared to "moderate" and "dead" condition sites. The "moderate" and "good" condition sites were significantly lower than "dead" condition sites for the 30-60 cm spoil depth. Vegetation cover exhibited a significant and similar relationship with EC and ESP as that observed on Upton-1 (Fig. 4 & 5).

Upton-3: This site had the most severe salinity and sodicity problems within the Upton location. EC values in spoil of "moderate" and "dead" condition sites were 15.7 and 14.2 dS/m, respectively. However, vegetation growth at this site, even in the "good" (12.1 dS/m) zone, was reduced because of the high osmotic potential created by EC. ESP exhibited similar trends as EC, with ESP averaging 39% ("good"), 45% ("moderate"), and 62% ("dead"), respectively. EC and ESP were fairly uniform within the spoil depths with only the 30-60 cm depth being significantly different from the upper depths. Vegetation cover response to EC and ESP were not significant at this site and cover was much lower than observed on the other Upton sites.

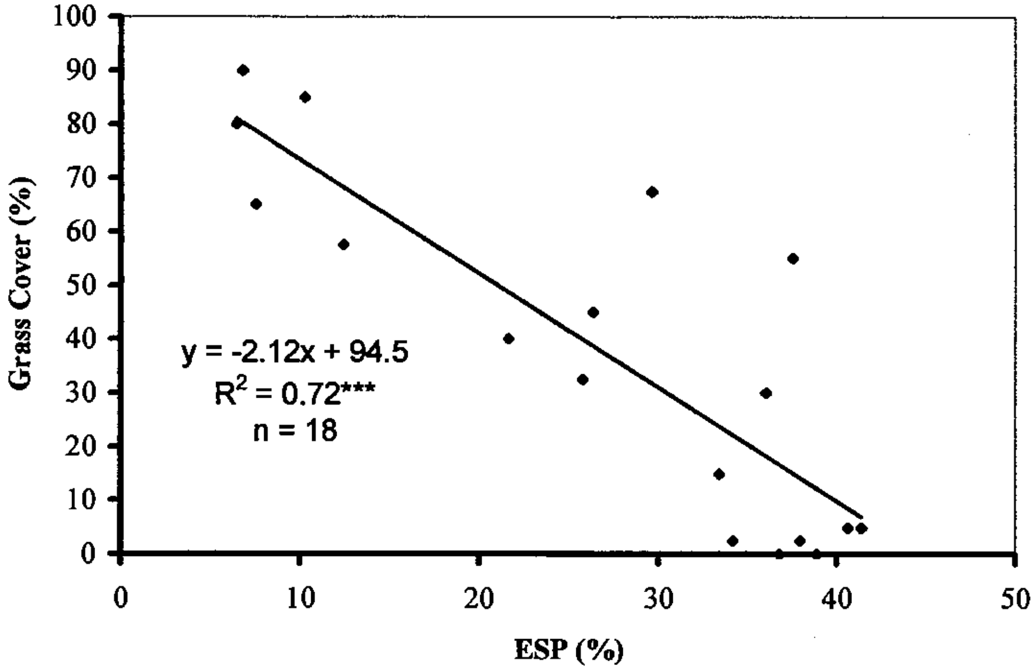

Figure 3. Relationship between grass cover and ESP, Upton-1. (*** P=0.01)

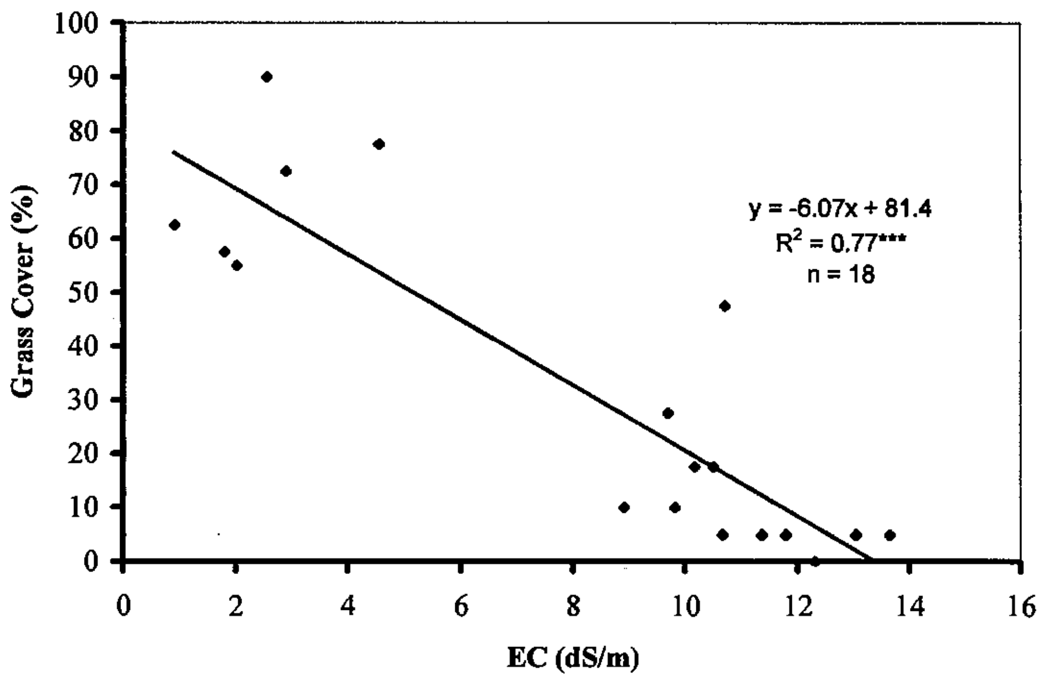

Figure 4. Relationship between grass cover and EC, Upton-2. (*** P=0.01)

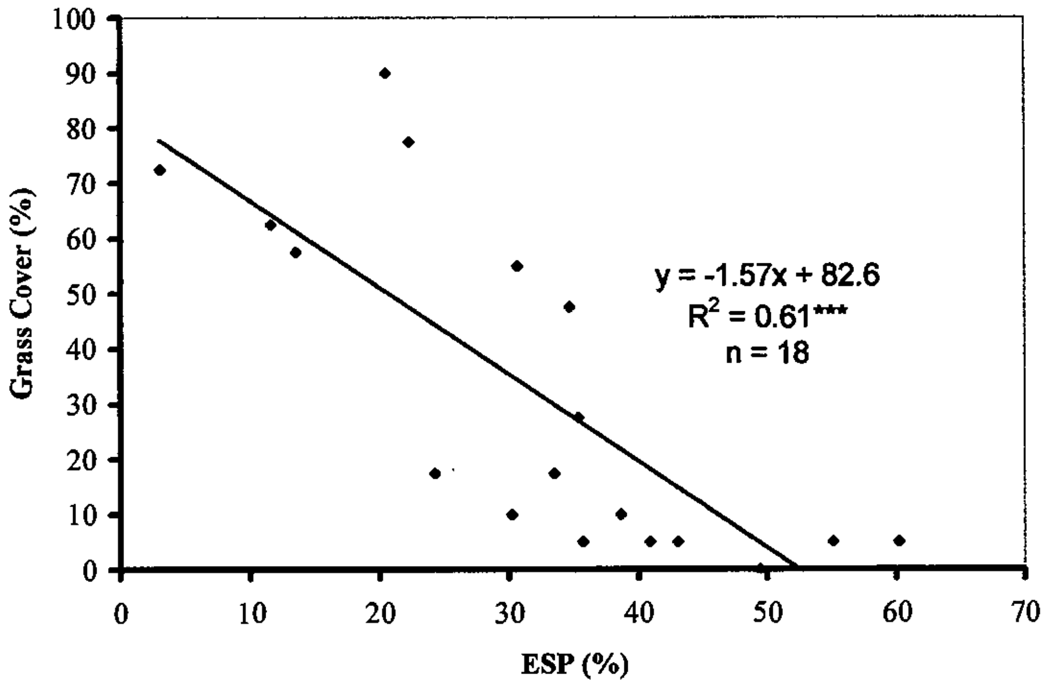

Figure 5. Relationship between grass cover and ESP, Upton-2. (*** P=0.01)

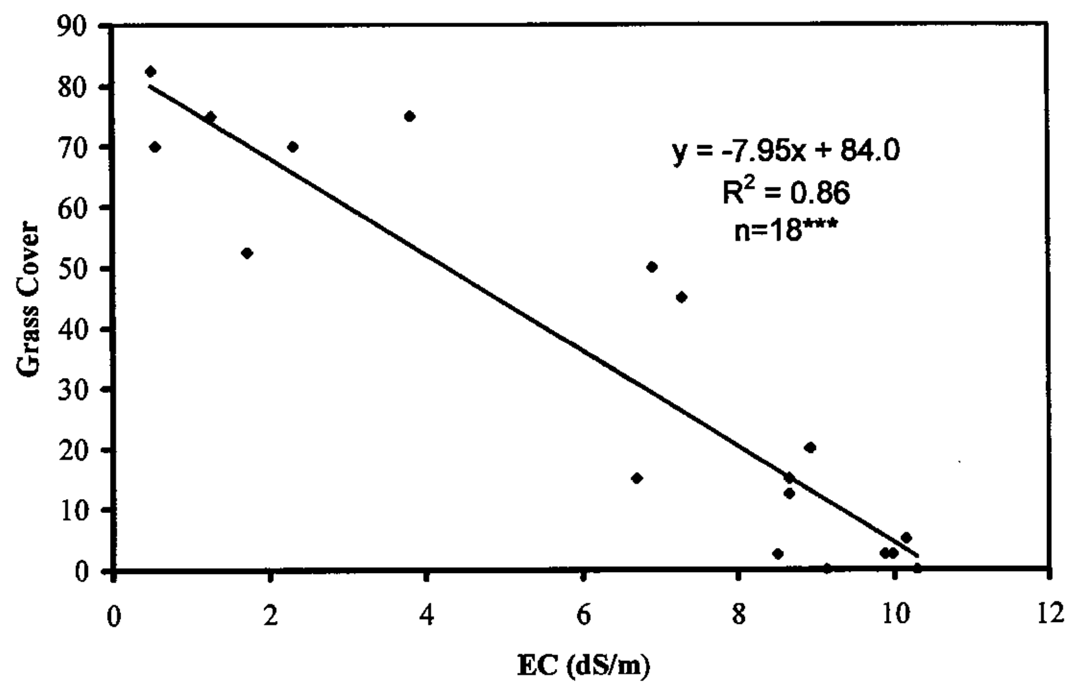

Figure 6. Relationship between grass cover and EC, Colony-1. (*** P=0.01)

Table I. Exchangeable-Na and ESP for vegetation condition and spoil depth, Upton-1[1].

Spoil Depth	Good	Moderate	Dead
cm			
		Exchangeable-Na (cmol/kg)	
0-15	4.1aA	9.0aB	13.7abC
15-30	6.4abA	13.5bB	16.0bB
30-60	8.0bA	13.3bB	12.0aB
		ESP (%)	
0-15	12aA	30aB	38abC
15-30	21bA	40bB	44bB
30-60	25bA	41bB	34aC

[1] To compare vegetation condition means within a depth, means with the same upper case letter are not significantly different; to compare depths within a vegetation condition, means with the same lower case letter are not significantly different; $P \leq 0.05$.

Colony Sites: These sites generally had less severe inherent spoil conditions, especially in regard to EC, ESP and clay content.

Colony-1: Vegetation condition declined significantly as EC increased from 2.9 dS/m on the "good" zone to 9.9 dS/m on the "dead" zone. ESP was significantly greater in "moderate" (21%) and "dead" (35%) vegetative condition zones than in the "good" (12%) zone. The CEC was also higher in the "dead" (37.3 cmol/kg) zone indicating a higher spoil clay content in that zone compared to the "moderate" (31.9 cmol/kg) and "good" (29.8 cmol/kg) zones. EC and ESP exhibited a significant relationship with plant cover (plant cover lower in higher EC and ESP spoil conditions, Fig. 6 & 7).

Colony-2: Vegetative condition did not exhibit a clear response to EC on this site. The highest EC occurred on the "moderate" (8.7 dS/m) condition zone and "good" and "dead" condition zones had similar EC (~4.5 dS/m). ESP of "moderate" (27%) and "dead" (45%) condition zones were significantly higher than the "good" (7%) condition zone and vegetation cover decreased significantly with increasing ESP (Fig 8). Vegetation at this site clearly responded to sodicity but not salinity.

Colony-3: This site exhibited similar trends in EC and ESP as Colony-2. The

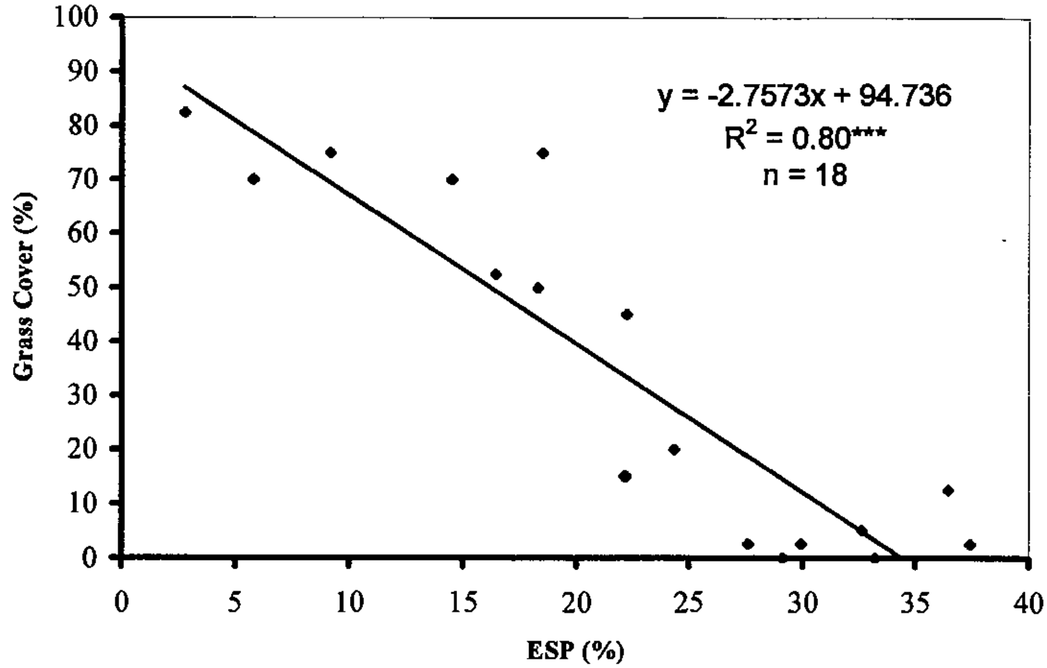

Figure 7. Relationship between grass cover and ESP, Colony-1. (*** P=0.01)

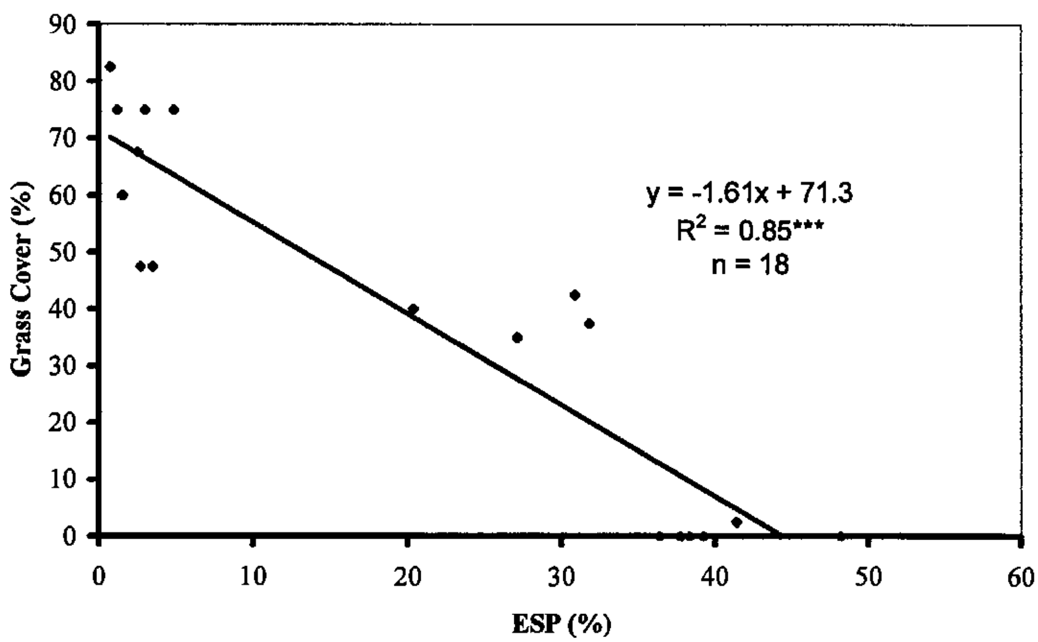

Figure 8. Relationship between grass cover and ESP, Colony-2. (*** P=0.01)

in the "moderate" condition zone, but the "moderate" was not different from the "dead" condition zone. This variable response is partly due to the fact that EC values are <8 dS/m and were as low as 1.3 dS/m; these levels appear to have less impact on the plant community than does sodicity of the spoil. ESP was significantly greater on "moderate" (21%) and "dead" (59%) zones than on the "good" (9%) condition zone. Plant cover showed a significant relationship to ESP (Fig. 9).

In general, Colony sites exhibited less plant response to saline conditions present in the spoil than Upton sites, partly because salinity was less severe and the site receives slightly more precipitation. Sodic conditions appear to be a primary cause of failure of vegetation in "dead" condition zones at the Colony sites.

Greybull Sites: Greybull sites responded quite differently to amendment applications than either the Upton or Colony locations. This location is very dry and spoil material possesses many limiting characteristics (i.e., low water holding capacity, saline, limited aggregation, and very powdery or shaley physical condition). Shrubs are a major component of the natural landscape and were predominant in the "good" condition zone at the Greybull-1 site and in the "moderate" condition zone at the Greybull-2 site.

Greybull-1: Vegetation, whether grass or shrubs, was very sparse at this site. Free crystalline gypsum was present in spoils and in numerous instances, this created difficulty in evaluating exchangeable Ca because gypsum dissolution interfered with the methodology. EC did not effect plant condition or plant cover at this site. ESP exhibited a significant effect on plant condition, with "good"(9%) and "moderate"(11%) condition zones having

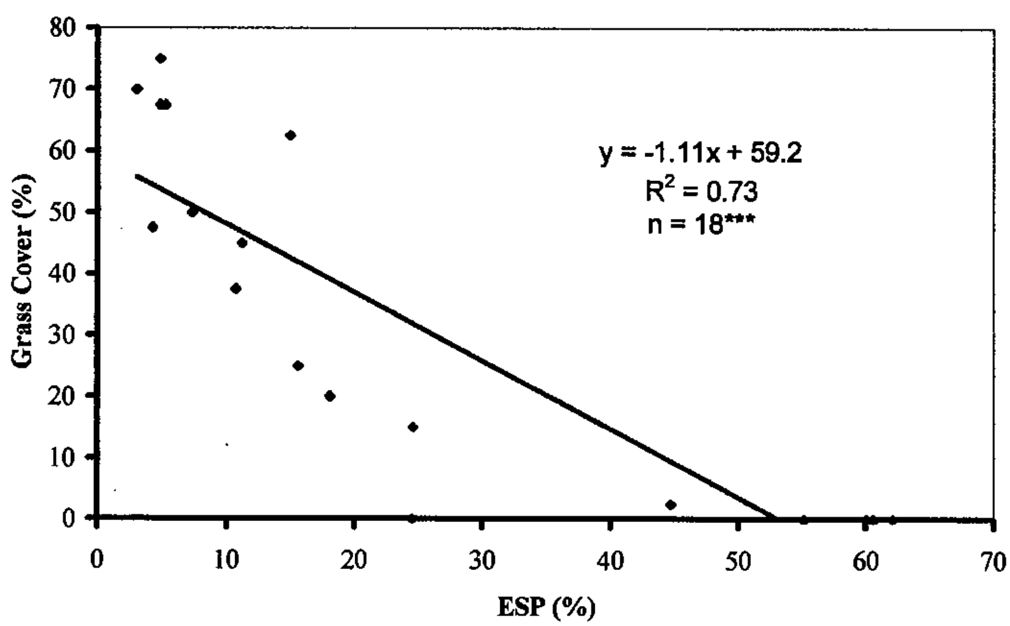

Figure 9. Relationship between grass cover and ESP, Colony-3 (*** P=0.01)

condition, with "good"(9%) and "moderate"(11%) condition zones having significantly lower ESP's than the "dead" (20%) condition zone. However, plant cover did not exhibit a significant relationship with ESP, which we believe is due to different plant community composition in the vegetative condition zones. Shrubs represent a considerably different growth form than the grasses found at other sites.

Greybull-2: At this site, "moderate" vegetative condition was represented by shrubs rather than grass. EC and ESP exhibited significant main effect responses to vegetative condition. EC was significantly lower at "good" (3.2 dS/m) compared to "moderate" (9.6 dS/m) and "dead" (8.5 dS/m) vegetative conditions. ESP was also significantly lower at the "good" (7%) compared to the "moderate" (33%) and "dead" (29%) vegetative conditions. Even though moderate" vegetative condition sites exhibited high ESP and EC levels, Gardner saltbush (*Atriplex gardnerii*) seemed to be persistent.

In general, this location was much more difficult to revegetate \because of the poor physical quality of the spoil and the arid climatic conditions of the area. Spoil material was very coarse textured or almost pumice-like with very low water holding capacity.

Summary

This study has demonstrated the necessity of thoroughly addressing and ameliorating the sodicity of bentonite mine spoils to ensure the sustainability of the revegetated landscape. Northeast Wyoming locations (Upton and Colony) clearly point out the importance of addressing sodicity through appropriate analytical and effective amendment programs. When the spoils possess high clay content (>30%) it is necessary to use sawmill wood residues as an amendment to enhance immediate water infiltration and deep percolation. This practice, along with the use of Ca amendments, enables dissolution and exchange of Ca on the clay complex to correct high ESP levels observed when exchangeable Na levels dominate the system. Establishing enhanced water relations in this material allows replaced Na to be leached and the general salinity of the rooting media to be reduced.

Data from northeast Wyoming locations show that sodicity was not adequately ameliorated on small areas of the reclaimed landscapes that resulted in "dead" vegetative condition zones. In several cases both EC and ESP values were high in these "dead" vegetative condition zones indicating water infiltration and percolation had not been achieved and inadequate Ca amendment had been applied to correct sodicity. These issues could be the result of an inadequate sampling procedure for determining amendments and/or inadequate quality control in amendment application. Therefore, from this study, three recommendations are proposed to prevent similar problems on future abandoned mine land reclamation projects: (1) regraded spoil sampling used to determine amendment applications should be increased, (2) bentonite cleanings should be more carefully delineated and buried to ensure no upward migration of salts occurs, and (3) there should be closer supervision of actual field operation on each phase of a project. While these recommendations will be useful for future abandoned bentonite mine reclamation programs, the question that remains unanswered is what should be done to address the small die-back areas observed within the thousands of hectares of reclaimed abandoned bentonite mine spoils? Schuman and Meining (1993) demonstrated that surface applied gypsum could be successful in ameliorating spoil sodicity. Therefore, gypsum application rates could be determined on these areas and gypsum applied to enable correction of the sodicity and subsequent natural interseeding be allowed to occur. However, it is the consensus of the authors that before any corrective action is initiated, further observation of these die-back sites should occur over the next five years to determine if the "dead" zones are expanding or stable. If stable, we recommend that these areas be left in their present form because small unvegetated areas are common in the native landscapes where outcrops of rock or bentonite occur naturally. If the areas continue to expand, then further amendment and possibly seeding may be necessary.

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