REVEGETATION OF NON-TOPSOILED, ORPHAN BENTONITE MINE SPOIL IN WYOMING AS INFLUENCED BY ORGANIC AND INORGANIC AMENDMENTS [1]

by

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Abstract. Revegetation of thousands of hectares of pre-law, abandoned bentonite minespoils in northeastern Wyoming has proven particularly difficult due to absence of topsoil and adverse physiochemical characteristics of spoil such as high clay content and sodicity. This paper presents 7th through 9th year findings of a project evaluating short and long-term effects of initially applied wood residue and N-fertilizer, and a later applied gypsum amendment on re-established vegetation. The initial benefits of higher rates of wood residue amendment (90 and 135 Mg/ha) to revegetation generally persisted through the 9th growing season, as did certain effects of initial N-fertilization within residue-amended treatments. Surface application of 56 Mg/ha of gypsum during the 6th year to ameliorate sodicity significantly enhanced plant growth during the 7th through 9th years. Findings thus supported the desirability of applying wood residue, N-fertilizer, and gypsum amendments in combination and at proper rates for effective revegetation of bentonite mine spoils.

Additional Key Words: Soil amendments, abandoned mined lands, sodicity, gypsum, wood residues.

Introduction

Bentonite clay has been surface-mined extensively in northeastern Wyoming for over 50 years. Although presently mined areas are being reclaimed according to current laws,thousands of hectares of orphan spoils existed a decade ago that were abandoned in a derelict state prior to enactment of Wyoming's reclamation law in 1973. Natural revegetation of these lands has proven limited even after several decades (Sieg et al 1983). In light of this, reclamation of orphan bentonite spoil has been a major focus of the State of Wyoming's Abandoned Mined Land Program since 1985 (Richmond 1989).

Several characteristics of bentonite spoil make reclamation difficult (Schuman et al 1984), including high expanding clay and soluble salts (particulary Na) content. These characteristics lead to a dispersed soil system which results in poor structure, low water infiltration, and a high runoff potential. The standard practice of topsoiling to overcome spoil problems is usually infeasible on orphan bentonite mined lands because topsoil was not salvaged during pre-law mining operations, and because topsoil borrowing from undisturbed areas often is not economically or environmentally sound (Richmond 1989). Therefore, most efforts toward reclaiming these spoils have centered upon applying various organic and/or inorganic

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amendments to directly ameliorate adverse spoil attributes (Schuman and Sedbrook 1984, Schuman et al 1989, Dollhopf et al 1989, Voorhees and Uresk 1990).

Results of a pilot study in northeastern Wyoming (Schuman and Sedbrook 1984) indicated that softwood residue (Pinus ponderosa sawdust, bark, and chips) from local sawmills was promising as an organic amendment to improve physical conditions of bentonite spoil and enhance revegetation. The present study was based upon this premise, and was initiated in 1981 to further refine wood residue amendment rates, investigate the role and rate of concurrent nitrogen (N) fertilization, evaluate plant species suitable for revegetation of amended spoil, and determine rate of wood residue decomposition. Initial findings (Smith et al 1985, 1986; Belden et al 1990) demonstrated enhanced establishment and growth of seeded plant species with increasing rates of wood residue amendment through the 5th growing season. These beneficial responses were attributed to improved physical (water infiltration and structure) and chemical (reduced salinity) qualities of residue-amended spoil (Belden et al. 1990). Findings also supported the value of N fertilization to insure adequate N for plant growth and residue decomposition (Schuman and Belden 1991).

Despite the rapidly-expressed benefits of wood residue amendment to reclamation, Belden et al (1990) noted an increase in spoil sodicity over time in residue-amended treatments. This was attributed to the overwhelming dominance of Na in the spoil cation pool, which resulted in increasing proportions of Na over other cations (i.e., sodium adsorption ratios [SAR]) following soluble cation leaching. The temporally increasing sodication raised concerns over negative impacts on revegetation, and led Belden et al (1990) to postulate that a calcium (Ca) amendment to reduce sodicity might be an essential complement to wood residue for successful long-term reclamation. Inorganic Ca amendments such as gypsum, calcium chloride, and phosphogypsum may reduce sodicity by replacing Na with Ca ions on cation exchange sites, thus freeing Na for downward leaching (Prather et al 1978).

The optimum mode of Ca enrichment is to incorporate Ca amendments into the soil concurrently with wood residue at the outset of reclamation and prior to revegetation. This approach is presently being utilized in most abandoned bentonite reclamation programs in northeastern Wyoming (Richmond 1989). However, soil incorporation of Ca amendments on previously revegetated sites (such as the 1981 study site) would obviously damage or destroy established vegetation. Consequently, research was initiated in 1987 at the 1981 study site to determine whether gypsum could be an effective Ca amendment if applied to the soil surface without incorporation. The thesis of Meining (1991) reported edaphic responses to varied gypsum and wood residue rate treatments. The following paper will address selected, major plant responses. The vegetation-related objectives of this study included:

1) evaluation of effects of surface-applied gypsum on productivity of seeded and non-seeded plant species,

2) determination of longer-term influence of varied wood residue rates and N-fertilization on seeded and non-seeded plant species, and

3) determination of any interactive effects among gypsum, wood residue and/or N-fertilization treatments on plant response.

Methods and Procedures

Experimental Design

The project was conducted at a site 7 km northwest of Upton, in northeastern Wyoming, that was mined and abandoned without reclamation in the 1950s. Climate of the area is semiarid (363 mm annual precipitation) and continental, with roughly 60% of yearly precipitation occurring from April through July. Prior to initiation of the study in 1981, the site was nearly devoid of the sagebrush/grassland and ponderosa pine woodland vegetation characteristic of unmined rangeland in the area. Topography consisted of rolling to steep-sloped, angle-of-repose minespoil without topsoil coverage. Table 1 summarizes pretreatment spoil attributes, and reflects the problems with high clay content, salinity, and sodicity that are characteristic of bentonite spoil in this region.

Spoils were graded to a nearly level topography in the summer of 1981. All combinations of the following treatments were then applied in a replicated split plot/split block experimental design (see Smith et al 1985 for a more complete description of treatments and plot arrangement):

1) rate of wood residue application: 0, 45, 90 and 135 Mg/ha, and

2) rate of nitrogen fertilization: 0, 2.5, 5.0 and 7.5 kg of N/Mg of wood residue in residue-amended treatments; the non-residue amended treatment received 0, 112, 224 and 336 kg N/ha, which was equivalent to the rates of N applied on the 45 Mg/ha wood rate treatment.

Initial results indicated that while vegetation was significantly stimulated by the lowest rates of N fertilization, little subsequent difference in plant response existed among the 3 rates of N application (Smith et al 1985). For the purposes of the present analysis, therefore, plant responses to non-N fertilization will be compared to the average of responses among the 3 N fertilization rate treatments (i.e., a non-N vs. N-fertilized treatment comparison).

Two mixtures of seeded species (native and introduced perennial grasses) were sown on the site in 1981 to comprise a seed mix treatment (Smith et al 1985). This report will present only responses of the native mixture, since this mix was later selected to receive the gypsum treatments because of better overall response to the initial spoil amendments. The native mixture included 5 cool-season perennial grasses ('Rosana' western wheatgrass, Agropyron smithii; 'Critana' thickspike wheatgrass, A. dasystachyum; 'Revenue' slender wheatgrass, A. trachycaulum; 'Sodar' streambank wheatgrass, A. riparium; and 'Lodorm' green needlegrass, Stipa viridula) and one shrub (Nuttall saltbush, Atriplex nuttallii). This mixture was seeded at rates to yield 130 live seeds/m^2 for each grass species and 32 live seeds/m^2 for Nuttall saltbush.

Table 1. Pre-treatment characteristics of bentonite spoils at Upton, Wyoming study site, 1981 (from Smith et al. 1985).

Spoil Attribute		Mean and Standard Error
Particle Size Distribution (%):	Sand	10.8 ± 0.8
	Silt	29.6 ± 0.8
	Clay	56.6 ± 1.1
NO_3-N (mg/kg):		7.7 ± 0.4
NH_4-N (mg/kg):		2.6 ± 0.1
Total Kjeldahl N (mg/kg):		751.1 ± 5.8
P (mg/kg):		8.1 ± 0.3
C (mg/kg):		10.0 ± 1.0
pH		6.8 ± 0.1
Electrical Conductivity [EC](dS/m)		13.4 ± 1.1
Sodium Adsorption Ratio [SAR]:		63.1 ± 1.2
Soluble Cations (mg/kg):	Ca	187.9 ± 9.2
	Mg	73.6 ± 4.2
	Na	3613.7 ±101.3
	K	32.0 ± 0.8

Site preparation after grading consisted of chisel plowing; application of varied wood residue and N-fertilization rate treatments (plus a uniform application of phosphorus at 90 kg/ha); and disk plowing to uniformly incorporate all residue and fertilizer amendments within the surface 30 cm. The seed mixture was subsequently sown with a grain drill in October 1981.

In April of 1987, the study was expanded by adding gypsum as a third soil amendment treatment (see Schuman et al 1989 for full detail). Two gypsum regimes were superimposed by dividing each native species plot, and randomly designating each portion to receive gypsum at either 0 or 56 Mg/ha. The 56 Mg/ha gypsum rate supplied sufficient Ca ions to reduce the exchangeable sodium percentage (ESP) of the spoil to 15. The gypsum was surface-applied with no subsequent soil incorporation, to avoid physically disrupting previously established vegetation.

Sampling (1988 - 1990)

Techniques of vegetation sampling and analysis for the pre-gypsum amendment years of 1981 through 1986 were described in preceeding reports (Smith et al 1985, 1986; Schuman et al 1989; Belden et al 1990). Methods and results of post-gypsum amendment soil sampling were described by Meining (1991), and will not be included in this paper.

Vegetation was sampled from 1988 through 1990 for density, canopy cover, and aboveground biomass. Within each replicate block, 2 permanent 0.25 m^2 rectangular quadrat locations were established within each wood residue-fertilization-gypsum treatment combination subplot for density and canopy cover estimation. Stem density was determined by counting all live plants rooted within each quadrat during late spring (May-June) each year. Canopy cover was ocularly estimated each year in all quadrats during the period of estimated peak seasonal live plant growth (June-July), using the general procedures of Daubenmire (1959). Density and canopy cover were estimated by growth form and individual species for annual forbs, perennial forbs, shrubs, and (cover only) perennial and annual grasses. Basal (ground) cover was also estimated for litter and bare ground.

One 0.50 m^2 (71 X 71 cm) quadrat was randomly located within each replicated treatment-combination subplot each year for aboveground biomass sampling, with different quadrat locations each year. All biomass within the quadrats was hand-harvested to ground level, and divided into the following growth-form categories: perennial grasses, annual grasses, perennial forbs, annual forbs, and shrubs. Only current year growth was harvested for all growth forms except shrubs, for which total standing live biomass was harvested. Standing dead plant material for all growth forms was harvested separately and composited. Harvested plant materials were oven-dried to constant weight at 60 C prior to weighing.

Data Analysis

Vegetation data from this factorially-designed study were analyzed for effects of 3 main treatments: wood residue rate (4 levels), N-fertilization (2 levels), and gypsum (2 levels). Analysis of variance procedures were employed to determine the occurence of significant treatment or treatment interaction effects on vegetation attributes within each of the 3 years, and differences among years within specific treatments or treatment combinations. Tukey's studentized range test was utilized to discern significant differences among main treatment means. Differences among treatment interaction means were evaluated using Student's t-tests. The minimum acceptable level of probability for ecologically significant differences and tests of mean separation was selected at $P \leq 0.10$.

Results and Discussion

Hanson et al (1986) found winter-spring (October through June) precipitation to be most influential on plant production on Wyoming rangelands. Precipitation during this period in 1989 was nearly identical to the long-term average of 25.6 cm, whereas winter-spring precipitation totals in 1988 and 1990 were 22% below average at 20.0 and 20.1 cm, respectively.

Canopy cover data indicated that species composition varied among treatments. Study site vegetation in 1988-1990 was variously dominated or co-dominated by the seeded species western wheatgrass, thickspike/streambank[1] wheatgrasses and Nuttall saltbush, and the volunteering (i.e., non-seeded) annual forb rillscale (Atriplex suckleyi). Major compositional changes from earlier years of the study (Smith et al, 1986) included a decrease of seeded slender wheatgrass and an increase of the volunteer shrub greasewood (Sarcobatus vermiculatus) in the community. Green needlegrass and all volunteering species other than greasewood and rillscale remained minor components of study site vegetation in 1988-1990.

No significant main effects of N-fertilization on vegetation were evident in 1988-1990, although several interactions between N-fertilization and wood residue-gypsum treatments existed. Tables 2 and 3 present main effects of wood residue rate and gypsum treatments on aboveground biomass of dominant plant growth forms from 1988 through 1990, plus all significant interactions among these 2 treatments and N-fertilization.

Wood Residue Amendment Effects

Productivity of seeded perennial grasses tended to increase with increasing wood residue rate (see Table 2). This trend was strongest and most consistent in N-fertilized plots in 1989 and 1990. Furthermore, a positive perennial grass response to N fertilization was evident in 1989 and 1990 only in plots amended with the highest rate of wood residue (135 Mg/ha).

A significant gypsum by wood residue rate interaction also existed in 1989 (see Table 2). Perennial grass productivity was progressively higher with increasing wood residue rates within both gypsum treatments, but this trend was most pronounced and consistent within gypsum-

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[1] Field differentiation of thickspike and streambank wheatgrasses proved impossible; therefore, only combined responses of these 2 species can be reported.

amended plots. Although the wood residue rate by gypsum treatment interaction for grass biomass disappeared in 1990, significant interactions existed for canopy cover of dominant individual grass species in that year (see Table 4). Western wheatgrass was the grass species most responsive to wood residue amendment, with similarly greatest cover at the 2 highest residue rates within both gypsum treatments. Combined canopy cover of thickspike and streambank wheatgrasses was maximized only at the highest (135 Mg/ha) residue rate. As with grass biomass the preceding year, canopy cover responses of individual grass species to increasing residue rate in 1990 appeared accentuated in gypsum-amended compared to non-gypsum-amended plots.

These findings demonstrated that the stimulation of perennial grasses by wood residue noted in earlier years of this study (Smith et al 1985, Belden et al 1990) persisted during the 7th through 9th growing seasons, and supported the implications of Belden et al (1990) that higher rates of residue (i.e., 90 and, particularly, 135 Mg/ha) may be necessary for longer-term soil improvement and enhancement of plant growth. Soils data for the current phase of this project (Meining 1991) indicated that the 2 highest rates of residue were most effective for salt leaching in the 1988-1990 period, presumably due to enhanced water infiltration and percolation through the spoil. The persistence of residue benefits to spoils and, hence, to growth of dominant perennial grasses may be related to a rather slow rate of residue decomposition. Schuman and Belden (1991) found that only about one-fourth of the applied wood residue had decomposed after 5 growing seasons on the more heavily N-fertilized treatments.

A strongly positive plant response to N-fertilization was both evident and logical in residue-amended plots during initial years of this study (Smith et al 1985). However, plant responses to one-time applications of N have often proven ephemeral due to the typically limited carryover of inorganic fertilizer-N in minesoils. The persistence of higher perennial grass productivity in N-fertilized, heavily residue-amended plots in 1989 and 1990 was therefore unexpected. The higher grass production in fertilized plots in 1989-1990 may be a residual manifestation of the greater plant density and vigor initially achieved with these treatments in earlier years. Other reclamation studies (e.g., Ries et al 1988, Schuman et al 1991) have noted similarly longer-term manifestations of initially enhanced plant establishment due to cultural practices.

Table 2 indicates that 1988-1990 productivity of volunteering annual forbs (mainly rillscale) declined with increasing residue rate. Despite the stimulation of rillscale by gypsum amendment (to be discussed in the next section), canopy cover of this species in 1990 nonetheless declined with increasing residue rates within the gypsum as well as the non-gypsum treatment (see Table 4). Rillscale is a poor competitor with perennial plant species (Sieg et al 1984). Its negative response to increasing residue rates probably reflects increasing competitive inhibition by wood residue-stimulated perennial grasses, since rillscale has been noted in other studies to respond positively to wood residue amendment in absence of grass competition (Voorhees et al 1987).

Interpretation of shrub biomass responses must be qualified because these data represent total live standing crop (i.e., not only current year's growth, but also residual live biomass produced in preceding years). Shrub biomass data were extremely variable from 1988 to 1990. Consequently, significant differences among residue rates were absent, with the exception of an interaction between residue rate and N-fertilization in 1989 whereby shrub standing crop was higher for the 135 Mg/ha residue rate-nonfertilized treatment combination than for all other treatments. In contrast, Smith et al (1986) noted a similar degree of stimulation of seeded Nuttall saltbush biomass under all 3 rates of residue amendment and no effect of fertilization during the second year (1983) of the study. The diminishment (and, in 1989, alteration) of shrub responses from 1983 through 1988-1990 may be partially related to confounding effects of non-seeded greasewood, which colonized the study site in a prolific but non-uniform manner over this 5 to 7 year period. Although data variability precluded detection of similar relationships in 1988 and 1990, the 1989 biomass data suggest a residual manifestation of shrub stimulation by wood residue only at the highest residue rate in absence of N-fertilization. Nitrogen fertilization was noted previously to enhance perennial grasses at the highest residue rate. This suggests that less grass competition in the non-fertilized, heavily residue-amended treatment may have promoted greater shrub survival and growth over time.

Table 2. Main effects of wood residue rates and/or significant interactions between residue rates and N-fertilization/gypsum treatments on aboveground biomass of dominant plant growth forms, 1988-1990. [1]

Growth Form	Year	Two-Way Interactions With Inorganic Amendments [2]	Wood Residue Rate (Mg/ha) 0	45	90	135
			Biomass (g/m^2)			
PERENNIAL GRASSES	1988	None	1 B	9 B	27 A	44 A
	1989	a) Gypsum-Amended	4 E	12 D	32 B	47 A
		No Gypsum	1 E	1 E	12 D	26 C
		b) N-Fertilized [3]	3 C	5 C	26 B	47 A
		Non N-Fertilized	1 C	4 C	12 BC	19 B
	1990	N-Fertilized [3]	1 C	8 C	40 B	76 A
		Non N-Fertilized	<1 C	11 BC	27 BC	27 BC
ANNUAL FORBS	1988	None	7 A	6 A	5 A	2 B
	1989	N-Fertilized [3]	18 B	12 C	8 CD	7 D
		Non N-Fertilized	28 A	12 C	2 D	1 D
	1990	None	59 A	15 B	8 BC	2 C
SHRUBS	1988	None	11 A	101 A	38 A	43 A
	1989	N-Fertilized [3]	7 B	35 B	16 B	19 B
		Non N-Fertilized	2 B	4 B	23 B	83 A
	1990	None	13 A	43 A	35 A	54 A

[1] Within growth forms, years and (if present) interactions, values followed by same letter are not significantly different at $P \leq 0.10$.

[2] Between wood residue rate and either or both N fertilization regime or gypsum regime; no significant three-way interactions among residue, fertilization and gypsum treatments occured.

[3] Values are means among 3 rates of initial N fertilization applied in 1981.

Gypsum Amendment Effects

Gypsum was surface-applied as an amendment treatment in April of 1987. Therefore, data collected in 1988, 1989, and 1990 reflect responses 1, 2, and 3 years after treatment application, respectively. Soils data of Meining (1991) demonstrated reductions in sodicity (exchangeable Na, ESP and SAR) and evidence of increased Na leaching in the upper 30 cm of gypsum-amended spoils during the 1988-1990 period.

Aboveground biomass of seeded perennial grasses and non-seeded annual forbs responded positively to gypsum amendment within the first 14 months after application in 1988 (see Table 3), although gypsum responses were confounded somewhat by a two-way interaction with N-fertilization. More clearly positive effects of gypsum on herbaceous species productivity emerged in 1989 and 1990. This may have been due to the passage of additional time for fuller expression of gypsum's ameliorative effects on spoil sodicity. Gypsum has been noted to require more time for effectiveness than certain other inorganic amendments due to its relatively lower

Table 3. Main effects of gypsum amendment and/or significant interactions between gypsum amendment and N-fertilization regime on aboveground biomass of dominant plant growth forms, 1988-1990. [1]

			Gypsum Regime	
Growth Form	Year	Two-Way Interactions With N-Fertilization Regime [2]	Gypsum Applied At 56 Mg/ha	No Gypsum Applied
			-------Biomass (g/m^2)-------	
PERENNIAL GRASSES	1988	N-Fertilized [3]	24 A	20 B
		Non N-Fertilized	28 A	9 C
	1989	None [4]	28 A	12 B
	1990	None	42 A	20 B
ANNUAL FORBS	1988	N-Fertilized [3]	15 A	3 B
		Non N-Fertilized	1 B	2 B
	1989	None	19 A	7 B
	1990	None	35 A	14 B
SHRUBS	1988	N-Fertilized [3]	74 A	33 C
		Non N-Fertilized	53 B	33 C
	1989	None	24 A	14 B
	1990	None	46 A	31 A

[1] Within growth forms, years and (if present) interactions, values followed by same letter are not significantly different at $P \leq 0.10$.

[2] Significant two-way interactions between gypsum and wood residue treatments are provided in Table 2; no significant three-way interactions among gypsum, fertilization and residue treatments occured.

[3] Values are means among 3 rates of initial N fertilization applied in 1981.

[4] This apparent gypsum main effect is confounded by a two-way gypsum-wood residue rate interaction in 1989; see Table 2.

solubility (Prather et al 1978). Soils data of Meining (1991) indicated that although SAR's continued to increase from 1988 to 1989 in both gypsum treatments, from 1989 to 1990 SAR decreased significantly in the gypsum treatment while remaining high in the non-gypsum treatment.

Gypsum was expected to more effectively ameliorate spoil sodicity and enhance plant growth when applied in combination with higher rates of wood residue because of the greater promotion of water infiltration, percolation and, consequently, potential for Na leaching afforded by heavier residue amendment rates. The soils data of Meining (1991), however, did not exhibit any statistically significant gypsum-wood residue rate interactions that would have indicated an influence of residue rate on gypsum effectiveness. In contrast, the gypsum-residue rate interaction for perennial grass biomass in 1989 (see Table 2) supports the postulate of increased gypsum effectiveness with higher residue rates. Grass productivity was increased by gypsum amendment only in residue amended plots and in generally greatest magnitude at the 2 highest wood residue rates. Although this grass biomass relationship

Table 4. Interactive canopy cover responses of dominant individual herbaceous species to wood residue and gypsum amendment treatments during the 9th (1990) growing season. [1,2]

		Wood Residue Rate (Mg/ha)			
Plant Species	Gypsum Regime	0	45	90	135
		Canopy Cover (%)			
Agropyron smithii	Gypsum-Amended	1 D	9 C	33 A	28 A
	No Gypsum	1 D	3 D	17 B	19 B
Agropyron dasystachyum + A. riparium[3]	Gypsum-Amended	1 B	4 B	7 AB	10 A
	No Gypsum	1 B	1 B	4 B	10 A
Atriplex suckleyi	Gypsum-Amended	54 A	23 B	6 CD	6 CD
	No Gypsum	20 BC	9 CD	5 D	2 D

[1] Within each species, values followed by same letter are not significantly different at $P \leq 0.10$.

[2] No significant gypsum or wood residue treatment main effects nor treatment interactions occured for cover of dominant individual shrub species in 1990.

[3] Accurate field differentiation of these 2 species was not possible.

disappeared in the subsequent, drier year of 1990, it persisted for canopy cover of western wheatgrass, the most dominant individual perennial grass species (see Table 4). Canopy cover of the predominant annual forb species, rillscale, responded positively to gypsum amendment in 1990 only under the reduced grass competition regimes of non-residue and lightly (45 Mg/ha) residue-amended treatments (see Table 4). Responses of rillscale may have been different in absence of grass competition, since Voorhees et al (1987) noted that gypsum greatly improved production of rillscale monocultures only with concurrent application of wood residue.

Total live biomass of shrub species was higher in the gypsum than in the non-gypsum treatment in 1988 (under both N-fertilization treatments) and in 1989 (see Table 3). This rapidand positive response of shrubs to gypsum was surprising considering the relatively slow annual growth rates of these woody species, and the anticipated undetectability of differences in current year growth between treatments due to the masking effect of antecedent live biomass produced in years preceding gypsum amendment. However, significant differences in shrub biomass between gypsum treatments disappeared in 1990. This may have been due to the high variability of shrub data and/or to an initial manifestation of competitive inhibition of shrubs by more gypsum-responsive perennial grasses in 1990.

Results indicate that the effectiveness of a 1987 surface application of gypsum in reducing spoil sodicity during 1988, 1989, and 1990 (Meining 1991) induced a remarkably rapid enhancement of plant growth during these 3 years. These findings are particularly significant considering gypsum's past performance as a relatively slow-acting inorganic amendment that is most effective when soil incorporated.

Conclusions

Vegetation responses during the 7th through 9th years of this continuing project strongly support the longer-term benefits from high rates of wood residue amendment for revegetation of non-topsoiled bentonite mine spoil, particularly for growth of dominant seeded perennial grasses. However, data also indicated that an inorganic Ca amendment is necessary in combination with wood residue to facilitate maximum plant growth through amelioration of spoil sodicity. Findings demonstrated that gypsum can satisfy Ca amendment needs, and can be applied effectively on the soil surface as a non-vegetative-destructive remedial technique on previously reclaimed sites experiencing sodication. The existence of residual effects of first-year N fertilization on vegetation during the 7th through 9th years indicates that certain benefits of this cultural practice, in combination with wood residue amendment, continued to be indirectly manifested over a long period. These findings illustrate the importance of rapid initiation of plant/soil systems through organic and inorganic amendments for effective reclamation of bentonite mine spoils. The success and nature of such rapid early establishment can continue to influence the adequacy, development, and maintenance of reclaimed ecosystems over extended periods of time.

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