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Plant responses to gypsum amendment of sodic bentonite mine spoil

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Abstract

Abandoned bentonite mine spoils are extremely difficult to revegetate because of their high clay content, salinity, sodicity, low permeability, and the semiarid climate of the area where bentonite mining occurs. Recent research has led to the development of technology utilizing sawmill wastes (chips, bark, and sawdust) to enable the successful revegetation of these lands. The use of wood residue amendments increased water infiltration, leaching of soluble salts, and vegetation establishment; however, sodicity continued to be a problem and threatened to destroy the established vegetation. Surface application of gypsum was evaluated to determine its effectiveness in ameliorating the spoil sodicity and its effect on plant growth. In a 3-year field study, surficial gypsum amendment resulted in significant increases in perennial grass biomass (150%) and canopy cover (140%). These changes were not evident until the second or third year after gypsum amendment. Annual forb biomass did not respond to gypsum amendment; however, canopy cover did exhibit a significant increase in the second year at lower wood residue amendment rates. This research demonstrates that surface applied gypsum can be effective in ameliorating bentonite spoil sodicity when applied to established plant communities.

Key Words: abandoned mine land, clay, sodium, reclamation, perennial grass

Abandoned bentonite mine spoils are extremely difficult to revegetate because of their high clay content, salinity, sodicity, low permeability, and the semiarid climate of the area where bentonite mining occurs. However, recent research has led to the development of technology enabling the successful revegetation of these lands (Schuman and Sedbrook 1984; Smith et al. 1985, 1986; Schuman and Belden 1991). This technology involved the use of sawmill wastes as a spoil amendment to improve water permeability and enable the leaching of salts from the root zone (Belden et al. 1990). Although spoil-incorporated sawmill wastes resulted in initially successful revegetation of these spoil materials, subsequent research demonstrated that spoil sodicity was increasing over time and threatening the long-term success of the revegetation (Belden et al. 1990, Schuman and Meining 1993). Early investigations of bentonite spoil characteristics pointed out the sodic nature of the material (Hemmer et al. 1977), but subsequent research initially investigating the use of inorganic amendments to address the sodicity problem resulted in minimal or no effect on plant establishment and growth (Dollhopf et al. 1981, Bjugstad et al. 1981). Later studies (Dollhopf et al. 1989, Schuman et al. 1989, Schuman and Meining 1993, Voorhees and Uresk 1990) demonstrated the positive effects of inorganic amendments on ameliorating spoil sodicity.

The objective of this study was to evaluate the effectiveness of surface-applied gypsum on revegetated sodic bentonite spoil on vegetation production and canopy cover.

Methods and Materials

The study site is located approximately 7 km northwest of Upton, in northeastern Wyoming. Bentonite deposits in this region occur at many stratigraphic positions in the Cretaceous strata. The strata mined in this area is the Mowry shale formation. The area was mined in the early 1950's and, at the time of research initiation in 1981, consisted of ungraded spoil piles and open pits about 10–15 m in height and depth. Approximately 2 ha of spoil were leveled in the spring of 1981. Spoil samples were taken to characterize the regraded spoil (Table 1). Wood residue amendment (bark, wood chips, and sawdust of *Pinus ponderosa)* was applied at rates of 0, 45, 90, and 135 Mg/ha (dry weight) and nitrogen fertilizer (NH_4NO_3) was applied at rates of 0, 2.5, 5.0, and 7.5 kg N/Mg of wood residue to develop a series of C:N ratios (469:1, 137:1, 81:1, and 57:1) within each wood residue rate. Nitrogen fertilizer was only applied once, at study initiation. Since nitrogen application

Table 1. Physical and chemical characteristics of pretreatment bentonite spoil samples (30 cm depth), Upton, Wyo. 1981 (Smith 1984).

Parameter	Mean and Standard Error*
Particle-Size-Separates (%)	
Sand (2–0.05 mm)	10.8 ± 0.8
Silt (0.05–0.002 mm)	29.6 ± 0.8
Clay (<0.002 mm)	59.6 ± 1.1
Saturation Percentage (%)	80.9 ± 1.7
NO_3-N (mg/kg)	7.7 ± 0.4
NH_4-N (mg/kg)	2.6 ± 0.1
TKN (mg/kg)	751.1 ± 5.8
Inorganic P (mg/kg)	8.1 ± 0.3
C (mg/kg)	10.0 ± 1.0
pH	6.8 ± 0.1
EC (ds/m)	13.4 ± 1.1
Water Soluble Cations	
Ca (mg/kg)	187.9 ± 9.2
Mg (mg/kg)	73.6 ± 4.2
Na (mg/kg)	3613.7 ± 101.3
K (mg/kg)	32.0 ± 0.8
SAR	63.1 ± 1.2

*Particle-size-separates obtained from 5 observations. All other parameters represent the mean of 144 samples.

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Table 2. Native plant species mixtures seeded on abandoned bentonite mine spoils, Upton, Wyo.

Scientific name	Common name	Cultivar	Drill seeding rate
			(PLS/m^2)
Pascopyrum smitthii (Rybd.) A. Love	Western wheatgrass	Rosana	130
Elymus lanceolatus (Scribner & J.G. Smith) Gould	Thickspike wheatgrass	Critana	130
Elymus trachycaulus (Link) Gould ex Shinners	Slender wheatgrass	Revenue	130
Agropyron riparium Scribn. & Smith	Streambank wheatgrass	Sodar	130
Stipa viridula Trin.	Green needlegrass	Lodorm	130
Artriplex nuttallii† S. Watts	Nuttall saltbush	PI 15658	32

†From Bridger Plant Materials Ctr., Bridger, Mont.

was based on wood residue amendment rate, the 0 Mg/ha wood residue treatment was given an application rate of 0, 112, 224, and 336 kg N/ha, which was equal to the 45 Mg/ha wood residue rate on a per hectare basis. Phosphorus was uniformly applied at the rate of 90 kg P/ha. Initial amendments (wood residue and fertilizer) were incorporated into the surface 30 cm of spoil. Two perennial grass mixture treatments (native and introduced species) were evaluated. The study reported here only evaluated the effect of gypsum amendment on the native species mixture (Table 2). Smith et al. (1985) presented detailed discussion of amendment incorporation, seedbed preparation, and seeding practices.

The study experimental design was a split plot type with a split block within the main treatment (wood residue) and 3 replications (Fig. 1). Each block consisted of 4 main plots representing each of the 4 wood residue treatments. Each main plot was split and half seeded to the native grass mixture and the other half seeded to the introduced species grass mixtures. Therefore, the study was comprised of 96, 14.6 by 9.6-m subplots.

To evaluate the effect of surface-applied gypsum on vegetation production and canopy cover, one-half of the native species grass mixture plots were amended with 56 Mg/ha of gypsum in April 1987 while the other half of the plots did not receive gypsum (Fig. 1). The gypsum was applied at a rate to supply sufficient calcium to reduce the exchangeable sodium percentage of the surface 30 cm of spoil to 15% from a pretreatment level of 48%. Gypsum requirement was calculated using the procedure described by the U.S. Salinity Laboratory Staff (1954). The gypsum, ground to pass a 200-mesh screen, was from a local source.

Vegetation sampling was accomplished in 1988–1990. Two permanent 0.25-m^2 rectangular quadrats were established within each wood residue-fertilizer-gypsum treatment combination subplot for estimating various cover components. Cover was ocularly estimated each year during the period of estimated peak live biomass (June–July), using the general procedures of Daubenmire (1959) as modified by Smith (1984). Canopy cover was estimated by growth form (total vegetation, perennial grass, annual grass, annual forbs, and shrub). Estimates of bare ground and litter cover were also performed. One 0.50-m^2 (71 by 71 cm) quadrat was randomly located with each replicated treatment combination subplot each year for determining aboveground biomass, with different quadrat locations each year. Biomass sampling occurred the first week in July all 3 years, which also represented the time of peak standing crop. All plant biomass within the quadrats was hand-harvested to ground level and divided into the following growth form categories: perennial grass, annual grass, 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

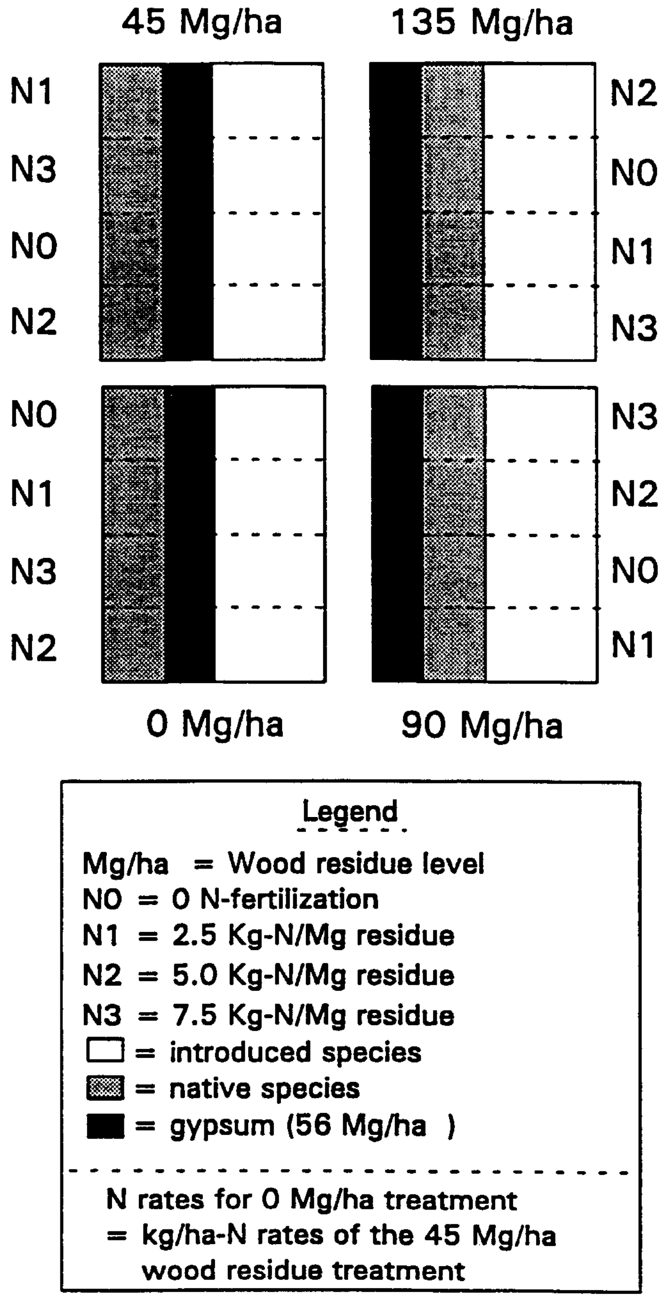

Fig. 1. Field plot design (replication) for evaluating the effectiveness of surface-applied gypsum on ameliorating the sodicity of revegetated bentonite spoils.

harvested. Harvested plant material was oven dried at 60° C and weighed.

The data were analyzed using analysis of variance and mean separation was accomplished using Least Significant Difference (LSD) at the 0.10 level of probability. Wood residue rates, nitrogen fertilizer rates, and gypsum rates were treated as independent variables.

Results and Discussion

Precipitation

Precipitation during the study period (1987–1990) was 77, 89, 106, and 83% of the 362-mm long-term average, respectively. Therefore, the effects of the gypsum on the sodic spoil and plant community were what one should expect during average climatic conditions.

Plant Biomass

Perennial grass biomass exhibited main effect responses to the gypsum amendment and time since application (years). Perennial grass biomass averaged 175 and 317 kg/ha over the years 1988–1990 for the 0 and 56 Mg/ha gypsum treatment, respectively, indicating a significant enhancement of productivity by gypsum amendment. Perennial grass biomass increased from 211 and 202 kg/ha in 1988 and 1989, to 325 kg/ha in 1990. The significant increase in biomass in 1990 is probably related to the continuing improvement in physical characteristics of the spoil and the resultant improvement in water infiltration and storage. Schuman and Meining (1993) showed a significant decrease in sodicity (ESP) and a significant increase in water storage as a result of the gypsum amendment.

Annual forb biomass exhibited a gypsum by wood residue amendment by year interaction (Table 3). Annual forb biomass was generally greater at the lower wood residue amendment rates, which agrees with earlier observations from this research (Smith et al. 1985). Annual forb biomass responded significantly to gypsum amendment only in 1990 within the non-wood residue amended treatment, where biomass was higher in gypsum (1,020 kg/ha) than in non-gypsum plots (365 kg/ha). The lack of other significant differences was probably the result of the extreme variation in annual forb biomass observed, which is reflected in a large LSD value of 535 kg/ha.

Table 3. The effect of wood residue and gypsum amendment of bentonite mine spoils on annual forb biomass over years, 1988–1990, Upton, Wyo.

Wood residue application	1988		1989		1990	
	Gypsum Amendment (Mg/ha)					
	0	56	0	56	0	56
(Mg/ha)	(kg/ha)					
0	39a	146a	115a	383a	365a	1020b
45	34a	122a	47a	257a	112a	308a
90	28a	133a	85a	44a	109a	116a
135	5a	45a	53a	73a	14a	52a

Means within a year and wood residue rate followed by the same lower case letter are not significantly different ($P \leq 0.10$).

Shrub biomass did not respond to gypsum or wood residue treatments, possibly due to their variable distribution on the plots and inadequate sample size. Vegetation biomass did not exhibit any response to the nitrogen fertilizer amendment treatment. This was not surprising, since fertilization comprised only a single application of N in 1981, 7–9 years earlier.

Canopy Cover

Perennial grass canopy cover exhibited significant wood residue rate by gypsum and gypsum by year interactions. Perennial grass canopy cover was higher when the spoil was amended with gypsum within the 90 and 135 Mg/ha wood residue amendment levels (Table 4). This response was similar to that observed throughout the study for many parameters. The 2 highest wood residue rates have consistently produced significantly greater plant biomass, plant densities, soil water storage, and soluble salt leaching than the 0 and 45 Mg/ha wood residue treatments, and have generally not been significantly different from each other (Smith et al. 1985, 1986; Smith 1984; Belden 1987; Belden et al. 1990). Perennial grass canopy cover did not differ between gypsum treatments in 1988, but was significantly higher in the 56 Mg/ha gypsum treatment in 1989 and 1990 (Table 5). The observed response demonstrates the effect of time necessary to dissolve the surface applied gypsum and cause any significant reduction in soil sodicity that will be reflected in improved water infiltration, water storage, and plant growth.

Table 4. The effect of gypsum and wood residue amendment of bentonite mine spoil on perennial grass cover (averaged over years, 1988–1990), Upton, Wyo.

Wood residue application	Gypsum Amendment (Mg/ha)	
	0	56
(Mg/ha)	% cover	
0	1a	1a
45	6a	10a
90	23a	38b
135	33a	39b

Means within a wood residue level followed by the same lower case letter are not significantly different ($P \leq 0.10$).

Table 5. The effect of gypsum amendment of bentonite mine spoil on perennial grass cover over years, 1988–1990, Upton, Wyo.

Gypsum amendment	1988	1989	1990
(Mg/ha)	% cover		
0	16a	17a	14a
56	19a	24b	24b

Means within a year followed by the same lower case letter are not significantly different ($P < 0.10$).

Annual forb canopy cover exhibited a gypsum by wood residue amendment by year interaction (Table 6). Annual forb canopy was significantly higher on gypsum treated plots at the 0 and 45 Mg/ha wood residue treatments in 1989 and 1990. Gypsum amendment had no significant effect on annual forb canopy cover at the 90 and 135 Mg/ha wood residue treatments. The lack of response at the higher residue amendment rates was not unexpected, since annual forb growth was considerably lower on those treatments because of increased competition from more residue-responsive perennial grass (Smith 1984, Smith et al. 1985).

Table 6. The effect of gypsum and wood residue amendment of bentonite mine spoil on annual forb canopy cover over years, 1988–1990, Upton, Wyo.

Wood residue application	1988		1989		1990	
	Gypsum amendment (Mg/ha)					
	0	56	0	56	0	56
(Mg/ha)	% cover					
0	3a	9a	9a	21b	18a	51b
45	1a	3a	4a	17b	8a	24b
90	3a	2a	7a	9a	10a	9a
135	1a	5a	4a	7a	3a	11a

Means within a wood residue level and year followed by the same lower case letter are not significantly different ($P \leq 0.10$).

Results of this research have shown that surface-applied gypsum can improve productivity and canopy cover of existing plant communities on sodic bentonite mine spoils. The data also indicated that approximately 2 years were necessary before plant response to gypsum amendment occurred. This delayed treatment response is probably due to the low dissolution rate of gypsum, the low precipitation of the area, and the effects of surface application on the dissolution of gypsum. It is likely that if the gypsum had been incorporated the dissolution rate would have been significantly increased and we should have observed a quicker response to treatment (Shainberg et al. 1989, Hira et al. 1981). The findings of this research also demonstrate that gypsum amendment can be effective when surface applied on vegetated sodic soils/spoils under natural rainfall conditions without the requirement of supplemental irrigation. These findings and those presented by Schuman and Meining (1993) suggest that potential benefits might be achieved from the utilization of industrial by-products (such as phosphogypsum) on sodic grassland soils.

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