UTILIZATION OF SAWMILL BY-PRODUCTS AND GYPSUM TO REVEGETATE SODIC BENTONITE MINE SPOILS

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FINAL REPORT TO THE ABANDONED MINE LAND PROGRAM
WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

Utilization of Sawmill By-Products and Gypsum to Revegetate Sodic Bentonite Mine Spoils

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INTRODUCTION

Lands disturbed by or abandoned after bentonite mining in the Northern Great Plains are difficult to reclaim because of adverse chemical and physical properties of the spoil material, the limited inherent topsoil, the arid/semiarid climate of the area, and to some extent, the mining methods utilized. Although large scale bentonite mining began in the region in the 1930's, few areas were reclaimed until after enactment of reclamation laws in the early 1970's. Ninety percent of the United States' supply of bentonite is mined in the Northern Great Plains states of Montana, South Dakota, and Wyoming (Ampian, 1980). The National Academy of Sciences (1974) reported that more land was disturbed in 1973 by bentonite mining than by coal mining in Montana, and that more abandoned spoils had accumulated over the years from bentonite than from coal mining. Although these statements refer to Montana, they are indicative of the regional situation as well.

Natural revegetation and man assisted reclamation seedings of non-topsoiled, non-amended bentonite spoils have resulted in no to poor plant establishment (Sieg et al., 1983; Dollhopf and Bauman, 1981); therefore, spoil modification is essential for successful revegetation of these sodic, saline, high clay content spoils. Reclamation of abandoned bentonite spoils has met with limited success (Hemmer et al., 1977; Dollhopf and Bauman, 1981; Bjugstad et al., 1981) unless organic amendments were utilized. Schuman and Sedbrook (1984) reported on a 1979-1983 study which demonstrated the effectiveness of sawmill wastes (sawdust, woodchips, and bark) in improving the physical characteristics of the spoil, greatly enhancing water infiltration and promoting vegetation establishment.

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Dollhopf and Bauman (1981) evaluated the use of woodchips (1660 m3/ha) and manure (224 Mg/ha) in conjunction with 4500 kg/ha of straw mulch in a 1980 study. They obtained good first year plant densities with woodchips; however, the manure only resulted in about 23% of the density obtained with the woodchips. They also evaluated the effectiveness of the inorganic amendments gypsum, calcium chloride, and sulfuric acid, but these amendments resulted in poor initial seedling establishment. Dollhopf and Bauman (1981) also evaluated the effect of these inorganic amendments on the hydraulic conductivity of the spoil and found that although they increased the hydraulic conductivity it was still below the 'very slow' permeability class, 0.125 cm/hr (Kohnke, 1968). The authors concluded that the poor plant establishment observed was because these chemical amendments did not alter the physical condition of the spoil rapidly enough to enable successful seedling emergence, but that over time these amendments may prove beneficial.

The findings of Dollhopf and Bauman (1981) are not unexpected since inorganic amendments used alone may require considerable time (perhaps years) to improve spoil physical characteristics through the replacement and leaching of sodium under natural precipitation conditions. Dissolution of the gypsum or calcium chloride and replacement of the sodium might have occurred, but leaching probably could not occur with a considerable amount of time and/or the alteration of the spoil in a way that improved infiltration, allowing the sodium to be leached from the spoil profile (U.S. Salinity Laboratory Staff, 1954; Hira et al., 1981; Prather, et al., 1978). Conversely, the dissolution of the inorganic amendments can result in a large increase in the salinity at levels otherwise not detrimental to growth and development of established plants (U.S. Salinity Laboratory Staff, 1954; Heather and Hegarty, 1979). It is noteworthy, however, that Dollhopf and Bauman (1981) demonstrated a very good initial plant density on the woodchip and topsoiled treatments where immediate improvement of physical characteristics occurred under the same precipitation conditions with which poor results were obtained with the inorganic amendments.

Research findings thus demonstrate the need for an effective bentonite spoil amendment program to achieve rapid and successful reclamation. To be successful, the program must achieve immediately improved water infiltration for vegetation establishment and sodium leaching to ensure the effectiveness of any inorganic amendment used to ameliorate the sodicity problems. If both of these requirements of improved infiltration and sodium replacement/leaching are not met, long-term reclamation may not be achieved or may require more time.

The use of topsoil placement over bentonite spoil is not seen as a viable option for abandoned mined land reclamation. No topsoil salvage was accomplished during the mining and in most situations/environments topsoil borrowing is not recommended. Topsoil is a limited resource in the area, and the disturbance of undisturbed rangeland results in a significant additional land area requiring revegetation and post-reclamation management (Richmond, 1991). Because existing soils are very shallow, only a limited depth of topsoil would be available to cover the characteristically sodic spoil materials. A shallow covering may enable initial revegetation, but experience has shown that unless sodic spoils are buried sufficiently, sodication of the soil will occur within a short time (Merrill, et al., 1980; Dollhopf, et al., 1985). Therefore, the use of topsoil was considered to technically and environmentally an unsound alternative practice.

The purpose of this report is to summarize the findings resulting from 12 years of bentonite reclamation research. This research was initially funded in part by the Department of Environmental Quality, Land Quality Division and in later years was funded by the Abandoned Mine Land Division. Funding was also supplied by the Agricultural Research Service, USDA, High Plains Grasslands Research Station and the Plant, Soil and Insects Sciences and Range Management Departments at the University of Wyoming.

RESEARCH FINDINGS

Evaluation of Organic Amendment-Sawmill By-Products

Field studies were initiated in 1979 on 1.5 ha of leveled abandoned bentonite spoils near Upton in northeastern Wyoming (Schuman and Sedbrook, 1984). These spoils were typical of the abandoned spoils associated with the Mowry shale formation (Table 1). The study involved an initial evaluation of the feasibility and effectiveness of wood residues (woodchips, bark, and sawdust) as an amendment to improve the soil physical characteristics of the spoil and thereby aid revegetation. Wood residue rates of 0, 112, and 224 Mg/ha, nitrogen fertilizer at 5.0 kg N/Mg of wood residue and phosphorus fertilizer at 90 kg P/ha were incorporated into the leveled spoil to a depth of 30 cm. Plots were drill seeded in mid-June with a mixture of wheatgrass, forbs, and shrubs.

The addition of 112 and 224 Mg/ha of wood residue doubled the soil-water content in the 0- to 20-cm spoil depth (Table 2). Soil-water at the 20- to 40-cm depth was also slightly greater in the amended plots compared to the control. The decreased effect of wood residue on soil-water at the deeper spoil depth is related to the fact that amendment incorporation only occurred to 30 cm; therefore, infiltration below that depth was limited. The observed increase in soil-water storage allowed for good seed germination, seedling establishment, and forage production.

Table 1. Physical and chemical characteristics of pretreatment bentonite spoil samples, Upton, WY, 1981. (Smith, 1984).

Parameter	Mean and Standard Error*
Particle-size Separates(%)	
Sand	10.8 ± 0.8
Silt	29.6 ± 0.8
Clay	59.6 ± 1.1
Saturation Percentage (%)	80.9 ± 1.7
NO3-N (mg/kg)	7.7 ± 0.4
NH4-N (mg/kg)	2.6 ± 0.1
TKN (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 (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
Sodium adsorption ratio	63.1 ± 1.2

*Particle-size separates obtained from five observations. All other parameters are a mean of 144 samples.

Table 2. The effect of wood residue amendment of bentonite spoils on the soil-water content, Upton, WY, 198 and 1982 average. (Means among wood residue levels within a spoil depth followed by the same letter are not significantly different, P≤ 0.05)(Schuman and Sedbrook, 1984).

Wood Residue Treatment (Mg/ha)	Spoil Depth (cm) 0-20	20-40	40-60
	Water Content (g/kg)		
0	115a	138a	139a
112	212b	166b	143a
224	232b	180b	155a

Seeded species production was significantly improved by the addition of the wood residue amendment (Table 3). In 1980, no statistically significant differences in production across wood residue rates were evident, partially due to the variability in the data. However, the 112 and 224 Mg/ha wood residue treated plots averaged 386 kg/ha compared to 17 kg/ha for the control. In other years, the production of the amended plots was significantly greater than the control, and responded to the 28% above average precipitation in 1982.

This preliminary study demonstrated the effectiveness of the wood residue amendment in enabling establishment of vegetation and subsequent forage production from abandoned bentonite mined lands. To better understand the long-term stability and management of these lands, information was needed that demonstrates the effects of the wood residue amendment on the chemistry of the spoil system. Therefore, in 1981 a second study was established about 1 km from the preliminary study site. This study was conducted to refine the wood residue and nitrogen fertilizer requirements to ensure the most efficient amendment combination for revegetation and to evaluate the treatment effects on the spoil chemistry. The study was a split-plot design with a split-block within the wood residue treatments (Figure 1). Four wood residue rates (0, 45, 90, and 135 Mg/ha), four nitrogen fertilizer rates (0, 2.5, 5.0, and 7.5 kg N/Mg of wood residue) and two seed mixtures (native and introduced species) were established. Nitrogen was applied at the rate of 0, 112, 224, and 336 kg N/ha on the 0 wood residue treatment. These nitrogen rates were equal to those applied on the 45 Mg/ha wood treatment on a per hectare basis. Phosphorus was applied uniformly at the rate of 90 kg P/ha. Smith et al. (1985) provided complete details on study design and implementation.

Table 3. Seeded species aboveground biomass on bentonite mine spoils as affected by wood residue amendment, 1980-1983, Upton, WY. (Means within a year followed by the same letter are not significantly different, P≤ 0.05)(Schuman and Sedbrook, 1984).

	Wood Residue Rates (Mg/ha)		
Year	0	112	224
		kg/ha	
1980	17 a	381 a	392 a
1981	15 a	703 b	554 b
1982	12 a	1006 b	1332 b
1983	3 a	760 b	1202 b

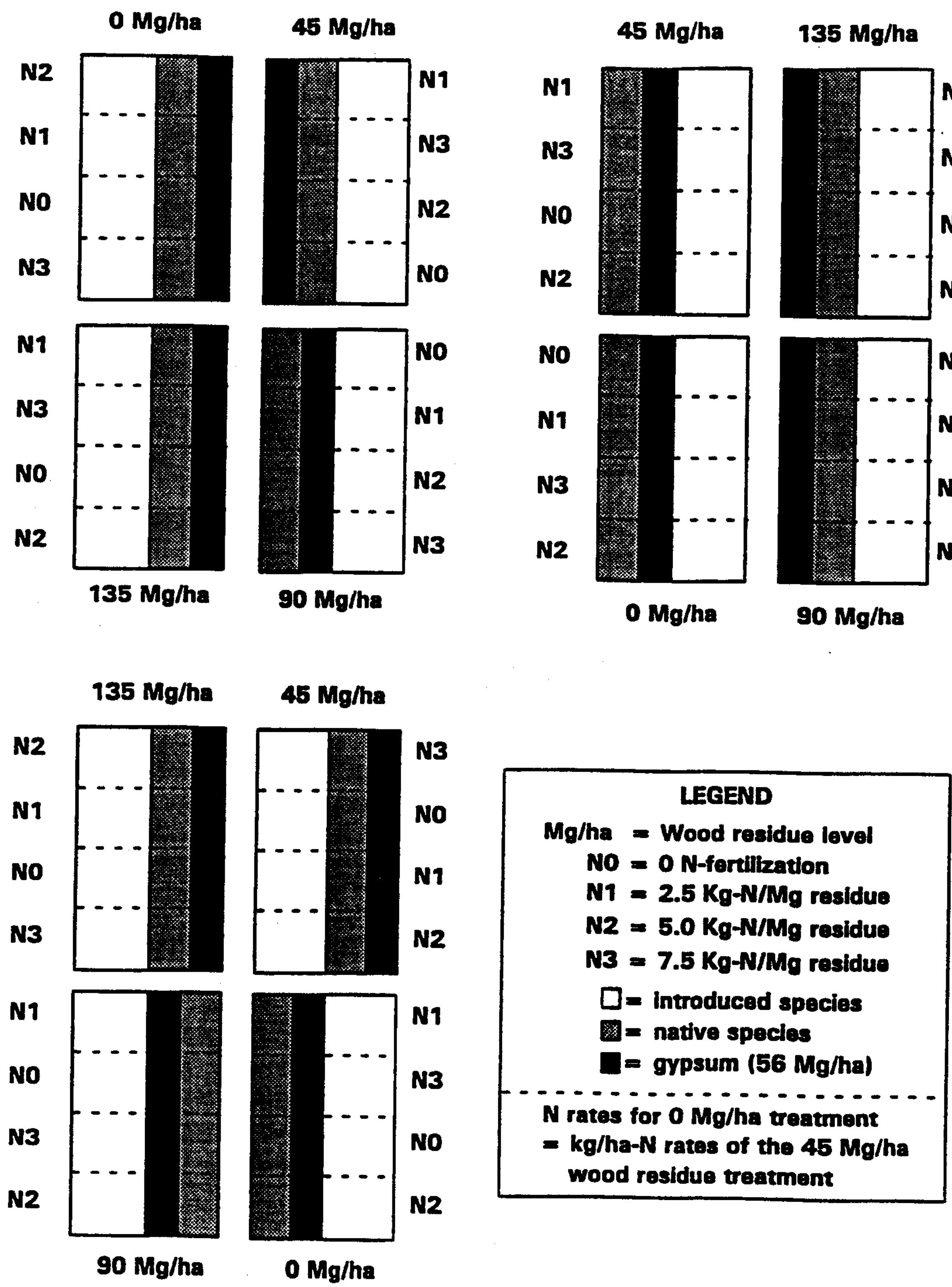

Figure 1. Field plot design for evaluating the effectiveness of wood residue, nitrogen fertilizer and gypsum on ameliorating the physical and chemical properties of bentonite spoils.

Vegetation Responses

Plant response to wood residue amendment in this study was similar to that observed in the preliminary study. Seedling density was significantly improved by wood residue amendment because of its effect on soil-water content, crusting, and bulk density. Seedling density was greater for the three nitrogen treatments (41, 60, and 70 plts/m2) than for the no nitrogen treatment (14 plts/m2). However, there were no differences in seedling density between the three nitrogen fertilizer levels. Perennial grass production increased as wood residue rates increased, with maximum production occurring at the 135 Mg/ha wood residue level (Table 4). Production in 1985 was extremely low compared to previous years because of extreme drought conditions that year. Precipitation from August 1984 through June 1985 was approximately 60% of normal for the period. However, normal precipitation occurred in late summer 1985 and during the 1986 growing season, resulting in the improved production observed in 1986. Visual observation of the plant community in 1986 indicated that some plant mortality had occurred as a result of the drought; therefore, predrought production levels may not be reached again for several years. Perennial grass production also responded to nitrogen fertilizer rates in 1983 and 1984 with peak biomass occurring at the 2.5 and 5.0 kg N/Mg of wood residue rates, respectively. In contrast, nitrogen had no appreciable effect on production in 1985 and 1986. The limited nitrogen response in these years was probably the result of the drought.

With the exception of tall wheatgrass (Agropyron elongatum Host.), all successfully established grass species in the initial growing season were rhizomatous (See Smith et al., 1986 for details of individual species response to the amendments). This suggests that sod-forming grasses are generally better suited than bunchgrasses for revegetation of bentonite spoils. The predominance of sod-forming grasses on clay soils in the region support this observation (Weaver and Albertson, 1956). Rhizomes have been noted to exhibit physical resistance to breakage and the capacity for regrowth and/or increased production from rhizomes after breakage in a high clay soil (White and Lewis, 1969). Findings have demonstrated that plant species potentially useful and/or successful in revegetation of wood residue amended, abandoned bentonite spoils should have at least some of the following characteristics: sod-forming morphology, drought and salt tolerance, adaptation to clay texture, and adaptation to a shallow, poorly drained spoil/soil environment (Smith, et al., 1986).

Table 4. Perennial grass production (averaged across species mixtures and nitrogen fertilizer treatments) in response to wood residue rate, Upton, WY, 1983-1986. (Means among wood residue rate followed by the same letter are not significantly different, $P \leq 0.05$) (Smith, 1984; Belden, 1987; and unpublished data).

	Wood Residue Rate (Mg/ha)			
Year	0	45	90	135
		kg/ha		
1983	59 a	669 b	1748 c	2550 d
1984	80 a	361 a	1220 b	1956 c
1985	10 a	55 a	148 a	448 a
1986	15 a	116 1	324 a	886 b

Spoil Responses

Edaphic responses to wood residue amendment were exhibited in three ways: increased water infiltration and storage, decreased salinity due to leaching, and increased sodicity. The improved water storage as a result of wood residue amendment has been adequately discussed, using results of the earlier studies by Schuman and Sedbrook (1984). However, the increased water movement into the spoil in the second study demonstrated significant leaching of the soluble salts from the surface 15 cm of the spoil from 1981 to 1984 (Figure 2). In 1985, the severe drought resulted in significant upward migration of salts as a result of upward water movement in response to high evapotranspiration demands. Although upward salt migration occurred during the drought year, the electrical conductivity of the 0-15 cm spoil depth in 1985, nonetheless, did not exceed that in 1982.

Leaching of soluble salts is desirable and necessary to encourage soil development and long-term stability of these lands. However, the leaching process resulted in an increase in spoil sodium-absorption-ratio (SAR) in the residue amended plots over time (Figure 3). The pool of soluble sodium (91% of soluble cations) is so large that as leaching occurs, the relative proportion of sodium in the system compared to calcium and magnesium has become greater, thereby increasing the SAR. This observed increase in SAR can have significant long-term effects on plant nutrition, spoil physical qualities and subsequent maintenance of the vegetation community. The increasing SAR indicates that chemical amendments are necessary in addition to the wood residue, to ensure long-term reclamation and revegetation success. Such chemical amendments may include gypsum, phosphogypsum, and calcium chloride.

Evaluation of an Inorganic Amendment-Short-term Effects of Gypsum

In 1986, an inorganic amendment study was designed to evaluate the feasibility and effectiveness of amending previously revegetated lands with superficially applied gypsum.

In April 1987, gypsum was surface applied at the rate of 56 Mg/ha to approximately 40% of each of the native seed mixture plots of the 1981 study (Figure 1). This level of gypsum amendment was adequate to reduce the exchangeable-sodium-percentage (ESP) of the sodic spoil to 15. By using the existing 1981 study plots, we could evaluate the effects of gypsum upon previously established vegetation, and we would have long-term baseline spoil data with which to determine the effectiveness of gypsum in alleviating the increasing sodicity problem.

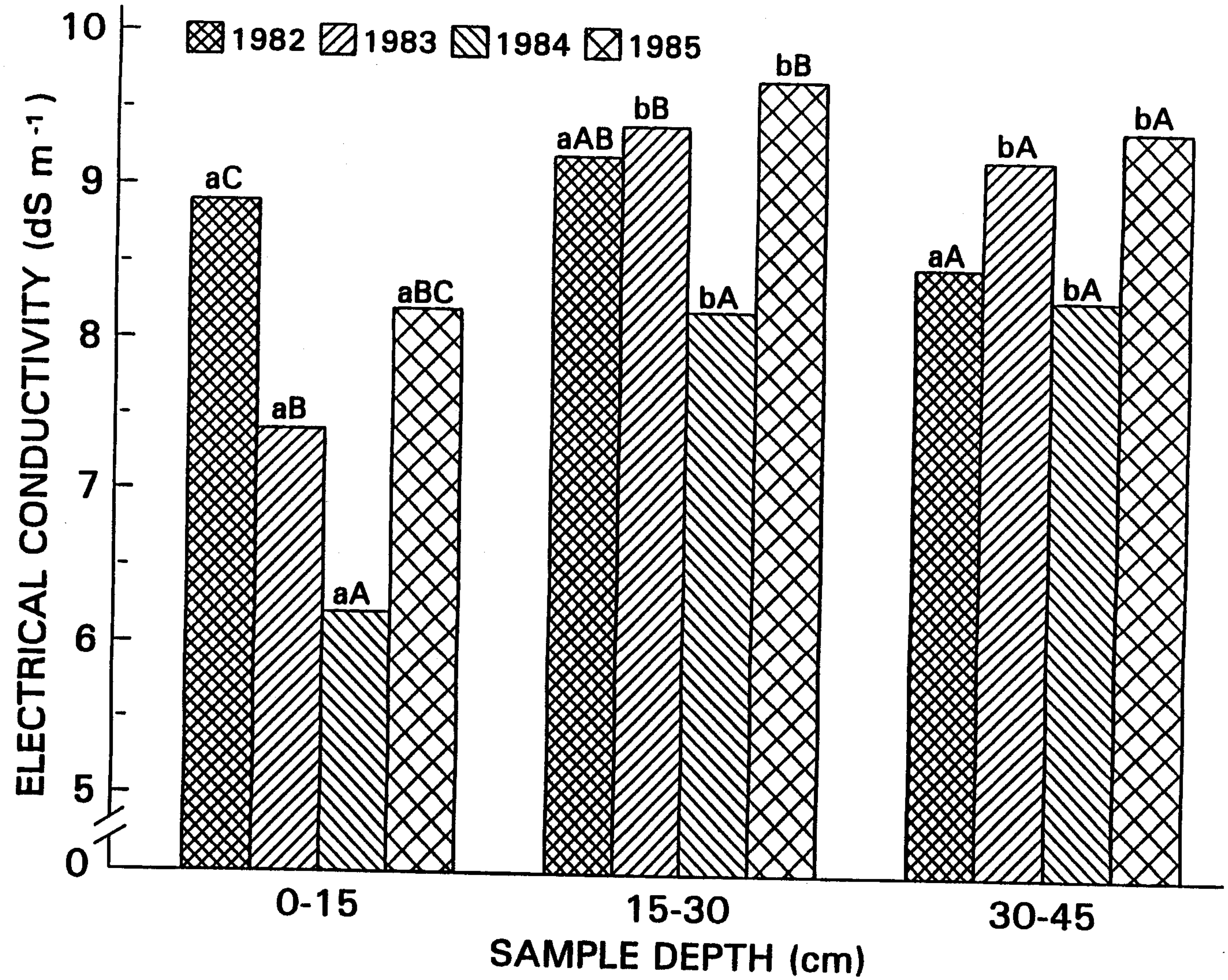

Figure 2. Mean electrical conductivity averaged across wood residue and nitrogen fertilizer treatments for 1982-1985, at three sample depths. Means among years and within years with the same lower case and upper case letter, respectively, are not significantly different at $P \leq 0.05$. (Belden 1987).

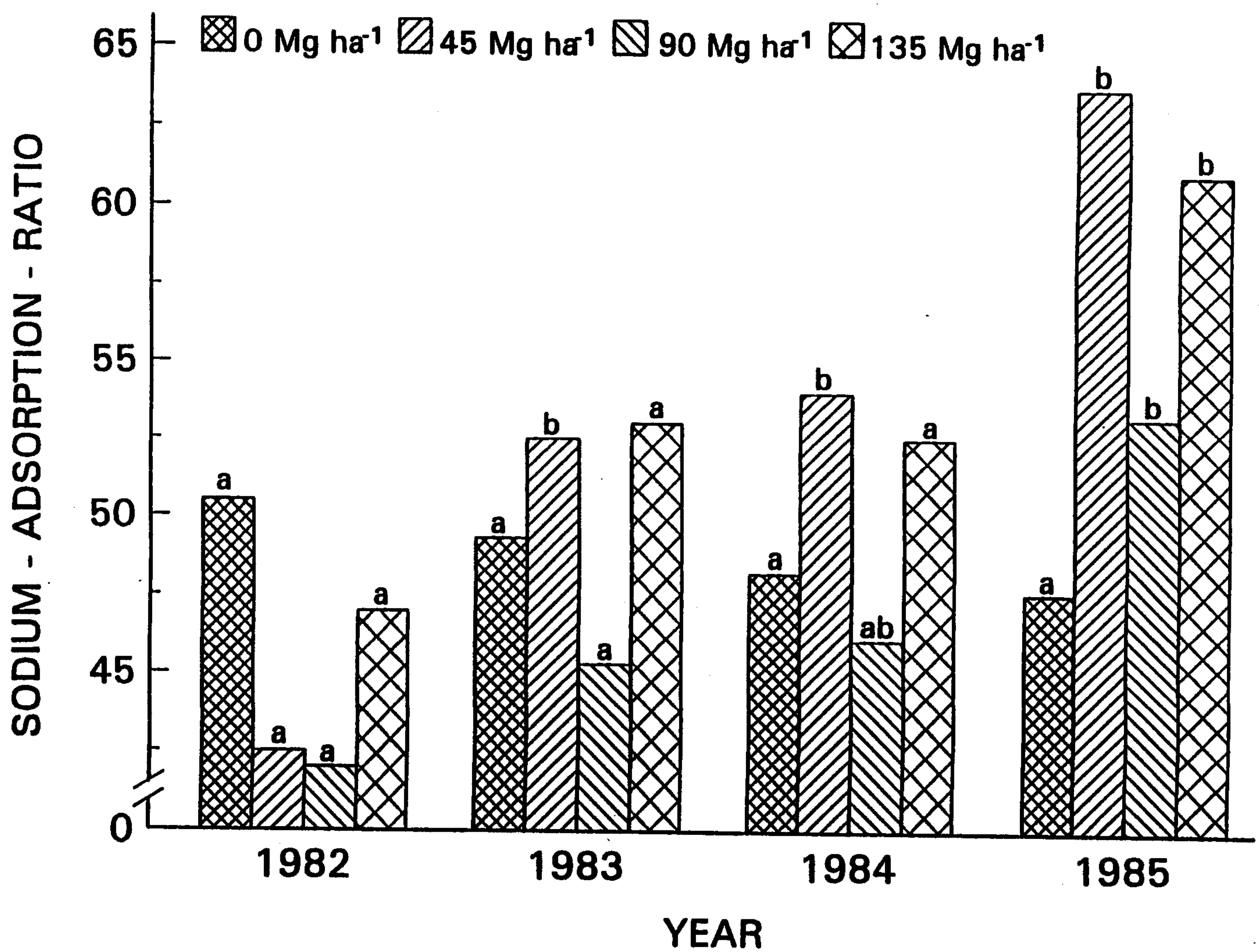

Figure 3. Mean sodium-adsorption-ratios averaged across nitrogen fertilizer treatments and sample depths, at four wood residue levels for 1982-1985. Means among years with the same lower case letter are not significantly different at $P \leq 0.05$. (Belden 1987).

Spoil samples were collected in October 1986 and in May 1988-1990 to evaluate the effects of gypsum. Figure 4 shows the effect of the gypsum amendment on the EC of the spoil. This observed increase in salinity due to the calcium-rich gypsum amendment was expected, but analysis of vegetation production data suggested no detrimental effects on the established plants. 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 (Schuman, et al., 1994). Perennial grass biomass increased from 211 and 202 kg/ha in 1988 and 1989, to 325 kg/ha in 1990 (Schuman, et al., 1994). However, such increases in salinity could result in reduction of germination and seedling establishment if applied during initial reclamation. Indeed, if gypsum had been applied during initial reclamation of this site, the EC would have been even higher in these spoils, since by 1987 leaching from the surface spoil depth had occurred several years to reduce EC considerably below the initial EC of 13.4 dS/m in 1981 (Table 1). However, the observed increase would have been less if the gypsum had been incorporated in a larger volume spoil. Such a large increase in salinity may have influenced seedling establishment in Dollhopf and Bauman's (1981) inorganic amendments study, since they observed fair-to-good seedling establishment when using deep chiseling with irrigation or woodchip amendment treatments. Even though the EC increased in 1988, it decreased significantly over the next two years. This decrease is considered to be the result of leaching (Schuman and Meining, 1993).

Gypsum treatment significantly reduced the exchangeable-sodium-percentage of the 60-cm spoil profile (Figure 5). These changes began to become evident within the first 13 months after treatment. The gypsum amendment also significantly increased the spoil-water storage in the 60-cm spoil profile (Figure 6).

The benefits exhibited during the 3 years documented by this phase of the study should be further enhanced with time.

Decomposition and Sustainability

Sustained long-term success of these reclaimed lands depends on the continued improvement and development of a 'soil'. In addition to amelioration of the saline-sodic condition and improved structure; 'the new' must develop active microbial functions to ensure nutrient availability through sustained nutrient cycles. Evaluation of wood residue decomposition indicates that microbial functions have begun to develop. Wood residue decomposition after 1, 2, 3, and 5 years was 10.7, 11.0, 16.5, and 26.3%, respectively (Figure 7). The single nitrogen addition in 1981 had a pronounced effect on decomposition during that 5 years period (Figure 8). Long-term evaluation of wood residue decomposition has shown that after 10 years little

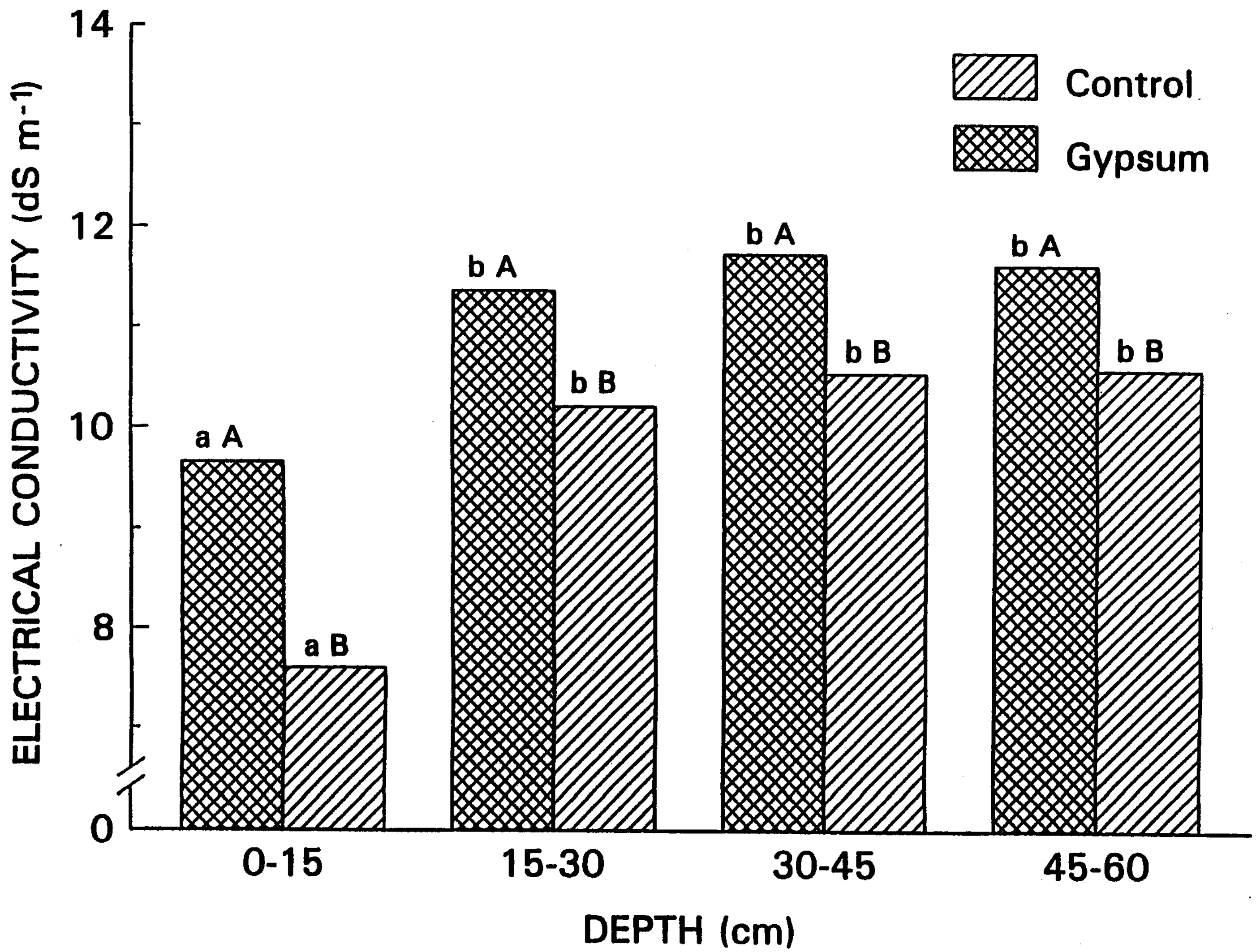

Figure 4. The effect of gypsum amendment on the electrical conductivity of wood residue amended bentonite spoil at four spoil depths, 1988 to 1990. (Means within a treatment with the same lower case letter and means within a depth with the same upper case letter are not significantly different, $P \leq 0.10$) (Schuman and Meining 1993).

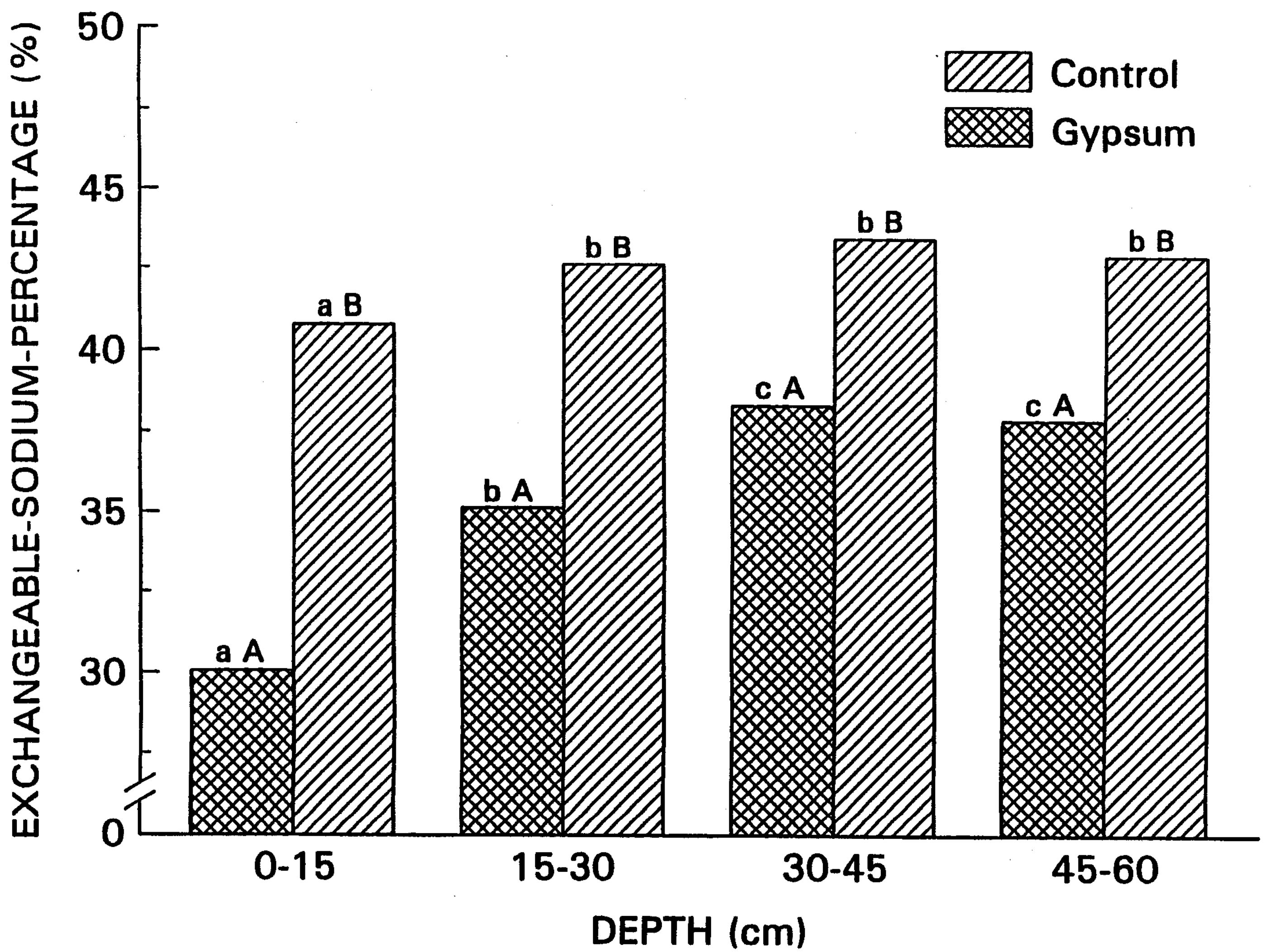

Figure 5. The effect of gypsum amendment on the exchangeable sodium percentage of wood residue amended bentonite spoil at four depths, 1988 to 1990. (Means within a treatment with the same lower case letter and means within a depth with the same upper case letter are not significantly different, $P \leq 0.10$) (Schuman and Meining 1993).

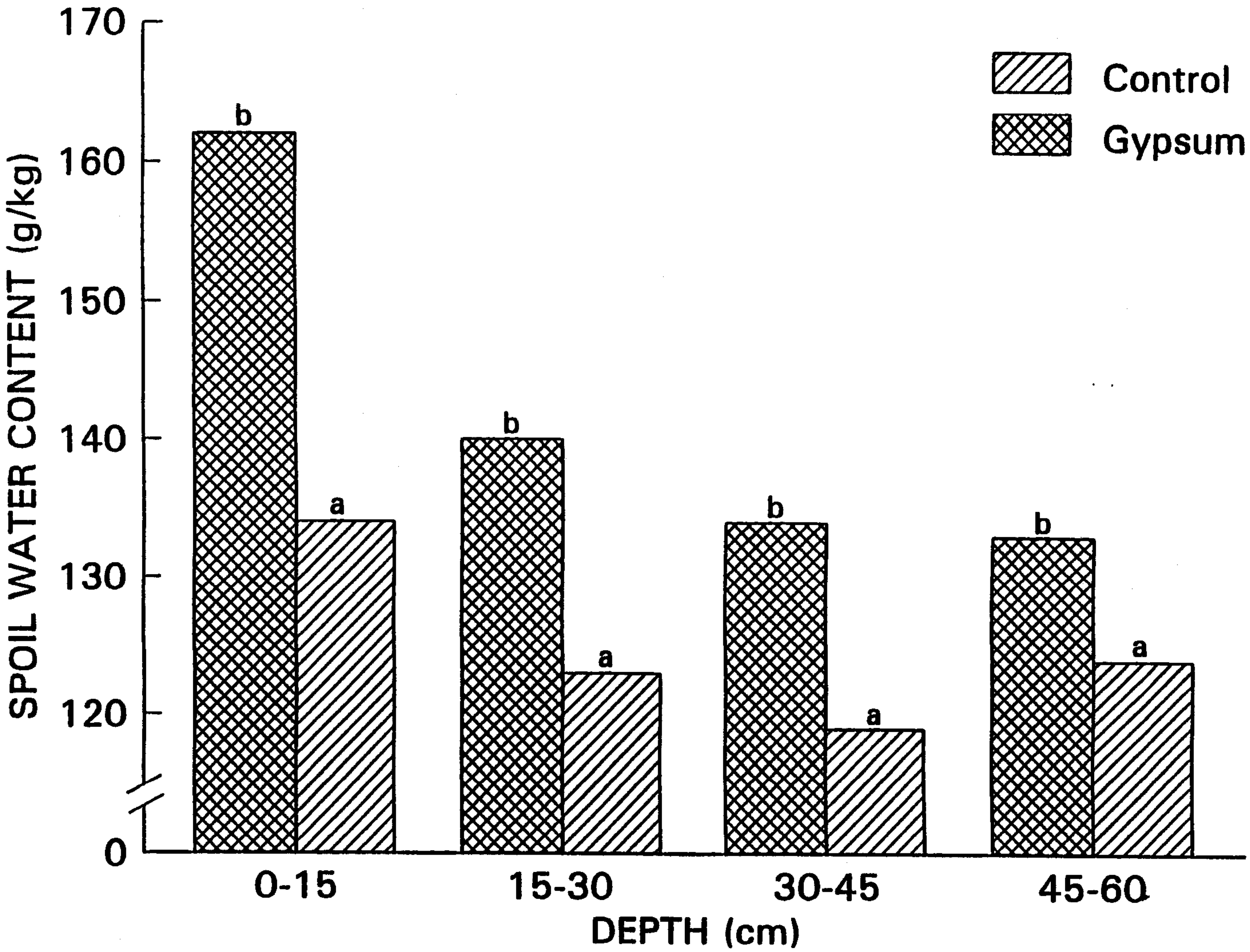

Figure 6. Response of spoil water content of revegetated saline-sodic bentonite mine spoil to gypsum amendment, 1988 to 1990. (Means within a spoil depth with the same lower case letter are not significantly different, $P \leq 0.10$) (Schuman and Meining 1993).

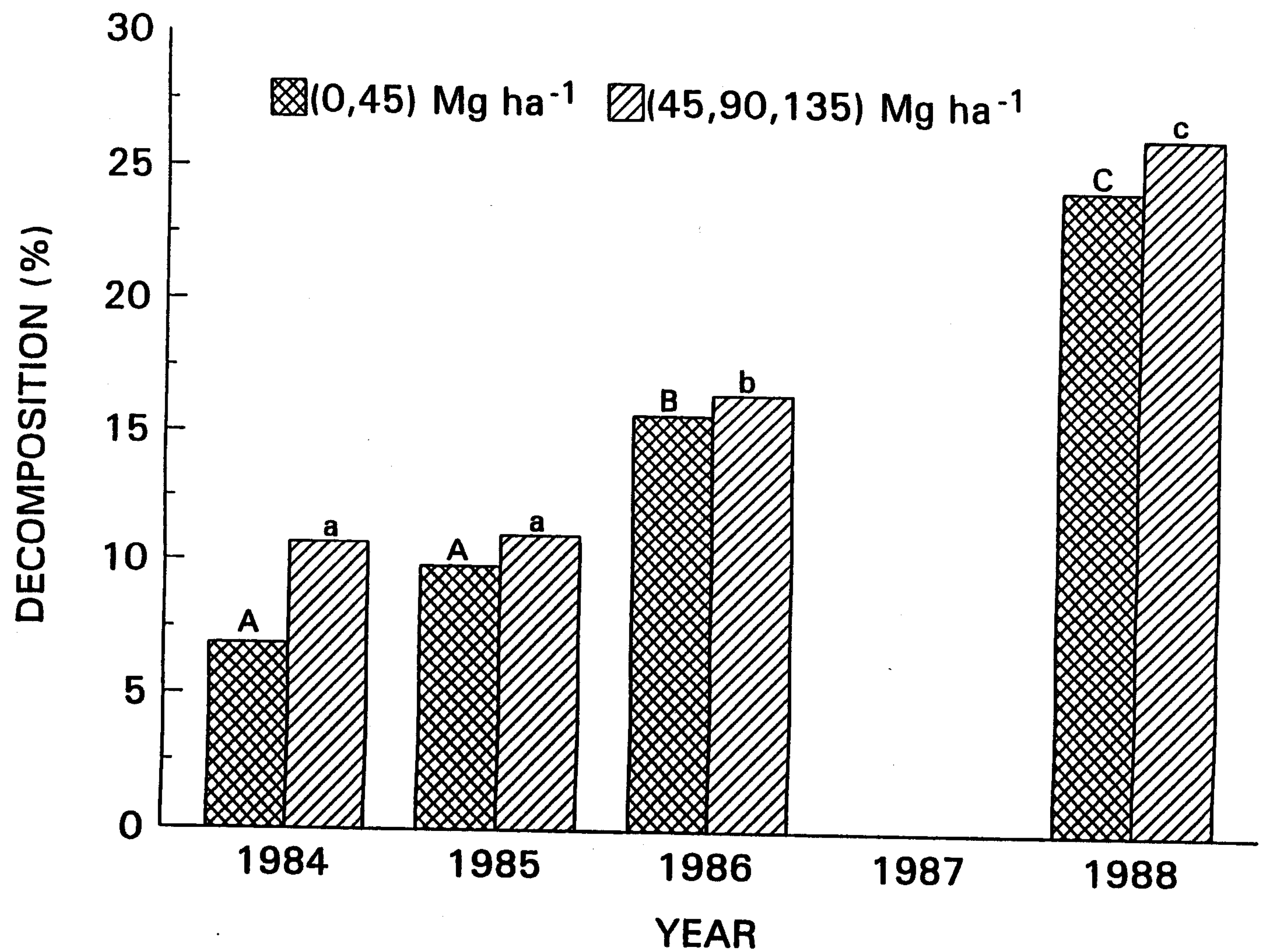

Figure 7. Decomposition of wood residues amended to bentonite mine spoil for a 5-yr period. (Data analyzed separately for 0 and 45 and 45, 90, and 135 Mg ha^{-1} wood treatment). Means within the 0,45 and 45,90,135 Mg ha^{-1} treatments with the same upper and lower case letter, respectively, are not significantly different at $P \leq 0.05$. (Schuman and Belden 1991).

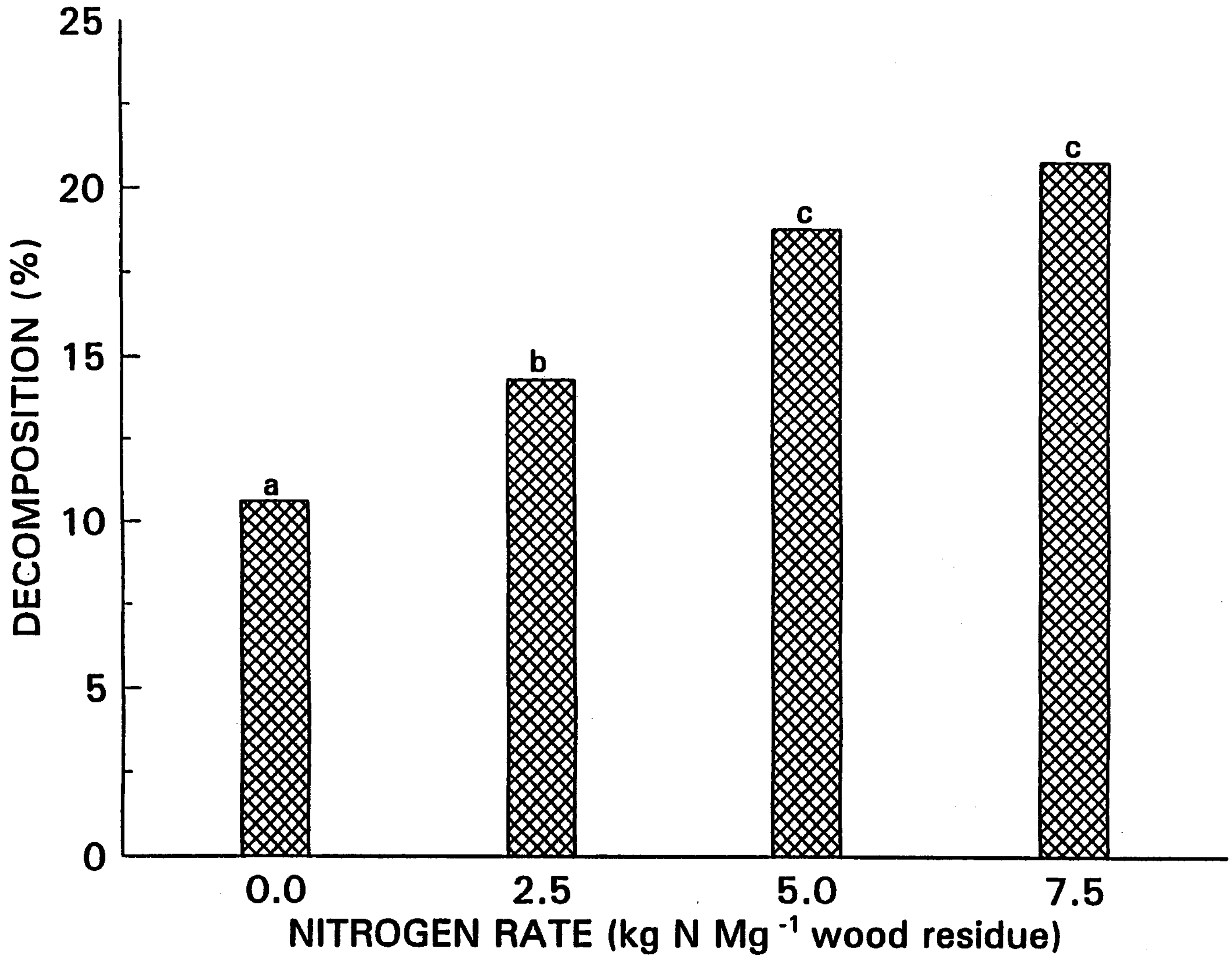

Figure 8. Decomposition of wood residue amended to bentonite spoils as a function of N-fertilizer application rate (averaged across all wood-residue rates). Means with the same letter are not different at $P \leq 0.05$. (Schuman and Belden 1991).

difference in the degree of decomposition is evident. Wood residue decomposition after 10 years was 29.4, 29.6, 35.4, and 29.9% for the 0, 2.5, 5.0, and 7.5 kg N/Mg of wood residue nitrogen treatments, respectively. It appears that decomposition has come to some equilibrium and that the initial nitrogen fertilizer application has not had any long-term effects on the decomposition. Whitford et al. (1989) concluded that in semiarid rangelands where moisture availability affects nitrogen immobilization and mineralization, high C:N ratio amendments (such as wood residue) can be beneficial. They suggested that more resistant sources of organic mulches are superior to readily decomposed material because they provide a slow release of organic particles that serve as energy sources for the microflora. The wood residues have enabled successful revegetation of these lands, which adds readily decomposed material in root and litter turnover. These two sources of organic materials (plant material and wood residue) help to ensure long-term success through sustainable nutrient cycles.

Summary

This paper has reviewed and summarized the findings of research leading to the development of a reclamation technology for abandoned bentonite mine spoils. Wood residue amendment resulted in immediate improvement of the physical characteristics of bentonite spoils, enabling improved water infiltration, leaching and the concurrent establishment of a desirable productive plant community. These studies have also pointed out the need for an inorganic amendment, such as gypsum, to be incorporated with the wood residue to replace the sodium in the system with calcium and prevent further sodication of the spoil. It is important to understand that inorganic amendments are complimentary to the wood residue (or other recalcitrant organic amendment that readily improves physical qualities) and not substitutes for organic amendments. Nitrogen fertilizer should also be incorporated with the wood residue to provide adequate nitrogen for both plant growth and wood residue decomposition. Wood residue decomposition data indicated that some level of microbial function has developed in these spoils, helping to promote the long-term success of the reclamation.

This technology has been readily adaptable to large scale reclamation of abandoned bentonite spoils. The Wyoming Abandoned Mine Land Program has reclaimed over 3500 ha of these spoils since 1985 using the technology. Average cost per hectare was $12,048 with amendments accounting for only 21.3% of the total cost (Richmond, 1991). Other states in the region are developing programs to address abandoned bentonite spoil reclamation. Much of the information and technology developed by/from this research is directly applicable to present-day mining and reclamation of bentonite mined lands even when topsoil salvage is practiced (since topsoil quantities are generally quite limited).

Although the research reviewed covered a period of 12 years, further investigations of lands reclaimed using this technology is desirable to evaluate long-term stability under normal, post-mining land uses. This would enable incorporation of new findings into the technology and reduce the chance of failure or deterioration of these lands based upon relatively short-term information.

Further and greater details of the findings summarized in this report can be found in the appended theses, abstracts, conference proceedings, and journal articles.

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