Reclamation of Bentonite Mined Lands in the Northern Great Plains

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ABSTRACT

Ninety percent of the nation's supply of bentonite is mined in Montana, South Dakota and Wyoming. These lands are difficult to reclaim because of the chemical and physical properties of the soil/spoil material and the arid/semiarid climate of the area. Replacement of the limited topsoil available has shown some benefit but supplies are generally inadequate. The use of inorganic amendments, such as sulfuric acid, gypsum, calcium chloride, vermiculite and perlite, have not shown consistent benefits in plant establishment and growth. Organic amendments; sawmill wood residues, straw and manure, have provided the greatest benefits in the reclamation of bentonite mined lands. Cultural and management practices are important in determining the long-term

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success of these reclaimed lands. Reclamation technology development for bentonite mined lands is recent and limited and the refinement and application of such technology will depend on increased activity and cooperation among researchers, regulators and the mining industry.

INTRODUCTION

Lands disturbed by bentonite mining in the Northern Great Plains are relatively difficult to reclaim because of adverse chemical and physical properties of spoil material, the arid/semiarid climate of the area, the limited topsoil resource and, to a certain extent, the mining methods.

Location and Nature of Bentonite Deposits

Ninety percent of the nation's supply of bentonite is mined in Montana, South Dakota and Wyoming. Wyoming alone accounted for 74% of the total U.S. production in 1979. Large scale bentonite mining began in this region in the 1930's. However, few hectares were reclaimed before the early 1970's, when most of the Northern Great Plains states passed reclamation laws. Hemmer et al. (1977) doubted the likelihood of pre-law bentonite mined lands being returned to productive uses. The National Academy of Sciences (1974) reported that in Montana more land was disturbed in 1973 by bentonite mining than by coal mining, and that more orphan spoils had accumulated over the years from bentonite mining than from coal. Although these statements referred to Montana, they are indicative of the regional situation.

Bentonite is called the clay of "1000 uses." Oil and gas drilling mud accounts for about 90% of total bentonite use, although considerable amounts are also used as binders in molding sands in foundries and in the processing of taconite ore (Romo, 1981). Since bentonite is used in numerous processes and products, it is anticipated that demands will remain high. Cooper (1970) reported that the 1968 demand for bentonite was 1.75 million metric tons and the projected national needs by the year 2000 were expected to range from 4.4 to 8.2 million metric tons. Another source reported 1978 demand as 4 million metric tons with 6.3 million metric tons needed by 2000 (Ampian, 1980). Therefore, continued disturbance of large areas can be expected from bentonite mining.

Bentonite is a mineral produced by the alteration of volcanic ash into clay minerals of the smectite group. Approximately 75 million years ago ash from volcanic eruptions in the Rocky Mountain Region was carried eastward by high-altitude winds. This ash was deposited in large, usually marine, bodies of saline water in the western Great Plains. Resultant clay beds cover extensive areas and represent several ash deposition periods.

Because most of the clay beds were formed in a marine environment, soils associated with these deposits are generally high in soluble salts, particularly sodium, resulting in a highly sodic and dispersed system. The soils/spoils are also generally characterized by low to medium fertility, high pH, low water infiltration rate, high runoff potential and high bulk density.

Climate of the region is arid to semiarid with cold, harsh winters. Precipitation of this region ranges from 15 to 38 cm, 25 to 40% of which occurs as snow. Annual evaporation demand greatly exceeds precipitation. The frost-free period averages about 125 days.

Mining Methods as Related to Reclamation

Bentonite is extracted with surface mining methods that differ somewhat from those associated with other minerals in the Northern Great Plains. Bentonite pits are shallow (not exceeding a 10:1 stripping ratio), generally less than 15m in depth and 1 to 8 ha in area. Due to the irregular distribution of mineable, high grade bentonite deposits, pits tend to be interspersed with non-mined areas in discontinuous patterns over the landscape. Thus, bentonite mining is more of an "extensive" than "intensive" land disturbance, directly or indirectly affecting large areas. This type of mining results in logistical problems in planning mining/reclamation and handling earth materials different from other types of mineral extraction, such as coal surface mining.

With current mining methods, scrapers remove the topsoil and replace it on regraded spoil or stockpile it for later use. The overburden is then removed, and either placed in adjoining pits, and regraded and contoured or stockpiled for later use as backfill for the open pit. The use of scrapers in a cast-back mining method results in the inversion of pre-existing strata, placing the material high in soluble salts closer to the surface. This material and poor quality bentonite may require additional overburden to insure adequate burial. The stripping of clay beds and disposal of low quality materials results in high clay material at the spoil surface which further complicates long-term reclamation success.

Current mining laws require that topsoil and suitable subsoil material be salvaged for replacement over regraded spoils. Because of limited soil development, the total soil resource can be as little as 10 cm up to 45 cm or greater in alluvial areas. Generally, salvage and respreading of topsoil results in a maximum of 30 cm of suitable material over the clay spoil. Thus, relatively little topsoil is available to cover the surface-deposited spoil. Orphan bentonite spoils, where no topsoil is available for respreading will require special technology for vegetation establishment, site stabilization and restored productivity. Only minimal natural revegetation has occurred on orphan spoils in Montana after 30 years post-abandonment (Sieg, et al. 1983).

Several problems encountered with bentonite mining and reclamation practices limit revegetation success: 1. topsoil contamination, 2. poor or no topsoil for redistribution, 3. compaction - restricted root penetration, and 4. initially established vegetation destruction as a result of livestock grazing (Hemmer, et al. 1977; Sieg, et al. 1983). These problems, plus adverse climatic and soils/spoils characteristics, make bentonite mined land reclamation extremely difficult compared to that associated with extraction of other mineral resources.

The purpose of this paper is to summarize reports, published lieterature and practical experiences of reclamation specialists relating to reclamation of orphan bentonite spoils and present-day mined lands in the Northern Great Plains.

CURRENT RECLAMATION TECHNOLOGY

Topsoil Replacement

Salvage and replacement of topsoil has become an accepted practice in coal mined land reclamation technology in the Northern Plains Region during the last decade. However, prior to the early- to mid-1970's, topsoil salvage and respreading was not a consistent practice in the bentonite industry. Because of its limited availability, topsoil is being replaced only on currently mined areas and is not an alternative for reclamation of orphan spoils. Many of the areas being mined possess limited or poor quality topsoil material; therefore topsoil depth requirements, such as to those evaluated in coal mined land reclamation, are often academic.

Hemmer et al. (1977), Dollhopf and Bauman (1981) and King (1983) all evaluated the effect of topsoil and/or subsoil material replacement as an aid to reclaiming bentonite spoils. Hemmer et al. (1977) evaluated seven study sites within Wyoming and Montana which were covered with an average of 10 cm of topsoil. They concluded that the limited topsoil (10 cm) was not an adequate depth of soil media. Surface treatments (gouging and deep furrowing) resulted in contamination of the topsoil with bentonite spoil material, reducing any benefits of the topsoil. However, Dollhopf and Bauman (1981) reported that as little as 10 cm of topsoil resulted in excellent first year plant establishment; although, no further evaluation of the treatment was made. King (1983) observing grass and shrub establishment on spoils with up to 30 cm of topsoil and subsoil replacement, reported greater establishment after three growing seasons than on those areas with minimal (10 cm) or no topsoil replacement.

Topsoil quality on bentonite mined areas varies widely (Hemmer et al. 1977). Soluble salt contents of the topsoils range from 0.5 mmhos/cm to greater than 4.0 mmhos/cm. The majority of topsoil material overlying bentonite beds has at least 50% clay content, compounding the problems of seedling emergence and establishment. Many of the topsoil materials in the Big Horn Basin of Wyoming are clay loams and are higher in available plant nutrients than soils found in other mining districts of the region (Dollhopf and Bauman, 1981; Hemmer, et al. 1977).

Inorganic Amendments

Inorganic amendments have been evaluated on both topsoil and spoil material. Dollhopf and Bauman (1981) evaluated the effect of sulfuric acid (16.8 mt/ha) and calcium chloride (28 mt/ha) on the crusting of both topsoil and spoil material (modulus of rupture). Modulus of rupture was reduced by 90% on the topsoil material and by 80% on the spoil by the addition of either amendment. To lower the modulus of rupture to 1.0 bar or less on the spoil material would require slightly greater application rates than those tested for sulfuric acid. Dollhopf and Bauman (1981) felt that if the modulus of rupture is less than 1.0 bar, no seedling emergence problems would exist.

Sulfuric acid (16.8 mt/ha), calcium chloride (28 mt/ha), gypsum plus sulfuric acid (20 and 6.7 mt/ha) and gypsum and calcium chloride (20 and 9 mt/ha) were all found to increase the hydraulic conductivity of topsoil and spoil material (Dollhopf and Bauman, 1981). However, the increase in the spoil conductivity was not great enough to bring it above the 'Very Slow' permeability class, 0.125 cm/hr (Kohnke, 1968). The amendments did not increase the hydraulic conductivity of the topsoil enough to change its permeability class (moderate, 2.0 to 6.25 cm/hr). Given the low permeability of the spoil material, leaching of salts from the root zone is improbable; therefore, salinization of replaced topsoil is likely.

King (1983) reported that gypsum applied to topsoils placed over spoil material at the rate of 19 mt/ha resulted in better seedling establishment and plant cover than the 9 mt/ha gypsum rate and the non-amended control after one growing season.

Gypsum plus calcium chloride (6.7 mt/ha plus 17.2 mt/ha), gypsum plus sulfuric acid (6.7 mt/ha plus 12.3 mt/ha) and gypsum plus sulfuric acid with irrigation (0.6 cm for 20 consecutive days) resulted in poor to zero plant establishment (Dollhopf and Bauman, 1981). The poor establishment was not limited to planted species, and was attributed to poor physical conditions of the spoil even though spoils were tilled and mulched with 4500 kg/ha of straw. Amendment toxicity and spring seeding may also have contributed to poor plant establishment. Season of seeding trials on bentonite mined lands have shown fall seeding to be superior to spring seeding (Hemmer, et al. 1977). Irrigation failed to improve establishment when used in conjunction with the inorganic amendments.

Bjugstad et al. (1981) also evaluated the effect of gypsum, perlite and vermiculite on the growth and survival of several shrub, forb and tree species in both a greenhouse and field study. Vermiculite and perlite resulted in the best survival and growth of the species tested in the greenhouse. However, all three treatments resulted in better survival than the control (no amendments) for fourwing saltbush (*Atriplex canescens*), common yarrow (*Achillen millefolium*), big sagebrush (*Artemisia tridentata*) and scarlet globemallow (*Sphaeralcea coccinea*).

Inorganic amendments generally have not shown consistent benefits to plant establishment and growth on amended bentonite spoils or topsoiled spoils. Some of the inconsistent and variable results reported may be the result of experimental design and/or varability among study sites. Further testing is warranted since certain amendments have been used successfully on sodic soils in other environments. To be effective, inorganic soil amendments will probably have to be used in conjunction with other amendments that improve the physical characteristics of the spoil.

Organic Amendments

In recent years, several projects have been conducted evaluating initial and longer term effects of sawmill wood residues, manure, and straw mulch on the establishment and production of vegetation on bentonite mined areas.

Schuman and Sedbrook (1984) evaluated the effect of 0, 112 and 224 mt/ha of sawmill wood residues on the reclamation of orphan bentonite spoils. Forage production of seeded species increased with increasing wood residue application. The residue was incorporated into 25 year old bentonite spoils to a depth of 30 cm. Forage production averaged 12, 712 and 897 kg/ha for the 0, 112 and 224 mt/ha wood levels, respectively, over four years. Production of the seeded species increased during the four years on the amended treatments, while non-seeded species production decreased each year. Wood residue amendment of the spoils resulted in greater water intake and storage and in improved soil physical conditions in the zone of incorporation.

A subsequent study evaluated spoils amended at 0, 45, 90 and 135 mt/ha of wood residue (Smith, 1984). He found soluble salt and sodium content were significantly decreased in the surface 15 cm of the spoil with an increase at lower depths, indicating leaching had occurred. Soil-water content was also greater in both years in the 0-30 cm spoil depth than in the 30-45 cm depth on all wood amended plots. However, the 90 and 135 mt/ha treatments had significantly greater stored soil-water present than the 45 mt/ha treatment.

Smith (1984) also demonstrated that plant density was significantly greater on plots amended with wood residue (40-70 plant/m^2) compared to the non-amended control (13 plant/m^2). Each increase in wood residue amendment rate resulted in a significant increase in plant density. First year seedling survival, canopy cover and aboveground biomass of seeded species showed significant increases with increasing wood residue rates.

Vegetation establishment with woodchip amendments has been found to be equal to that of topsoiled spoils (Dollhopf and Bauman, 1981). From preliminary results, they concluded that woodchips may be a feasible substitute for topsoil where the latter is limited or unavailable. King (1983) observed wood mulch applied to topsoiled spoils to be more effective, after one growing season, than topsoil alone in promoting vegetation establishment.

Manure amendment of bentonite spoils has not proved as effective as wood residue amendment in promoting vegetation establishment. Dollhopf and Bauman (1981) applied 224 mt/ha and 112 mt/ha plus sulfuric acid to spoil material, and achieved variable and poor results. They attributed the poor establishment to increased salt content (1 to 3 mmhos/cm) resulting from the manure. Other research has shown high levels of short chain fatty acids present in manure that are toxic to seedlings (Schuman and McCalla, 1976). Straw mulch has also been shown to increase vegetation establishment, plant density and cover on bentonite mined lands when applied at the rate of 3.7 mt/ha (King, 1983).

In general, organic amendments have provided the greatest benefit when used on bentonite spoils rather than on areas where topsoil has been replaced. One of the main benefits derived from the organic amendments is improved physical characteristics of the spoil, such as increased water infiltration rates, reduced bulk density and increased aggregation. Such characteristics can provide improved soil water availability and a better rooting growth medium for plants.

Fertilization

Plant response to nitrogen and phosphorus fertilizers on bentonite mined lands has been variable. Dollhopf and Bauman (1981) found no response to phosphorus fertilization which was attributed to high inherent phosphorus concentrations in the soils/spoils (12-25 μg/g). Smith (1984) found inherent phosphorus levels of only 8.1 μg/g, and after fertilization with 90 kg P/ha the spoil levels were 25 μg/g, however, phosphorus effects were not evaluated. The clay present in these spoils has a high potential for phosphorus fixation and the formation of nearly insoluble compounds such as iron phosphate. Dollhopf and Bauman (1981) observed significant plant biomass increases from all levels of nitrogen addition (34, 84, 101 and 168 kg N/ha) as compared to non-fertilized treatments.

When organic amendments with a high C/N ratio are utilized, the addition of nitrogen is necessary to insure adequate nitrogen is present for microbial decomposition and plant growth. However, Dollhopf and Bauman (1981) and King (1983) used woodchips and straw mulch as soil/spoil amendments, but did not investigate the effect of nitrogen fertilizer on these amendments. They found no evidence of nitrogen deficiencies; however, both studies only evaluated first year plant establishment. Nitrogen deficiencies resulting from the addition of large amounts of organic amendments probably would not be evident until the second and subsequent years.

Smith (1984) studied the effect of nitrogen fertilization (0, 2.5, 5.0 and 7.5 kg/mt of wood residue) on plant establishment, plant density, plant canopy cover and biomass as a function of four wood residue levels (0, 45, 90 and 125 mt/ha). Plant density, canopy cover and biomass were significantly higher for all three nitrogen treatments than for the non-fertilized control. However, there were no differences in total plant density between the 2.5, 5.0 and 7.5 kg N/mt of wood residue treatments. Individual plant species varied in fertilizer responsiveness. Biomass of western wheatgrass (*Agropyron smithii*), streambank wheatgrass (*A. riparium*), thickspike wheatgrass (*A. dasystachyum*), intermediate wheatgrass (*A. intermedium*), crested wheatgrass (*A. desertorum*), and smooth brome (*Bromus inermus*) responded positively to nitrogen fertilization. Conversely, green needlegrass, (*Stipa viridula*) pubescent wheatgrass (*A. trichophorum*) and Gardner saltbush (*Atriplex gardnerii*) did not respond to nitrogen fertilization, and tall wheatgrass (*A. elongatum*) biomass decreased as nitrogen levels were increased.

General fertilizer requirements for reclamation of bentonite soils/spoils should be based on laboratory analysis, the C/N ratios and amount of organic amendments to be applied.

Tillage, and Surface Preparation

The single most limiting characteristic of bentonite spoils is the high clay content and subsequent high bulk density. Prime consideration needs to be given to cultural practices and or methods that will loosen the spoil and promote root penetration, water infiltration and leaching. These cultural practices must be effective for several years to enable good vegetation establishment and initial soil formation and structural development. However, care must be taken to avoid contamination of topsoil with poor quality or toxic subsoil materials.

Hemmer et al. (1977) evaluated the effects of gouging and deep furrowing on seedling establishment and development on topsoiled bentonite mined lands. They found these treatments resulted in inconsistent plant cover and production and in contamination of the topsoil with spoil material brought to the surface by the surface treatment, causing a salt buildup in the topsoil. However, King (1983) found that gouging improved plant cover and density but that dozer basins did not show any benefits. Site specific edaphic (and possibly climatic) characteristics may govern the effectiveness of such treatments. Factors such as the presence, thickness and quality of topsoil and the characteristics of the spoil should be considered on an individual site basis in the selection of specific surface manipulation and/or tillage practices.

Plant Species Selection

Proper selection of plant species is of obvious importance to successful revegetation. Past research has demonstrated, in general, that plant species potentially successful on bentonite mined lands in the Northern Great Plains should possess one or more of the following qualities: drought tolerance, salt tolerance, adaptation to clay soils, rapid initial establishment traits and for grasses, rhizomatous growth form.

Plant species response to fertilizer, surface modification treatments and amendments varies tremendously. Smith (1984) concluded that native grass species examined generally had higher density and cover at low rates of wood residue amendment, and lower aboveground biomass at higher wood residue levels than introduced grass species examined. Rhizomatous grasses also generally performed better than bunchgrasses in the high shrink-swell environment of the clay spoil. Hemmer et al. (1977) found pubescent wheatgrass, streambank wheatgrass and crested wheatgrass responded more favorably than western wheatgrass or Indian ricegrass (Oryzopsis hymenoides) on reclaimed bentonite mined areas. Meadow foxtail (Alopecurus pratensis), alkali sacaton (Sporobolus airoides), streambank wheatgrass, slender wheatgrass (A. trachycaulum), tall wheatgrass and pubescent wheatgrass were the most successful species established on topsoiled and bare spoil in a greenhouse study where twenty-two species were evaluated (Dollhopf and Bauman, 1981).

Bjugstad (1979) evaluated the survival of seven bare root and container grown shrubs and trees transplanted into bentonite spoils. Green ash (Fraxinus pennsylvanica lanceolata) showed the greatest survival of those species planted as bare root stock. Ponderosa pine (*Pinus ponderosa*) and Rocky Mountain juniper (*Juniperus scopulorum*) showed greater survival when planted as container grown stock. Green ash and Russian olive (*Elaeagnus angustifolia*) showed less survival from the container grown stock than the bare root plantings and the other species evaluated showed no differences.

Successful establishment of fourwing saltbush and Gardner saltbush by direct seeding has been demonstrated (Smith, 1984; Bjugstad, et al. 1981; King, 1983). Establishment of native shrubs by direct seeding is feasible for some species; however, limited success has been the rule for many of the other desired species. Some plants invade mine spoils from adjacent unmined habitats (Sieg, et al. 1983). Smith (1984) for example reported black greasewood (*Sarcobatus vermiculatus*) became established from a natural seed source adjacent to revegetated spoils.

LONG-TERM RECLAMATION CONCERNS

Research conducted on bentonite mined lands has been short-term. Success or failure of applied practices must be ascertained via long-term monitoring studies. Long-term concerns include vegetation permanence, soil stability, salinization of the topsoil, and management of the reclaimed lands. Information on such concerns is, at present, non-existent for bentonite mined lands.

Smith (1984) has pointed out that the large increase in water intake and storage by wood amended spoils results in areas that are quite unstable in initial years. Therefore livestock exclusion is a necessity to prevent destruction of the vegetation by hoof action. This unstable soil situation could also be a problem on steep slopes where organic amendments such as wood residue are used.

Irrespective of the reclamation practices applied, general exclusion of livestock grazing from revegetated bentonite mined lands during the initial years following seeding may be a highly beneficial, if not an essential, management practice (Hemmer, et al. 1977; Sieg, et al. 1983). However, the logistical and economic constraints posed by the extensive pattern of bentonite mining may preclude fencing in many instances.

Wildlife use of reclaimed areas will probably not result in deterioration of the vegetation. Schuman and Sedbrook (1984) and Smith (1984) have not observed any deterioration due to wildlife utilization of reclaimed bentonite spoils. Hull (1981) reported that deer mice were the most common of five species of small mammals captured on a reclaimed bentonite site. No detrimental effects of the deer mice were evident on the reclaimed area and less than 1% of their diet consisted of species seeded on reclaimed land. Conversely she found mycorrhizae in the mouse feces and concluded that the mice were possibly beneficial in mycorrhizae dispersal and inoculation.

Salinization of good quality topsoil replaced over saline-sodic spoils must also be considered in bentonite reclamation planning. Upward migration of salts, particularily sodium, from sodic spoils into the topsoil has been studied by Merrill, et al. (1980) and Dollhopf, et al. (1981). Upward migration of salts depends upon the texture of the topsoil overlying the spoil, the clay mineralogy and the hydraulic conductivity of the spoil. If leaching can be assured, upward migration and salinization of the topsoil will not be as eminent. Therefore, attention should be given to the proper design of the reconstructed profile of high clay spoils to facilitate water movement.

CONCLUSIONS

Reclamation of bentonite mined lands in the Northern Great Plains has received relatively little research emphasis until recently. Currently applied reclamation technology has been largely extrapolated from that developed for other types of mining. While such extrapolation may be valid to a point, it cannot solve reclamation problems unique to bentonite mining. Bentonite mining poses mine operation, geologic and edaphic constraints to reclamation that are different and, in many cases, more difficult to overcome than those associated with other types of mining.

Existing information supports the benefits of applying suitable quality topsoil and/or subsoil over bentonite spoil; however, firm recommendations on the necessary amount of cover soil material, cannot be drawn at this time. The use of various inorganic amendments to ameliorate specific soil/spoil problems has met with varied and inconsistent results. Organic amendments, most notably wood residues and straw mulches, have improved adverse soil/spoil characteristics and resultant plant growth. With adequate water, nitrogen fertilization has resulted in improved plant growth, particularly in cases where organic amendments are applied. The need for phosphorus fertilization, has not been demonstrated. Effects of various tillage and/or surface manipulation practices, specific revegetation practices and selected plant species on revegetation, have received limited research attention;

and the work that has been accomplished is sometimes, contradictory. The question of long-term effects of initial reclamation practices and a number of specific concerns such as vegetation permanence, soil stability, topsoil salinization and management of reclaimed lands remain unanswered.

Two points should be evident from this review. First, bentonite reclamation of mined land has received minimal research emphasis. Consequently, development of a reclamation technology, both comprehensive and site-specific, requires a great deal of further research and subsequent synthesis/interpretation. Secondly, success with certain reclamation practices in some situations suggests that, despite the difficulties, orphan and current bentonite mined lands may ultimately be reclaimed with proper practices. Development, refinement and application of such practices will depend on increased activity and cooperation among researchers, regulators and the mining industry.

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