Evaluation of Bentonite for the Control of Acid Drainage from Surface-Mined Lands, Part 2

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Introduction

This study to evaluate the effectiveness of bentonite in retarding water flow through potentially toxic materials was undertaken by the Northeastern Forest Experiment Station with financial support from an Acid Mine Drainage Technical Advisory Committee (AMDTAC) grant. An initial report showing details of the installation of the plots and preliminary data was published earlier (Crews and Dyer 1984).

Bentonite is a montmorillonitic clay formed from deposits of volcanic ash. Sodium bentonite absorbs nearly 5 times its weight in water and, at full saturation, occupies a volume close to 15 times its dry bulk. The key to the expansion and water-sealing action of bentonite lies in its structure (Weaver 1946). The clay flake is composed of crystalline sheets so minute that when completely dispersed in water, a cubic inch of dry bentonite subdivides into nearly 10 billion flakes with a combined surface area of nearly an acre. The thin sheets are parallel, and layers of tightly held water molecules force their way between the sheets, spreading them apart until a hull of water many times thicker than the sheet is held by electrostatic attraction.

Bentonite cannot be used to impede the flow of salty or acid water because it loses its swelling power and, therefore, its sealing power when in contact with such water (Weaver 1946).

Methods and Materials

The bentonite evaluation plots were constructed by a joint effort of the Mashuda Construction Company (Evans City, Pennsylvania and Morgantown, West Virginia) and the USDA Forest Service on the Jack Maxon property near Morgantown, West Virginia. Nine plots of near uniform composition and physical arrangement were constructed in 1983 to evaluate the use of bentonite. The plots were arranged in a 3 x 3 Latin square design and were established on a slope of approximately 5 percent. Three plots were untreated control, three contained a 1 lb/ft bentonite seal, and three contained a 2 lb/ft bentonite seal.

Each plot measured approximately 16 by 16 feet for a total surface area of 256 ft^2 . Each plot was underlain with a sheet of 20-mil PVC plastic liner turned up at the edges over plank divides to hydrologically isolate each plot and to intercept all downward percolating water. An 18-inch layer of coarse, toxic mine spoil (coal washings in this case) was placed over the plastic in each plot; this was covered with 18 inches of "topsoil" composed of intermixed A, B, and C horizon material containing nonpyritic rock. The topsoil layer was applied in two increments to those plots treated with bentonite. First, 6 inches of topsoil were applied and smoothed; then the bentonite was spread and incorporated to a depth of 3 or 4 inches with a garden tiller; finally, 12 more inches of topsoil were added (Fig. 1). The topsoil on all plots was smoothed by hand raking. Some of the topsoil intended for the plots was used to construct the berms, so there was only enough left for seven of the nine plots. Texturally similar topsoil was scraped from the nearest accessible unmined lands and applied a few minutes later to plots 5 and 8.

Surface runoff was monitored by flumes equipped with automatic stage recorders. Water failing to penetrate the bentonite layer was intercepted by a thin sand-collecting zone placed along the lower edge of the plots just above the bentonite layer. Water ponding on top of the bentonite layer and water penetrating through the bentonite and into the toxic material was drained through 1 1/4-inch plastic pipes leading from the lower edge of each plot to 55-gallon barrels equipped with stage recorders. Runoff was monitored continuously except in the winter months. Samples of runoff collected in the barrels were analyzed for pH, common ions, and selected trace elements. Surface runoff was not evaluated chemically. A recording, tipping-bucket rain gage was installed at the plot site to monitor rainfall.

Samples of toxic mine spoil and topsoil were collected the day the plots were installed. These were air dried, then passed through sieves with 20-mm and 2-mm-diameter openings. Each size fraction was recorded separately. Soil texture was determined for the less than 2-mm fraction by the hydrometer method of Bouyoucos (1951).

Chemical analyses performed on the less than 2-mm toxic mine spoil and topsoil fractions included pH determined on a 1:2 soil:water suspension and specific conductance determined on the 1:2 soil water extract. These same analyses were performed on a 1:20 bentonite:water suspension. Available potassium, magnesium, and calcium were determined by the North Carolina extractant and procedure described by Flannery and Markus (1971). Available phosphorus was determined by the Bray No. 1 phosphorus method described by Olsen and Dean (1965, p. 1040-1041). Total exchange acidity, exchangeable aluminum, and exchangeable hydrogen were determined by the procedure of Yuan (1959), except that aluminum was determined on the extracts with a Perkin-Elmer atomic absorption spectrophotometer Model 2380.[1/]- Organic carbon was determined by the Walkley-Black method (Allison 1965, p. 1372-1375), except that the endpoint was determined electrically at 640 mv rather than colorimetrically. Exchangeable basic cations were determined by the ammonium acetate procedure described by Thomas (1982). Cation exchange capacity was calculated as the sum of the four major exchangeable bases plus the exchange acidity.

.1 / The use of trade, firm, or corporation names in this paper is for the information and convenience of the user. Such use does not constitute an official endorsement or approval by the U. S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Water samples were analyzed for pH, calcium, magnesium, sodium, and potassium. The four cations were analyzed on a Perkin-Elmer atomic absorption spectrophotometer Model 2380.

Hydrologic data were collected at the site, usually on a weekly basis, from September 1 through November 30, 1983; from March 27 through October 25, 1984; and from March 13 through July 2, 1985. Drains were disconnected during the winter months since freezing and thawing would interfere with the study and render data collected during these months unusable or questionable.

The plots were sowed in September 1983 to a mixture of Ky-31 tall fescue (35 lb/acre), birdsfoot trefoil (30 lb/acre), weeping lovegrass (3 lb/acre), redtop (1 lb/acre), and oats (1 bushel/acre). Plots were fertilized and limed at rates normally used by the mine operator. A nearly complete vegetative cover was established on all the plots by November 1, 1983. Herbage yields were determined in 2 September 1984 by harvesting the vegetation in three randomly placed 2.4 ft quadrats in each plot. The vegetation, clipped about 1/2 inch above the ground surface, was oven dried and weighed, and the yields were converted to pounds per acre.

Results and Discussion

Rainfall and drainage data for the study plots are given in Table 1. Surface runoff was measured on eight of the nine plots but is not included in this report. It is a minor portion of the hydrologic picture and could not have affected the conclusions reached in this study. The barrels collecting drainage from the plots frequently overflowed between measurements, so we do not know the exact drainage for these occasions; we only know that drainage exceeded that measured in the barrels. Incomplete drainages given in Table 1 are followed by a plus sign. Percentages based on these incomplete drainage values are in parentheses, and, though not absolutely correct, circumstantial evidence would indicate they, and inferences based on them, are substantially correct. The bentonite had little effect on drainage for the period September through October 1983, intercepting only 17 percent of the drainage water from the 1 lb/ft^2 bentonite plots and 5 percent of that from the 2 lb/ft^2 bentonite plots. Corresponding interception rates for April through October 1984 were 34 and 53 percent, and for mid-March through mid-June 1985 they were 52.5 and 66 percent, respectively. The bentonite layer appears to have become more effective in intercepting drainage water as time went on. There was a period from August 1984 to the end of October when the 1 lb/ft^2 bentonite layer was not as effective in intercepting drainage water as it had been previously. The bentonite-soil mixture may have dried enough for minor cracks to have developed during this summer dry period. Dehydration of the bentonite-soil mixture could cause it to shrink and crack or pull away from the edge of the plastic mat and from around stones in the bentonite-soil mixture, allowing more water to penetrate to the toxic mine spoil.

Rollins and Dylla (1970) studied the effectiveness of a buried "blanket" of bentonite and sand similar 2 to the soil-bentonite layer used in this study. In their study, about 3 lb/ft^2 bentonite was incorporated into a 3-inch sand layer. Leakage through their bentonite seal ranged from 0.3 inch per day the first year to 10.2 inches per day in the sixth and last year of the study. Even at its best, their seal was less effective than that observed in this study. Their study indicated that with time, bentonite seals are likely to become less and less effective in impeding the downward seepage of water.

Clark and Moyer (1974) cite references that indicate that the swelling characteristics of bentonite are highly dependent on its sodium content. The higher the sodium percentage, the greater its propensity to swell. The bentonite used in this study was high in Na, with Na accounting for 25 percent of the exchangeable bases (Table 2). Water draining from the overlying topsoil was low in sodium, with a sodium adsorption ratio (SAR) of only 0.01. According to the U.S. Salinity Laboratory Staff (1954), this means that percolating water of this quality will gradually lower the exchangeable sodium percentage of the bentonite, eventually shrinking the bentonite volume and reducing its ability to retard the flow of water draining through it. The inevitable loss of sodium from the bentonite layer will, in time, reduce its effectiveness in impeding the flow of water. The rapid loss of effective sealing reported by Rollins and Dylla (1970) probably was due largely to the displacement of exchangeable sodium from the bentonite blanket by salts contained in the irrigation water that seeped through the blanket. Less water with a lower salt content percolated through the bentonite layer in our study; therefore, the sealing effectiveness of this bentonite layer should last much longer.

Factors involved in reducing seepage with a bentonite-soil mixture include type of soil; particle size of both soil and bentonite; percentage of bentonite mixed with the soil; thickness of the bentonite-soil layer; means of confinement; and hydrostatic head (Ferris 1943). Ferris found that soils with a high clay content are not suitable for sealing with bentonite because the essential dense layer will not form when in contact with water. When rocks are present in the bentonite-soil mixture, even in small quantities, water passes along their surface, washing the bentonite away and causing seepage to increase, particularly when adjacent rocks form a chain through the layer. Fine sandy soils or sandy loams that form a dense blanket are most effectively sealed with bentonite. Ferris found that the bentonite-soil mixture should be less coarse than the mean grain size of the soil. This prevents the expansion of the individual bentonite particles from decreasing the density and causing new voids. Data on the distribution of particle sizes in Table 1 indicate that the topsoils used in this study probably were suitable for use with bentonite. The clay percentage of 13 to 28 percent seems satisfactory; however, the percentage of coarse fragments - 31 to 40 - may be less satisfactory.

Plant roots can penetrate a bentonite layer; as the plants die, channels through decaying roots could act as conduits by which water could pass through the bentonite layer. This would likely be a problem only where trees or plants with tap roots have been allowed to grow. Shallow-rooted grasses should cause little problem. If the site is not maintained in grasses, trees will sprout and grow eventually. The depth of the bentonite seal from the soil surface also would determine whether roots would have a major effect on the seal.

In this study, bentonite was found to be partially effective in reducing the flow of drainage water into the underlying toxic coal wastes. This in itself is of limited practical value. Unless all water and/or oxygen can be kept from toxic spoil and waste materials, the overall rate of acid production likely will not be reduced. Brant and Shumate (1971) observed that drainage diversion may slow the rate of product release; but unless all water entry to and drainage from the system can be eliminated, the system drainage may ultimately reach a new equilibrium, lower in flow rate but proportionally higher in concentration of acid products. Similarly, Braley (1951) stated that it has been assumed that the pounds of acid draining from a given mine are roughly constant with time, and that the concentration of acid in the drainage is inversely proportional to the volume of flow.

The data in Table 3 indicate that pH was higher in the drainage from toxic spoils that were overlain by bentonite, especially that applied at 1 lb/ft^2 . Presumably, this water also would be lower in acidity. This improvement in pH and acidity in drainage from the toxic spoil can be explained in either of two ways: (1) Partial neutralization from the alkaline water seeping through the bentonite, or (2) a lower flow of oxygen through the bentonite into the toxic spoil, which would reduce the rate of acid mine drainage production. The greatly increased sodium levels in drainage from toxic spoils underlying the bentonite show that the bentonite is directly affecting the chemistry of this drainage water.

The higher pH values and calcium concentrations of the drainage water that was intercepted and diverted by the bentonite layer were caused by calcium carbonate (limestone) in the sand that was placed around the drains to help lead drainage water into them. The sand fizzed violently when 50 percent hydrochloric acid was dripped on it, demonstrating an appreciable concentration of carbonates. The calcium and alkalinity contributed by the limestone make comparisons of water quality from upper drains with that from lower drains of little importance.

The data in Table 3 indicate a general decline in dissolved constituents from 1983 to 1985. The disturbance caused when topsoil and spoil were moved, stored, and moved again would contribute to the release of soil chemicals that had been less available in soil and overburden still in place at their original sites. These released chemicals leached out rapidly so that concentrations soon reached lower and more stable levels.

The following plant yield data indicate that the bentonite had little discernible effect on the growth of the seeded vegetation, though slightly lower yields were measured in plots where higher rates of bentonite were applied:

Treatment and plot no.	Yield in September 1984 (lb/acre, oven dry)
Control	
2	2082
4	1948
9	2126
Average	2052
1 lb/ft^2 bentonite	
3	2236
5	1972
7	1992
Average	2067
2 lb/ft^2 bentonite	
1	1952
6	1852
8	1409
Average	1738

While bentonite apparently is ineffective in totally sealing toxic spoils from percolating water, it can still be of value on the mine site in retarding the flow of water in situations where total exclusion of water is not necessary. Its use in reducing leakage from ponds and sediment basins is well known. Bentonite also could be used in the construction of barriers in spoils to direct the flow of water through or around these materials. These barriers could be constructed before or during placement of spoil in such a way that they would impound water to immerse pyritic spoils buried at or near the base of the highwall; this would prevent the oxidation of these spoils and the formation of acid mine drainage. Because of periodic recharge to such buried underground pools, there would be no need for the bentonite seal in the barrier to be 100 percent effective. If overtopped by impounded water, buried barriers of bentonite can erode in much the same way as above-ground barriers unless they are protected by nonerodible spillways.

Conclusions

At the rates applied in this study, bentonite is only partially effective in retarding the downward percolation of water through toxic mine spoil. During and immediately following periods of drought, the bentonite seems less effective than in wet periods in retarding the downward percolation of water. Acid drainage was reduced somewhat by the use of the bentonite but not sufficiently to be cost effective. Presently, bentonite at the application rates used in this study is not recommended as a sealant for preventing deep percolation of water through soils into underlying toxic mine spoils. Higher rates of bentonite that may result in a more nearly complete seal probably would be no more economical than other practices currently used to limit the adverse effects of acid mine drainage.

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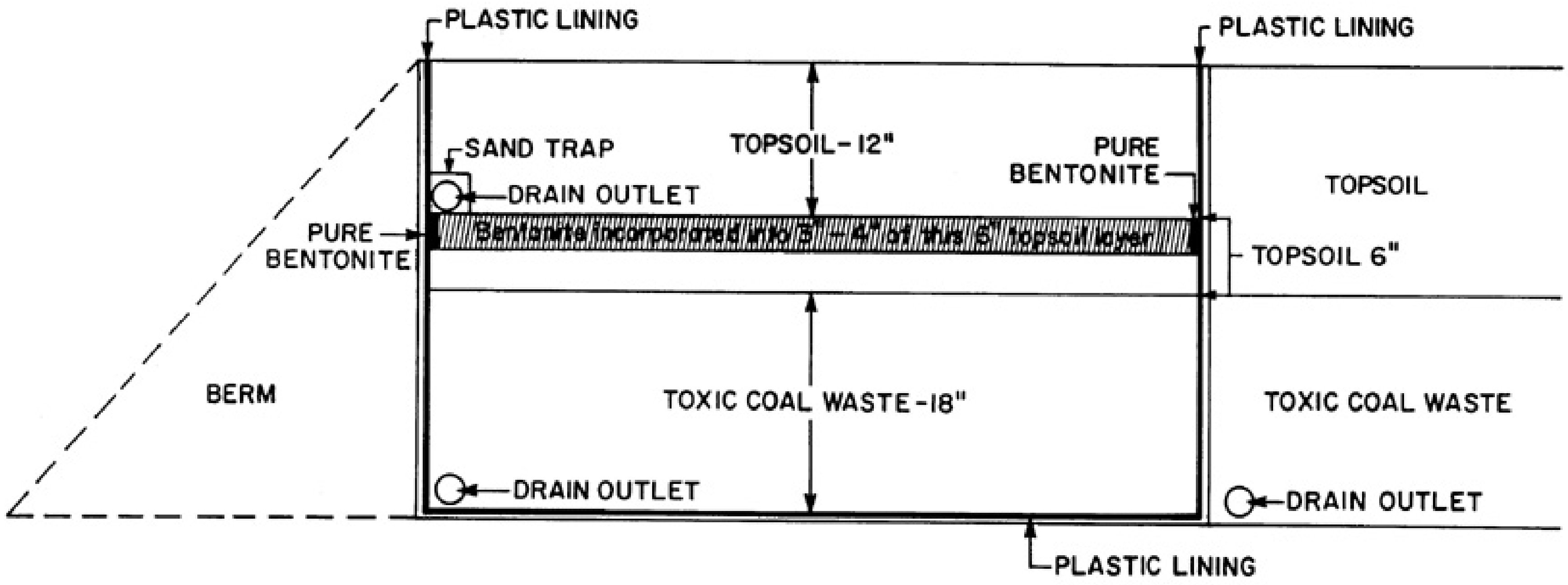

Figure 1.--Profile description

Dyer + Crews: Fig. 1

Table 2. Characteristics of toxic mine spoil and topsoil

Item	Toxic Mine Spoil[a]	Topsoil			Bentonite
		Composite[b]	From Plot 5	From Plot 8	
		PHYSICAL[c]			
Coarse fragments (> 2mm)	54	31	31	40	
Soil (< 2mm)	46	69	69	60	
Sand	69	55	55	32	
Silt	23	31	32	40	
Clay	8	14	13	28	
Classification	Very gravelly silt loam	Gravelly silty clay loam	Gravelly silty clay loam	Gravelly silty clay loam	
		CHEMICAL			
Avail. potassium (mg/kg)	51.8	55.2	42.8	80.4	
Avail. magnesium(mg/kg)	76.5	8.6	9.7	22.1	
Avail. calcium (mg/kg)	554.9	52.4	53.6	154.6	
Avail. phosphorus (mg/kg)	5.01	3.07	2.14	2.82	
pH	3.7	4.4	4.3	4.6	9.8
Conductivity (mmhos/cm)	.16	.07	.07	.08	
Organic carbon (%)	23.20	.95	.12	.66	
Exchange. acidity (meq/100 g)	11.44	2.48	2.96	2.80	
Exchange. Al (meq/100 g)	8.18	1.91	2.40	2.13	
Exchange. Ca (meq/100 g)	.66	.27	.26	.73	52.4
Exchange. Mg (meq/100 g)	.24	.05	.04	.22	14.7
Exchange. Na (meq/100 g)	.03	.02	.03	.04	23.0
Exchange. K (meq/100 g)	.12	.15	.13	.27	2.2
Base Exch. Cap. (meq/100 g)	12.49	2.97	3.42	4.06	92.3
Percent base saturation	9	16	13	31	

[a] Beneath bentonite zone.

[b] From plots 1, 2, 3, 4, 6, 7, and 9.

[c] Values are in percent by weight.

Table 3. Chemical characteristics of drainage water

Collection year	Lower drain[a]			Upper drain[b]	
	Control	1 lb/ft^2 bentonite	2 lb/ft^2 bentonite	1 lb/ft^2 bentonite	2 lb/ft^2 bentonite
			pH		
1983	--	--	--	-	-
1984	4.0	5.1	4.5	7.6	7.7
1985	4.8	6.7	4.8	7.9	7.8
			CALCIUM (mg/l)		
1983	37.5	46.4	48.8	37.6	43.1
1984	15.0	23.8	21.1	64.7	82.8
1985	5.7	13.5	6.9	40.1	54.9
			MAGNESIUM (mg/l)		
1983	16.2	20.5	19.2	4.3	5.4
1984	6.4	7.4	9.1	7.1	7.3
1985	2.2	2.6	2.7	3.7	4.2
			SODIUM (mg/l)		
1983	9.7	31.6	34.9	38.6	84.0
1984	2.2	30.3	37.8	30.9	46.7
1985	1.5	14.3	20.2	15.0	21.1
			POTASSIUM (mg/l)		
1983	21.4	21.8	34.9	20.4	39.6
1984	5.8	5.2	6.4	7.2	8.6
1985	3.6	3.0	3.6	3.5	2.7

[a] Drain at bottom of toxic mine spoil layer (toxic coal washings) beneath the bentonite zone.

[b] Drain at bottom of topsoil layer just above the bentonite zone.