HYDROLOGIC EVALUATION OF TOPSOILING FOR REHABILITATING BLACK MESA COAL MINE LANDS

by

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ABSTRACT

Two experimental paired watersheds on Black Mesa Mine, in the Four-Corners region of Arizona were compared by several hydrologic variables in order to determine their relative capabilities for vegetative reestablishment. From July 1977 to the present, precipitation ranged from 5 to 7 inches; runoff was 7 times lower on the topsoiled watershed. Because of its structureless nature, the non-topsoiled watershed tended to crust and seal the surface. In general, the sediment yield was lower on topsoiled spoils; however, increased sediment yields were observed during intense storms, possibly reflecting the fact that the topsoil was not anchored to the underlying spoils. The non-topsoiled watershed was found to have a higher soil moisture at wilting point (13.8%) and high soluble salts (3,000 - 5,000 ppm), making water unavailable at higher suctions. The range of available water was higher on the non-topsoiled watershed. Tests indicated that most soil moisture water storage results from winter frontal storms of long duration. A vegetation survey indicated a more successful rate of seedling establishment (8.1 plants/m) on the topsoiled watershed, but with a high subsequent die off rate due to drought conditions. Mechanical treatment of and chemical ammendments to spoils and topsoils are discussed. It is concluded that the practice of topsoiling will greatly enhance revegetation of mine spoils in arid environments. If it is necessary to directly revegetate spoil materials without topsoiling, salt and drought tolerant species are recommended.

INTRODUCTION AND AREA DESCRIPTION

The passage of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) made it mandatory (in most cases) to topsoil graded coal mine spoils. Investigations on the feasibility of topsoiling, for increasing the speed of reclamation and of vegetation establishment have been suggested by various authors. Some investigators have questioned the use of topsoiling for seedling and vegetative establishment in western coal mining areas as being unnecessary and very costly (Bradshaw, 1973). Some feel that in most arid land areas topsoil is undefined and restricted to the upper 2-3 inches of the A horizon (Wahlquist, et al. 1975) and that stripping this topsoil could be economically unfeasible. Others contend that topsoiling is a necessity if anything is to be established on graded spoils, due to the unstable nature of the spoils (United States Federal Register, 1978). Much of the semi-arid western coal mining lands have poor quality topsoil, are low in organic matter and nutritive value (Wahlquist, et al. 1975), and may seem a doubtful medium for vegetative purposes. Very little has been done by way of comparing topsoiled and non-topsoiled areas. One Northwestern New Mexico study points to limited success in seedling establishment on topsoil, and subsequent high die off rates (Wahlquist, et al. 1975). The intent of this study is to compare a topsoiled with a non-topsoiled area, and to propose what each area may have to offer for the rehabilitation of coal strip mined lands.

Spoils have unique chemical and physical properties and cannot be called soils in the pedological sense. They may present problems in revegetation due to higher salt content and finer texture, although some areas in the southwest anticipate a favorable response from mine spoils as a growing medium (Yamamoto 1975). Of particular concern on the Black Mesa (included in the Four-Corners area), is its low and variable rainfall, which averages from 9-12 inches per year with a range between 6 inches in the basin areas and 15 inches near the rim where mining is less intensive (National Academy of Sciences, 1974). There are two rainy seasons. The winter season (November - April) brings in long duration frontal storms and aids mostly in the buildup of soil moisture. The summer season (late July - early September) usually consists of high intensity convective cells which cause most of the runoff and result in little soil moisture storage. During this season, some areas may receive considerable quantities of rainfall during a storm, while others may not receive any, a situation that makes vegetation efforts difficult. Because of the low and sporadic rainfall, an important consideration was made for topsoil and spoil moisture retention and storage, and possible mechanical and chemical alterations of these media to increase moisture retention.

The study areas were two experimental paired watersheds in the J-27 area on Black Mesa Mine, in Northern Arizona, leased and operated by the Peabody Coal Company. The topsoiled watershed (3.0 acres) was first regraded to blend in with the existing topography and covered with 12 inches of reddish, moderate, coarse, crumb, sandy loam, alluvial soil, that had been scraped away from the surface three feet, and stockpiled before overburden removal. Slopes varied from 5 - 15%. The non-topsoiled watershed was 5.4 acres, consisting of structureless, fine, platy, sandy loam gray spoils material. Slopes again varied from 5 - 15% and conformed to existing natural terrain.

Continuous data for runoff and precipitation have been collected since July of 1977. The watersheds were equipped with a standard 8-inch continuous recording raingage located between the watersheds. Each watershed had provisions for measuring and collecting runoff by use of 2.0 ft. deep "H" - flumes, measuring a maximum of 10.98 cfs. Each flume was equipped with FW-1 continuous recording water level recorders. In addition, each had a Coshocton splitter dividing the runoff into 1/200 of the total, and diverts it into a runoff collector. From this first collector, another splitter further divided the runoff 1/10 more, making runoff in the 2nd collector 1/2000 of the total runoff. Sediment samples were taken in the collectors. Neutron access tubes have been established on the watersheds to help evaluate the soil moisture regime. No other treatments were added to the watersheds until June 1979, when the area was seeded with a mixture consisting of Indian Rice Grass (Oryzopsis hymenoides), Vernal Alfalfa, saltbush (Atriplex spp.), Alkalai Sacaton, a variety of Crested and Western Wheatgrass (Agropyron spp.), and sweetclover.

The areas were first disked across the contour, broadcast seeded, and finally chained for adequate seed coverage. No fertilizer amendments were made. After seeding, a vegetation study was initiated to compare differences in seedling establishment.

CHEMICAL ANALYSIS OF SOILS

Chemical analysis of the topsoiled and non-topsoiled watersheds were conducted in August, 1977 and August 1979 to compare differences, and to check for any salinization, nitrification, or mineralization. Soils were collected randomly and submitted to the University of Arizona Soils and Water Testing Laboratory for analysis. Results of the analysis are shown in Tables 1 and 2.

Table 1. Chemical Analysis of Topsoiled and Non-topsoiled Mined-Land Materials on the Black Mesa

Characteristic	August 1977 Non-topsoiled 0-6 in.	August 1977 Non-topsoiled 6-12 in.	August 1977 Topsoiled 6-12 in.	August 1979 Non-topsoiled 0-6 in.	August 1979 Topsoiled 0-6 in.
pH	5.48	5.33	7.73	4.00	8.00
$EC_e \times 10^3$	4.92	7.50	1.57	10.01	1.59
Sol. salts, ppm	3444	5252	1099	7007	1113
ESP	0.62	1.09	1.67	1.89	1.19
Na, meq/l	9.80	7.10	4.63	14.18	4.05
K, meq/l	0.49	0.63	0.17	0.36	0.21
N, ppm	30.88	45.21	4.15	194.00	5.75
P, ppm	0.13	0.21	0.36	0.20	1.25
SAR				2.17	1.68

Samples taken for the 1977 analysis of all constituents, except particle size, were not mixed in order to check for variations between samples. Coefficients of variation for ESP, sodium, and nitrogen were particularly high. Values for nitrogen in the non-topsoiled watershed varied from 170 ppm to 3.0 ppm in the 0 - 6 inch strata and 63 to 2 ppm in the 6 - 12 inch strata. This high variation may suggest a need for supplemental nitrogen applications to insure adequate nitrogen distribution. The topsoiled watershed was deficient in nitrogen as indicated from both 1977 and 1979 analyses. The ESP and sodium values were low enough in both areas, even with high variations, to be inconsequential for plant growth. All other values were well below the standards set for a sodic soil (United States Salinity Laboratory Staff, 1954). Of particular concern for the non-topsoiled watershed is the high $EC_e \times 10^3$, soluble salts, and low pH values. The $EC_e \times 10^3$ exceeds the accepted value of 4, making the spoils material saline in nature (United States Salinity Laboratory Staff, 1954). Being a fine sandy loam to fine loam in texture, and having high salts, causes this material to have a very high runoff capacity in a very arid area. Furthermore, pH values of below 5.5 may have a detrimental effect on the germination of many of the rangeland species planted. The relatively low coefficient of variation for the non-topsoiled area indicates pH values very near the mean. This may indicate that pH is becoming progressively lower as revealed by the pH value of 4.0 in the 1979 analyses as compared to the 5.4 found in 1977. A pH range of 6 -77 is optimum for plant nutrient availability (Lyon, et al. 1952). Also, higher soluble salts in the non-topsoiled watershed in 1979 point to salinization, affecting both plant soil water availability and salt tolerance. Thus, both topsoiled and non-topsoiled watersheds need some adjustments. Addition of lime for the non-topsoiled watershed may prove ineffective since the

Table 2. Analysis of Variance for Topsoiled (TS) and Non-topsoiled (NTS) Materials (Data in Table 1)

Characteristic	Coef. of Variation TS (0-6")	Coef. of Variation NTS (0-6")	F[1]	Coef. of Variation TS (0-6")	Coef. of Variation NTS (6-12")	F[1]
pH	0.06	0.14	69.3**	0.06	0.15	72.0**
$EC_e \times 10^3$	.55	.26	47.1**	.55	.64	14.9**
Sol. salts, ppm	.55	.26	9.2**	.55	.64	9.2**
ESP	1.25	1.22	0.2	1.25	.75	0.6
Na, meq/l	.88	1.58	1.1	.88	.58	1.8
K, meq/l	.29	.48	17.1**	.29	.63	10.3
N, ppm	.39	1.25	5.3*	.39	1.03	7.2*
P, ppm	.77	.54	5.8*	.77	1.09	1.6

[1] F values to be exceeded: $F_{.05,1,18} = 4.5$; $F_{.01,1,18} = 8.3$

exchange surface is already saturated primarily with calcium and/or magnesium (low SAR). Leaching with large amounts of water would help to ameliorate the situation. As for the topsoiled watershed, addition of gypsum may increase the solubility of P, Fe, Cu, and Zn ions (Yamamoto, 1975). Both watersheds had low concentrations of available phosphorus, indicating a need for phosphorus addition to raise the levels to 2 - 3 ppm. The potassium value for both areas was adequate, but the non-topsoiled area was significantly higher at both depths.

It should be noted that graded mine spoils are homogenous for some parameters (salts, E.C., and K) but are highly variable, depending on substrata, for other constituents. A low pH is generally indicative of layers with high sulfur content, and can be remedied by proper stockpiling of spoils. This indicates a need for extensive overburden analyses before mining to insure placement of acid spoils far below the surface growing region. Soil analyses have been made on other Black Mesa mine spoils in which pH values similar to topsoiled areas (7.5 - 8.0) were found.

RAINFALL, RUNOFF, AND SEDIMENT

Measurements began in July 1977 after installation of the monitoring equipment. It is important to note that the topsoil was untouched from the time of placement on the spoil until June, 1979. Federal regulations require topsoil to be anchored somehow, possibly with a straw or hay mulch and contour disking (United States Federal Register, 1978). From the hydrologic data collected it may be noted that topsoil anchoring is of utmost importance to prevent heavy sediment loads during high intensity summer storms. The summer storms of August 1978 washed out over 8 tons/acre on the topsoiled watershed versus over 4 tons/acre on the non-topsoiled watershed. Low intensity storms are an aid to the topsoiled watershed for building up soil moisture, and sediment loss is low. With the exception of the very intense storms on 8/15/77, sediment loads were much lower on the topsoiled watershed. If anchored, the sediment loss might have been much less. Runoff was about seven times lower on the topsoiled watershed during the 1978 and 1979 water years. This was probably due to establishment of natural vegetative species from seeds brought in with the topsoil, and Russian Thistle (Tumbleweed), a drought tolerant species whose seeds blow in from natural areas. Because of its structureless nature, the non-topsoiled spoils crusted over and sealed off. Also, because of low amounts of humus, little root growth and/or microbial activity, the spoils have developed few water stable aggregates (Hillel, 1971). Infiltration was impeded allowing less available water for plant growth.

SOIL MOISTURE

Soil moisture data were collected using a Campbell Pacific Hydroprobe 503 with access tubes at the lower, middle, and upper areas of the watersheds. A calibration curve was developed for the probe derived from gravimetric determinations. Soil moisture was found on a weight basis and then converted to percent by volume from bulk density determinations of 1.25 g/cm^3 for spoils and 1.19 g/cm^3 for topsoil. Soil samples were randomly collected at 0 - 6 inches, mixed and submitted to the University of Arizona's Soil and Water Testing Laboratory for moisture tension analysis. The graph of the soil moisture characteristic curves indicates similar holding capacities, but different ranges between wilting point (15 bars) and field capacity (0.3 bars). The non-topsoiled 15-bar value of 13.8% by volume is generally above the low soil moisture values found in the spoils during critical growing periods. The wilting point value for the topsoiled watershed is below the moisture contents found even in months of drought.

Thus, the mine spoil material, even though it has a high water holding capacity, cannot supply water to growing plants in very dry seasons. The soil moisture content must be above 13.8% to be available to most seedlings and plants. There are some drought hardy plants which are able to obtain water against pressures exceeding 15-bars, but they are the exceptions rather than the rule.

VEGETATION STUDY

Ten plots of 1.0 m^2 were randomly selected on each watershed in an attempt to obtain representative samples of seeded vegetation. Seedlings were counted and found to include species from both the seeded mixture and natural sources that have invaded the area, such as Russian Thistle. Data are presented in Tables 3 and 4. The topsoiled watershed had varied success in the establishment of new species. Die-off rates for grasses were almost 100% while only about 50% for clover. Probably, dieoff rates were so high because of drought conditions from 8/18/79 to 9/26/79 when no rain fell. Seedling efforts on the non-topsoiled watershed were a failure. Russian Thistle, a drought hardy, salt tolerant species, was not even present, except for a few small patches observed on the watershed. The spoils material not only had a high runoff potential, but also a high soluble salt content, which raises osmotic potential. Even though it had a higher water holding capacity, the ranges for soil water availability for plants were too high in the arid environment. Though seedling dieoff was high on the topsoiled watershed some plant establishment occurred, and dead plants were found to contribute to humus production needed on arid soils. Additional amendments such as phosphorus, nitrogen, and gypsum, plus mechanical alterations such as drilling seed and deep disking with 36 inch range disks may increase productivity.

Table 3. Vegetation Study on Black Mesa Coal Spoils, August 18, 1979

Station	Number of Seedlings	Alive or Dead	Seedling Types, Number, and Maximum Height			
			Grass		Clover	
			No.	Max Ht (cm)	No.	Max Ht (cm)
1 (TS)	2	Alive	1	7	1	6.0
2	3	Alive	1	5	2	5.0
3	1	Alive	0	-	1	2.5
4	1	Alive	0	-	1	1.5
5	6	Alive	1	10.5	5	4.0
6	7	Alive	1	7.5	6	6.0
7	26	Alive	9	9.5	17	9.0
8	20	Alive	6	7.0	14	5.0
9	9	Alive	0	-	9	5.0
10	6	Alive	1	1.0	5	0.5
Totals	81	81 Alive	20	-	61	-
Mean	8.1	8.1 Alive	2.0	6.8	6.1	4.4
1 (NTS)	0	-	0	-	0	-
2	0	-	0	-	0	-
3	0	-	0	-	0	-
4	0	-	0	-	0	-
5	0	-	0	-	0	-
6	0	-	0	-	0	-
7	0	-	0	-	0	-
8	0	-	0	-	0	-
9	0	-	0	-	0	-
10	0	-	0	-	0	-
Totals	0	-	0	-	0	-
Mean	0	-	0	-	0	-

DISCUSSION AND CONCLUSIONS

Reclamation of arid strip mined lands is a difficult endeavor. There must be an effort to use every process available to conserve precious water for plant consumption. The medium for growing plants must be of a desirable nature to make water highly available for plant use. Finally, the growing medium must not be toxic in any way to the growing seedling or plant. Unfortunately, the mine spoils examined on Black Mesa do not meet these criteria. Its low pH values make it toxic to some rangeland species. An EC_e of 10 will reduce yields of Crested Wheat grass (Agropyron desertorum) 25%, Alfalfa (Medicago sativa) over 50%, other Wheat grasses (Agropyron spp.) 10 - 25%, and Clover (Trifolium Alexandrinum)

50% (Ayers and Westcot, 1976). The "total soil water potential" is thus raised due to increases in pressure and osmotic potentials (Hillel, 1971). Because of this, the plant must work harder to extract water for consumption compared to the topsoiled watershed with lower soluble salts and lower pressure potentials. A low pH (<5.0) may change physiological conditions making it unfavorable for lime loving plants such as alfalfa, sweet clover, and red clover (Brady, 1974). Runoff and erosion potential was higher for the non-topsoiled watershed. All this evidence points to the necessity of topsoiling mine spoils in order to reestablish vegetation on Black Mesa.

Table 4. J-27 Vegetation Study on Black Mesa Coal Spoils, September 26, 1979

Station	Number of Seedlings			Live Seedling Types, Numbers, and Maximum Heights					
	Alive	Dead		Grass		Clover		Russian Thistle	
	No.	No.	Type	No.	Max Ht (cm)	No.	Max Ht (cm)	No.	Max Ht (cm)
1 (TS)	6	1	grass	0	-	1	4.5	5	28.0
2	2	1	grass	0	-	2	5.0	0	-
3	4	0	-	0	-	1	2.5	3	25.0
4	1	1	clover	0	-	0	-	1	18.0
5	3	3	grass	0	-	3	1.5	0	-
		1	clover						
6	5	1	grass	0	-	5	4.5	0	-
		1	clover						
7	13	9	grass	0	-	13	2.0	0	-
		4	clover						
8	10	6	grass	0	-	5	3.0	5	30.0
		9	clover						
9	2	8	clover	0	-	1	4.5	1	71.0
10	0	5	clover	0	-	0	-	0	-
		1	grass						
Totals	46	22	grass	0	-	31	-	15	-
		29	clover						
Mean	4.6	2.2	grass	0	-	3.1	3.4	1.5	22.4
		2.9	clover						
1 (NTS)	0	-		0	-	0	-	0	-
2	0	-		0	-	0	-	0	-
3	0	-		0	-	0	-	0	-
4	0	-		0	-	0	-	0	-
5	0	-		0	-	0	-	0	-
6	0	-		0	-	0	-	0	-
7	0	-		0	-	0	-	0	-
8	0	-		0	-	0	-	0	-
9	0	-		0	-	0	-	0	-
10	0	-		0	-	0	-	0	-
Totals	0	-		0	-	0	-	0	-
Mean	0	-		0	-	0	-	0	-

For areas not required by law to be topsoiled, it is recommended that species of high salt and drought tolerance be planted at times when soil moisture is highest (early spring). Deep furrow contour disking and range drilling would facilitate moisture capture and adequate seed cover. Supplemental irrigation on saline spoils could be hazardous unless the salts are leached to depths below the root zone. This may require water in amounts exceeding available supplies. It has been found that acid spoils can be adjusted by either liming or addition of fly ash from coal-fired power plants. Fly ash is cheap and available in nearby Page, Arizona at the Page Power Plant. Fly ash also helps to increase soil moisture capacity and certain nutrients such as P, B, and Zn (Capp and Gillmore, 1973). For topsoil, additions of N and P are necessary, and possibly small amounts of gypsum. Also mulching with hay or straw with a tucker disk to anchor topsoil would be necessary. Again, deep contour disking and seed drilling would be advantageous for water conservation and adequate seed cover. Supplemental irrigation of topsoiled areas may help decrease seedling dieoff in times of drought, especially since wet periods at Black Mesa are episodic and unpredictable.

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SOIL MOISTURE CHARACTERISTIC CURVE FOR J-27

TOPSOILED AND NON-TOPSOILED WATERSHEDS (DESORPTION)