Runoff and Erosion Characteristics of Surface-Mined Sites in Western North Dakota

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Runoff and Erosion Characteristics of Surface-Mined Sites in Western North Dakota

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ABSTRACT

A rainfall simulator was used to measure runoff and erosion from rangeland, spoil and topsoil sites. Measured soil losses were greatest on bare topsoil plots and least on the non-cultivated rangeland site. Application of a straw mulch reduced erosion on topsoil by over 90 percent. However, the measured erosion and runoff values from the mulched topsoil sites were still over 50 percent higher than from the rangeland site.

INTRODUCTION

Increased utilization of coal from the Northern Great Plains is expected as a result of growing national energy requirements. Removal of these coal deposits will require surface-mining of productive agricultural areas. As yet, proven procedures for restoration of these surface-mined sites to pre-existing agricultural productivity have not been established.

Water is a principal limiting factor for plant growth in the Great Plains. Runoff from mined areas may not only reduce the plant water supply but also can create sedimentation problems. Studies were initiated to determine erosion and runoff losses from surface-mined sites. Soil loss information from both pre-mined and mined situations is presented and methods for reducing erosion are examined.

Erosion has been extensively studied in the United States. These investigations have led to adoption of cultural practices to reduce sediment production and maintain agricultural productivity. Research has primarily focused on predicting soil losses from cropland.

The universal soil loss equation (Wischmeier et al., 1958 and Wischmeier, 1960) has been accepted as a tool to predict erosion losses. This equation incorporates such factors as rainfall, soil erodibility, land slope, slope length, cropping and land use, and erosion control practices. The rainfall erosion index (EI) of a storm is defined as the total kinetic energy of the rainfall times its maximum 30-min intensity. An EI value of 50 is representative of the energy impact (coal mining) area of western North Dakota (Wischmeier and Smith, 1965).

Prior to mining, the soil material considered most suitable for plant growth, “topsoil”, is removed and stockpiled. The overburden, or material overlying the coal deposits, is then excavated and placed in trenches resulting from previous stripping activities. The disturbed overburden or spoil is then smoothed, the topsoil replaced and the area seeded. The stripping and reshaping process involves a mixing of overburden materials. The spoil is characteristically heterogeneous consisting of geologic materials from varying overburden depths. The material left at the surface sometimes has higher concentration of sodium than calcium and magnesium. Materials with high sodium adsorption ratios (SAR) disperse readily when exposed to water, and as a consequence, infiltration is reduced.

Concern has grown over the magnitude of sediment losses associated with construction activities. Reports indicate that serious erosion problems sometimes occur from highway, housing and business development (Bathurst, 1965; Schmidt and Summers, 1967 and U.S. Dept. of Agri. and Dept. of Housing and Urban Dev., 1967). The same difficulties could result from extensive land disturbance and modification resulting from surface-mining. However, little information is presently available on erosion and runoff losses from surface-mined areas.

PROCEDURE

Runoff and erosion studies were conducted at the North American Coal Corporation’s Indian Head Mine near Zap, North Dakota. A native rangeland site with sandy loam texture was located within the mine complex on a 9.0 percent slope. The grass cover was last cut and harvested in September 1974. Testing was performed in October 1975. The rangeland area served as a pre-mined condition for comparison with mined conditions.

Additional study sites were located on bare spoil materials representing three textures. Plots with slope gradients of 4.6 and 17.0 percent were located on a sandy clay loam material, while plots with slopes of 10.0 and 12.9 percent were established on clay loam and silty clay loam spoil, respectively. Each of the spoil treatments consisted of cultivated and non-cultivated plots. The cultivated area was rototilled to a depth of 5 to 8 cm immediately preceding testing. The borders of the noncultivated plots were installed in November 1974 and the cultivated plot borders in July 1975. Field evaluations were conducted in August and September 1975. The sparse vegetative growth on the noncultivated plots was clipped prior to testing.

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Treatments of sandy loam topsoil thicknesses of 25 and 61 cm were established in July 1975 on slopes of 10.4 and 9.9 percent, respectively. The topsoil was taken from a soil classification as Flexton fine sandy loam. The clay loam spoil material of SAR 37 on which the topsoil was placed was disked to a depth of 8 to 10 cm before topsoil placement. There was approximately 24 mm precipitation in late September 1975 just prior to rainulator runs. The topsoil sites were rototilled to a depth of 5 to 8 cm immediately preceding testing. The area on which the spoil and topsoil plots were located was mined in 1971 and reshaped in 1973. Study site characteristics are described in Table 1.

Plots were 4.1 m across the slope by 22.1 m long, separated by a 2.1 m border area. Standard procedures were used to measure rainfall intensity, runoff and soil loss (Meyer, 1960). The first rainulator application (initial run) was conducted at existing soil-water conditions and the second about 24 hr later (wet run). An additional run for 30 min duration was conducted on the topsoil and clay loam spoil sites immediately following the second simulated rain event. This application was on plots having 4500 kg/ha wheat straw placed immediately after the wet run. Application intensities were maintained near 64 mm/hr for each of the runs. A typical rainulator test site installation is shown in Fig. 1.

Adjustments to deviations from the design intensity were made to runoff and soil loss data (Meyer et al., 1971). Runoff information was adjusted by the amount the actual application differed from 64 mm for the initial and wet runs or 32 mm for the straw run. Erosion losses were modified by the ratio of (64)² to the square of the actual intensity.

RESULTS

The soil loss and runoff data from each of the simulated rainfall events are summarized in Table 2. Averages of two replications on the topsoil and rangeland sites are shown. Other entries describe non-replicated treatments.

Rangeland

The predominate land use for much of the area designated for energy development in the Northern Great Plains is range. With proper management, the grasslands provide a stable, renewable resource.

The grass cover serves as an effective rainfall energy dissipator and protects the underlying soil material from potential erosion.

Sediment production from the rangeland site was 200 kg/ha. Almost all of the loss occurred during the wet rainulator run. Despite high application intensities, runoff losses totalled only 15 mm or 12 percent of the applied rainfall. Thus, runoff and erosion losses from the rangeland site were considered minimal.

Spoil

For the combined rainulator runs, soil losses on bare spoil were consistently higher on non-cultivated plots and averaged 15,000 kg/ha and 21,000 kg/ha for all cultivated and non-cultivated sites, respectively. For the 4.6 percent sandy clay loam site, the non-cultivated plot yielded nearly 100 percent more sediment than the cultivated plot (Table 2). For the cultivated areas, only minor variations in soil loss were found among the three textures of spoil material tested. Sediment loss was reduced by 39 and 18 percent on cultivated and non-cultivated sandy clay loam spoil, respectively, when slope was decreased from 17.0 to 4.6 percent.

The straw mulch proved very effective in decreasing sediment production. Soil losses between the straw run and the final 30 min of the preceding wet run on bare clay loam spoil showed a reduction of 84 percent.

Runoff for all spoil textures averaged 66 percent and 74 percent of the water applied on the cultivated and the non-cultivated sites, respectively. Reduction in slope from 17.0 to 4.6 percent caused a reduction in runoff of 26 percent on both the cultivated and non-cultivated sandy clay loam spoil.

Topsoil

Sediment production from the bare topsoil plots averaged 74,000 kg/ha. Soil water content was near field capacity prior to testing on both topsoil sites. Soil losses were similar between the initial and wet runs. Increasing the topsoil thickness from 25 to 61 cm reduced runoff by 24 percent and slightly increased the soil loss by 7 percent. The soil loss to runoff (SL/RO) ratio was highest on the 61 cm bare topsoil plot.

Straw cover also proved very effective in reducing sediment loads from the topsoiled sites. An average soil
TABLE 2. RUNOFF AND EROSION FOR RAINULATOR STUDY OF SURFACE-MINED CONDITIONS

<table>
<thead>
<tr>
<th>Surface material</th>
<th>Texture</th>
<th>Slope, percent</th>
<th>Surface treatment</th>
<th>Runoff, mm</th>
<th>Soil loss, kg x 10^3/ha</th>
<th>SL/RO ratio, percent by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rangeland #</td>
<td>sl</td>
<td>9.0</td>
<td>N</td>
<td>Initial+Wet</td>
<td>2</td>
<td>15</td>
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<tr>
<td>Spoil</td>
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<td>4.6</td>
<td>C</td>
<td>Initial+Wet</td>
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<td>74</td>
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<tr>
<td></td>
<td>scl</td>
<td>17.0</td>
<td>C</td>
<td>Initial+Wet</td>
<td>130</td>
<td>76</td>
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<tr>
<td></td>
<td>cl</td>
<td>10.0</td>
<td>C</td>
<td>Initial+Wet</td>
<td>220</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>sicl</td>
<td>12.9</td>
<td>C</td>
<td>Initial+Wet</td>
<td>210</td>
<td>99</td>
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<td>Topsoil #</td>
<td>sl</td>
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<td>C</td>
<td>Initial+Wet</td>
<td>710</td>
<td>87</td>
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<tr>
<td></td>
<td>sl</td>
<td>9.9</td>
<td>C</td>
<td>Initial</td>
<td>760</td>
<td>66</td>
</tr>
<tr>
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<td>N</td>
<td>Initial</td>
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<tr>
<td></td>
<td>scl</td>
<td>17.0</td>
<td>C</td>
<td>Initial</td>
<td>83</td>
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<td>10.0</td>
<td>C</td>
<td>Initial</td>
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<td>12.9</td>
<td>C</td>
<td>Initial</td>
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<tr>
<td></td>
<td>sl</td>
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<td>C</td>
<td>Initial</td>
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<td></td>
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<td>C</td>
<td>Wet</td>
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<td>36</td>
</tr>
<tr>
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<td>C</td>
<td>Straw;</td>
<td>9</td>
<td>18</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>N</td>
<td>Straw;</td>
<td>7</td>
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<tr>
<td>Topsoil #</td>
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<td>C</td>
<td>Straw;</td>
<td>18</td>
<td>18</td>
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<tr>
<td></td>
<td>sl</td>
<td>9.9</td>
<td>C</td>
<td>Straw;</td>
<td>11</td>
<td>15</td>
</tr>
</tbody>
</table>

* Plots were 4.1 by 22.1 m.
† scl = sandy clay loam, cl = clay loam, sicl = silty clay loam, sl = sandy loam.
‡ Straw mulch was placed at a rate of 4500 kg/ha.
§ C = cultivated, N = non-cultivated.
¶ Initial and wet runs lasted 60 min; the run after straw was applied lasted 30 min; application intensity 64 mm/hr.
# Data are averages of two replications.

loss reduction of 93 percent for the two treatments occurred between the run after straw was applied and the final 30 min of the preceding wet run.

K Factors

Adjusted soil losses per unit of rainfall erosion index (EI) and K (soil erodibility) factors are presented in Table 3. The calculated K factors were obtained by dividing the soil loss per EI values on the cultivated plots by the recommended slope gradient factor, S (Wischmeier and Smith, 1965). The slope length, cropping management and erosion-control practice factor were all set equal to one. The K values were calculated only for the cultivated plots.

DISCUSSION

Sodic (high SAR) spoil materials erode in a different manner than replaced topsoil. Three important observations are:

1. the consistent decrease in sediment loss resulting from cultivation at all spoil sites,
2. the small effect of slope on erosion from spoil materials, as observed on the sandy clay loam sites (Table 2), and
3 the apparent low rates of erosion from all spoil sites.

These observations can be explained by the nature of the sodic spoil materials. Gee and Bauer (1976) reported high crust strengths and high dispersion for sodic spoil materials with SAR values above 30. The SAR values at all spoil sites ranged from 33 to 41 (Table 1). The non-cultivated plots had crusts, compacted, smooth surfaces. Rototilling broke the crusts and increased surface roughness. The decrease in soil loss on cultivated plots is attributed to increased surface roughness and improved surface infiltration. However, the highly dispersive nature of the spoil material caused eventual surface sealing observed on the cultivated plots. The dispersion and surface sealing are factors contributing to the reduced effect of slope and the apparent low rates of soil loss from the tested spoil sites.

The S factor given by Wischmeier and Smith (1965) predicts at least a 5 fold difference in sediment production between the 4.6 and 17.0 percent cultivated spoil plots (Table 3). Less than a 2 fold difference was observed (Table 2). If a linear extrapolation of the "Adjusted soil loss per EI" values (Table 3) is made for the cultivated sandy clay loam sites, a modified slope factor can be computed. This modified slope factor is

\[ S' = 0.61 + 0.0435 \times S \]

where \( S \) is the percent slope. Using the modified slope factor, \( S' \), the recalculated K factor for the cultivated sandy clay loam spoil plots is 0.05. If \( S' \) is assumed to be valid for the other spoil materials, the K factors for the clay loam and silty clay loam materials are 0.08 and 0.06, respectively (Table 3). Additional work will be required to more accurately determine the slope factor for sodic spoil materials. In any case, the spoil material was clearly less erosive than the topsoil. The low K factors are attributed to the crusting and surface sealing characteristics of sodic spoils.

Present reclamation procedures provide for replacement of suitable plant growth materials to reshaped spoil areas. Using a yearly EI value of 50 (Wischmeier and Smith, 1965), average annual sediment production on the site with 61 cm of topsoil would be approximately 37,000 kg/ha. Extrapolation of these data to a topsoil site with 16 percent slope and 124 m length, by using the universal soil loss equation and recommended slope-length factors, predicts an annual topsoil loss of over 210,000 kg/ha. Thus, the need for suitable conservation practices is apparent.

Mulching with straw was found to be an effective erosion control practice. Reduction in soil losses of 84 and 93 percent as compared with the final 30 min of the preceding wet run occurred for mulched spoil and topsoil plots, respectively (Table 2). Tests of other mulching rates and use of other type mulches are logical extensions of the present work.

Field testing on the spoil and topsoil sites was conducted under fallow conditions and, therefore, represents a soil loss extreme. Reclamation practices provide for seeding of the disturbed areas soon after topsoil is replaced. As a vegetative cover becomes established, sediment losses would be expected to correspondingly decrease.

Management techniques may be needed to reduce potential erosion, especially during the period of plant establishment. These techniques could include restricted slope length and gradient, concave slope configuration and placement of a mulch. Establishment of a protective vegetative cover as soon as possible after topsoiling should be an important priority.

### SUMMARY

Erosion and runoff resulting from simulated rainfall were measured for treatments representing pre-mined and mined conditions. Sediment production averaged 74,000 kg/ha for the bare topsoil sites compared to 18,000 and 200 kg/ha for the bare spoil plots and rangeland, respectively. Application of straw reduced soil losses by 84 percent on the spoil and 93 percent on the topsoil sites. Runoff averaged 60 percent and 70 percent of rainfall applied on the bare topsoil and spoil treatments, respectively, in contrast to 12 percent on a rangeland site. Results indicate the need for suitable management practices on bare topsoil materials to maintain erosion and runoff losses within acceptable tolerances.

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References