EFFECT OF CRUSTING ON RUNOFF AND EROSION FROM RESHAPED SPOIL[1]

S. A. Schroeder[2]

Abstract.--Artificial rainfall techniques were employed to study the effects of crusting versus a disturbed (fallow) surface at two mining locations on reshaped spoil located over a range of slopes. Soil losses at each location for both surface conditions generally increased as the slope increased. However runoff amounts did not always follow the same pattern. Soil loss values between the two locations were as high as 21 and 17 t/ha on the fallow and crusted spoil surfaces, respectively.

INTRODUCTION

One of the most important considerations involved in surface mining operations concerns the ability to predict runoff and sediment yield from reshaped spoil areas for designing sediment pond size. Regulations included in both state and federal laws require protection of undisturbed and reclaimed areas from possible contamination by runoff and sediment originating from reshaped, nonreclaimed areas.

Gilley et al. (1977) used a rainfall simulator on highly sodic spoils that had either been cultivated or were crusted. Soil losses over a range of slopes ranged from 4.9 to 12 t/ha and 8.3 to 14 t/ha under dry conditions for the cultivated and crusted plots, respectively. Under wet conditions the soil loss values ranged from 4.3 to 8.5 t/ha and 8.7 to 10.0 t/ha (cultivated and crusted, respectively). Runoff losses were also generally higher on the crusted spoil. Hartley et al. (1984) reported soil losses as high as 7.5 t/ha on bare mine spoil regraded to a 12% slope.

Much of this soil loss data has been used to evaluate the soil erodibility, K, factor in the Universal Soil Loss Equation (Wirschmeier et al., 1978) for predicting future soil losses. Gilley et al. (1977) estimated K values at one sodic spoil location of 0.02 to 0.10 t·ha·hr/ha·mJ·mm while another location had estimates of 0.01 to 0.12 (Gilley et al., 1981).

Singer et al. (1982) concluded that nomograph K values for soils with exchangeable sodium percentage (ESP) greater than 2.0 should be increased as much as 20%. However, other research (Rubio-Montsya et al., 1984) has shown that for a combination of overburden, topsoil, and spoil samples containing from 12.1 to 100.0 ESP that the nomograph K value should be reduced by upwards of 50%. Both experiments used small laboratory simulators.

The objective of this study was to determine crusting effects on runoff and erosion losses on regraded spoil to be used for development of a model to better estimate K values for the Universal Soil Loss Equation.

METHODS AND MATERIALS

Only the fallow spoil plots on a site regraded in 1982 at the Baukol-Noonan Inc. lignite mine near Center, ND were completed in 1983. The runoff plots were reinstalled during the summer of 1984 at approximately the same locations for testing under crusted conditions. This resulted in somewhat different slopes due to additional mining activities. The Beulah spoil sites were installed in 1984 on a site regraded in 1983 at the Knife River Coal Mining Co. lignite mine near Beulah, ND. The same plots at Beulah were used for both crusted and fallow conditions.

Crusted surfaces, as used herein, refer to a naturally formed crust resulting from previous traffic and precipitation events. Fallow surfaces (used to simulate freshly respread conditions) were created by disturbing the upper 2-3 cm by hand raking to destroy any traces of a surface crust and to create a uniform plot surface.

Prior to rainfall application, cores to a depth of 30 cm were removed for particle-size analysis (Day, 1965), bulk density (Blake, 1965),

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[2]Stephan A. Schroeder is an Associate Soil Scientist, North Dakota State University Land Reclamation Research Center, Northern Great Plains Research Center, Mandan, ND. 58554.

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and antecedent moisture content (Gardner, 1965). A bulk sample of the 0-5 cm material around the plots were also taken for analyses of sodium adsorption ratio (SAR), electrical conductivity (EC), and pH (Richards, 1984). This data is shown in Table 1.

Rainfall was applied to each replicated 1.8 by 4.9 m plot through the use of an overhead-rail rainfall simulator (Dunne et al., 1980) which had been modified from the original design by automating both the movement of the nozzle assembly and water application, changing to Spraying Systems 80100 Veejet nozzles, and enclosing all but the downslope end of the simulator frame with plasticized canvas to reduce wind effects. The two nozzles on the nozzle assembly were spaced 1.5 m apart, located at an elevation of 2.5 m from the ground surface, and operated at a pressure of 41.4 kPa to give an approximate kinetic energy of 21 J/m^2 per mm of applied water.

Runoff was measured using a pre-calibrated .6 HS flume and stage recorder. Simultaneously, small samples of the runoff (over 10 min intervals) were collected by an automatic sampler located at the plot end of the flume. These samples were analyzed for sediment concentration for soil loss estimates.

Adjustments to measured amounts of runoff and soil loss were made due to deviations from the design intensity. Runoff was adjusted by the ratio of the actual application to the target intensity of 56 mm/h (or 28 mm/30 min for the latter runs described later) times the actual runoff while soil losses used the square of the ratio times actual soil loss (Meyer et al. 1971).

The sequence of storms for the 1983 fallow spoil plots was an initial (dry) run for 60 min at antecedent moisture conditions followed 24 h later by another 60 min run (wet). The sequence in 1984 was a 60 min dry run followed 30 min later by two 30-min runs (wet and very wet) also separated by 30 min. The wet run on the 1983 fallow spoil plots was subsequently divided into two 30 min segments.

A modified randomized block design and PROC ANOVA (SAS Institute 1982) was used to test slope effects on runoff and soil loss for each run. Analysis of covariance (slope as covariant) was used to test surface conditions effects at and between the two locations.

RESULTS AND DISCUSSION

The range of textures under crusted surface conditions was generally much greater and more variable (as measured by the standard deviation (SD)) than the fallow surfaces for both locations. The average bulk densities were lower for the fallow conditions. Chemically, the range of pH values was less at Beulah versus Center while the range of SAR was greater.

Penetration of the applied water from the dry run for fallow conditions at both locations was as high as 10 cm although it varied considerably from plot to plot. Under crusted conditions at both locations, depth of penetration of water was generally restricted to the upper 0 to 5 cm depth increment.

Table 1. Physical and chemical characteristics at the two mining location runoff plots.[1]

Parameter	Units	Surface							
		Fallow				Crusted			
		Mean Center	SD	Mean Beulah	SD	Mean Center	Sd	Mean Beulah	SD
Slope	%	----	---	----	---	----	----	----	---
Sand	%	19.5	5.9	28.4	3.8	16.0	11.1	26.1	8.5
Silt	%	50.6	2.7	39.9	2.7	43.6	7.3	40.7	8.5
Clay	%	29.9	6.0	31.7	3.4	40.4	15.9	33.2	2.2
Bulk Density	Mg/m^3	1.1	0.1	1.2	0.1	1.3	0.1	1.5	0.1
SAR	$(mmol_c)^{1/2}$	4.2	0.8	7.6	4.6	NM[2]	----	Same as fallow	
pH	-------	7.6	0.3	7.5	0.1	NM	----		
Moisture-Dry[3]	%	12.3	2.5	11.7	4.4	17.2	4.2	10.0	1.9
-Wet	%	24.9	1.1	28.8	3.1	28.9	5.7	16.2	6.0

[1]0.5 cm depths where applicable. Values averaged over slopes and replications (yi=6).

[2]Samples lost, should be similar to fallow values.

[3]Gravimetric samples taken prior to application runs.

Center Plots

Effects of slope on adjusted runoff and soil loss are shown in table 2. For the fallow surfaces, the data generally showed an increasing trend in both runoff and soil loss as slope increased although runoff under dry conditions showed no trend with slope. No significant differences due to slope effects on runoff were found for the crusted surfaces in any run. Significant differences between the slopes for the fallow plots was most likely the result of textural differences. Increased amounts of runoff from the wet to very wet run for the fallow surfaces was due to the application methodology whereas the crusted surfaces showed little change from the wet to very wet runs.

Slope significantly influenced the measured soil loss in all but the very wet run on the crusted surface. In all cases soil losses increased with increasing slope even though the amount of runoff always did not. This may have been due to the velocity of runoff and thus its transport capacity. Rills were readily visible on the fallow plots following each run but were not visible on the crusted plots except where rills existed beforehand. Variation in soil loss as denoted by the coefficient of variation (CV) values listed were higher in all cases than those for runoff. This was partly due to variations between replicates in addition to the effects of slope.

Runoff and soil loss values showed no statistically significant differences for surface condition effects for any of the three application runs (table 2) because the CV values increased in almost all cases from those when the surfaces were analyzed separately. Runoff and soil loss from the crusted surfaces was initially greater than the fallow surfaces during the dry run (31.8 mm and 14.8 t/ha versus 28.7 mm and 13.0 t/ha, respectively). How-

Table 2. Runoff and soil loss from the Center spoil sites as affected by slope and surface condition.[1]

		Application Run					
		Dry		Wet		Very Wet	
Condition	Slope %	Runoff (mm)	Soil Loss (t/ha)	Runoff (mm)	Soil Loss (t/ha)	Runoff (mm)	Soil Loss (t/ha)
				Slope Effects			
Fallow	8.7	25.3	20.9	21.8	11.7	27.4	20.4
	4.9	30.6	15.2	18.6	7.3	20.3	8.5
	0.6	29.6	6.5	15.1	2.0	17.0	2.4
	LSD(.10)[2]	3.0	12.1	NS	6.1	6.6	8.1
	CV[3]	3.6	29.3	13.5	29.8	10.5	26.6
Crusted	6.8	29.0	17.2	16.7	8.6	16.4	9.3
	3.2	37.1	16.1	19.0	6.4	18.5	5.8
	0.2	30.5	7.4	17.8	2.4	18.7	3.8
	LSD(.10)	NS	7.2	NS	4.3	NS	NS
				Surface Effects[4]			
Fallow	---	28.7	13.0	18.3	6.2	21.1	9.2
Crusted	---	31.8	14.8	18.3	6.5	18.3	7.5
	LSD(.10)	NS	NS	NS	NS	NS	NS
	CV	14.3	23.1	14.8	22.3	18.3	41.4

[1]Average of two replications.

[2]Least significant difference at the 0.10 probability level. NS = nonsignificant.

[3]Coefficient of variation from analysis of variance or covariance.

[4]Least square means adjusted for slope.

ever, during the wet and very wet runs the values for runoff and soil loss from the crusted surfaces were generally equal to or less than those of the fallow plots. This indicates that a surface seal formed during the dry run on the fallow plots similar in nature to that occurring from natural events on the crusted plots.

Beulah Plots

In direct contrast to the Center plots, no statistically significant differences due to slope effects (except for the crusted surfaces' dry-run soil losses) were found for the Beulah plots (table 3). Runoff amounts generally increased on both the fallow and crusted surfaces as the slope increased from 1.1 to 3.6% but then generally decreased from 3.6 to 7.0% except for the dry-run crusted surfaces. As the slope increased so did soil loss except within the dry run for fallow surface conditions.

Runoff and soil loss values decreased slightly from the wet to very wet run for both surface conditions. Again, though, the CV values were large reflecting differences between the replicated plots over the slope ranges tested.

Runoff from the crusted plots during the dry run was significantly greater than from the fallow plots using the slope-adjusted values. No other significant differences between the surface conditions existed. The CV values indicated the large amount of variation present in the soil loss data. While runoff was greater from the crusted surfaces in both the wet and very wet runs, the resultant soil loss values were not. This may have been due partially to surface scouring differences between the two surface conditions.

Table 3. Runoff and soil loss from the Beulah spoil sites as affected by slope and surface conditions.[1]

		Application Run					
		Dry		Wet		Very Wet	
Surface Condition	Slope %	Runoff (mm)	Soil Loss (t/ha)	Runoff (mm)	Soil Loss (t/ha)	Runoff (mm)	Soil Loss (t/ha)
		Slope Effects[2]					
Fallow	7.0	20.0	8.3	19.0	6.1	18.8	6.0
	3.6	26.6	8.6	19.9	4.6	19.4	4.0
	1.1	26.5	9.1	18.2	4.1	17.7	3.6
	LSD(.10)[3]	NS	NS	NS	NS	NS	NS
	CV[3]	10.7	14.1	10.0	46.3	5.3	41.2
Crusted	7.0	40.5	20.5	20.1	6.0	20.0	5.2
	3.6	36.6	10.9	20.7	4.1	20.4	3.2
	1.1	32.1	6.9	19.8	3.2	19.2	3.0
	LSD(.10)	NS	6.0	NS	NS	NS	NS
	CV	5.9	16.2	6.4	33.0	10.8	30.4
		Surface Effects[4]					
Fallow	---	24.4	8.7	19.0	4.9	18.8	4.5
Crusted	---	36.3	12.8	20.3	4.4	19.8	3.8
	LSD(.10)	3.3	NS	NS	NS	NS	NS
	CV	14.3	36.1	7.2	26.2	8.1	25.3

[1]Average of two replications.

[2]Least significant difference at the 0.10 probability level. NS = nonsignificant.

[3]Coefficient of variation from analysis of variance or covariance.

[4]Least square means adjusted for slope.

Location Comparisons

The soil loss values at Center were significantly greater in all three runs than the values at Beulah (table 4) even though no significantly different, or a significantly smaller amount of runoff occurred at Center. Visual observations of all the plots noted that the Center plots did have a higher tendency to rill than at Beulah, in general.

Runoff was significantly greater from the crusted surfaces for the dry run due to greater amounts of infiltration on the fallow surfaces as suggested by the depth of water penetration (previously discussed). However, no differences existed in the wet and very wet runs and, in fact, runoff was greater for the fallow surfaces in the very wet run. This was due, in part, to the application methodology differences as discussed earlier.

Soil loss was significantly greater during the dry run from the crusted versus the fallow surfaces (13.6 versus 10.9 t/ha, respectively) but was nonsignificantly less during the wet and very wet runs. This was due, in part, to the greater amount of runoff during the dry run from the crusted surfaces and to less scouring in the other runs.

The individual surface conditions by location slope-adjusted mean values are also shown in table 4. An initially significant effect for runoff due to the crusted surfaces in the dry run is very evident while the differences become smaller towards the very wet run (differences in this run again attributed to application methodology).

Soil loss values were very variable in all three runs resulting in significant differences. In both the wet and very wet runs the fallow surface soil loss for each location was greater than its crusted counterpart.

Table 4. Comparisons of runoff and soil loss between the locations (using least square mean values from analysis of covariance).

		Application Run					
		Dry		Wet		Very Wet	
Location[1]		Runoff (mm)	Soil Loss (t/ha)	Runoff (mm)	Soil Loss (t/ha)	Runoff (mm)	Soil Loss (t/ha)
				Location Effects[2]			
Center		30.5	13.8	18.0	6.3	19.6	8.3
Beulah		30.5	10.8	19.8	4.7	19.3	4.2
	LSD(.10)[3]	NS	2.5	1.5	1.1	NS	2.2
	CV[4]	13.8	28.7	11.1	29.1	14.0	49.5
				Surface Condition Effects[5]			
Fallow		26.4	10.9	18.8	5.6	19.8	7.0
Crusted		34.0	13.6	19.3	5.4	18.8	5.5
	LSD(.10)	3.0	2.5	NS	NS	NS	NS
				Location by Surface Effects			
FC		28.7	13.1	18.3	6.4	21.1	9.5
CC		32.0	14.5	18.0	6.3	18.0	7.0
FB		24.4	8.8	19.0	5.0	18.8	4.6
CB		36.3	12.8	20.3	4.5	19.8	3.9
	LSD(.10)	3.3	NS	NS	NS	2.8	NS

[1] FC = fallow, Center; CC = crusted, Center; FB = fallow, Beulah; and CB = crusted, Beulah.

[2] Averaged over surface conditions.

[3] Least significant difference at the 0.10 probability level. NS = nonsignificant.

[4] Coefficient of variation from analysis of covariance. Same for all effects.

[5] Averaged over locations.

CONCLUSIONS

Runoff and soil loss were measured by employing rainfall simulation techniques on both fallow (disturbed by hand) and crusted surfaces on regraded spoils that were fairly similar in characteristics. Results from the study included the following observations:

1. Runoff and soil loss under dry conditions was higher on crusted versus fallow surfaces but not always under wet conditions,

2. Degree of slope affected one location more than the other,

3. Spoil material at Center was more erodible than at Beulah based on adjusted soils losses, and

4. The surface seal formed under the simulated rainfall in the dry run resulted in similar runoff and soil loss data under wet conditions for both locations.

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