RUNOFF FROM RECLAIMED GRASSLANDS
COMPARED TO UNDISTURBED GRASSLANDS[1]

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Abstract--Artificial rainfall techniques were employed to study the effects of age after reclamation and antecedent moisture on runoff from reclaimed versus undisturbed grasslands. Runoff amounts and Soil Conservation Service curve numbers for the reclaimed grasslands generally were not significantly greater than their undisturbed grassland counterparts for initially dry surface conditions. However, both parameters were generally significantly larger for the reclaimed grasslands for both wet and very wet surface conditions. Reduced total porosity and, possibly, hydraulic conductivities for the replaced topsoil materials on the reclaimed grasslands as compared to the undisturbed grasslands were the main causative effects for these differences.

INTRODUCTION

One criteria for the successful reclamation of stripmined lands is stability against erosion by water runoff. Establishment of a dense vegetative cover provides protection from soil dispersion by raindrop impact and subsequent soil loss in runoff water. Vegetative cover also decreases the potential for surface seal formation by raindrop impact on the surface thereby maintaining higher infiltration rates. This protective function of cover has been well documented in empirical formulas such as the Universal Soil Loss Equation (Wischmeier and Smith 1978).

Reduction in runoff amounts also decreases soil losses by reducing the transport of soil aggregates which are removed by saltation along the bottom of flow channels (Moldenhauer and Koswara 1968). This loss mechanism has been shown to be related to overland flow velocity (Foster and Meyer 1972). Decreasing flow velocities results in the deposition of the larger sediment particles and thus reduces total soil loss. Reducing flow velocities also increases infiltration amounts by increasing the time the water on the surface has to enter the soil profile before being lost as runoff.

This potential plant-available soil water gained through reduction of runoff amounts may be critical in the determination of "equal to or better than" productivity on the reclaimed minelands versus undisturbed areas, another criteria for successful reclamation. Water stress conditions during the growing season due to low precipitation amounts (such as in a semi-arid climate like North Dakota) are not unusual. The additional stored soil water would help maintain vegetative growth during these stressful periods.

One method commonly employed to estimate potential runoff amounts from total-event rainfall amounts is the Soil Conservation Service curve number method (U. S. Department of Agriculture 1972). Incorporated into the method are factors that account for the hydrologic properties of the soil materials, cover, and antecedent moisture conditions. This procedure may allow a "first estimation" of total soil water available for vegetative production during a growing season if components such as plant-available soil water at initiation of plant growth in the spring and growing-season rainfall patterns (distribution and rates) are known or can be estimated.

Reclamation techniques used on stripmined lands have previously been shown to have affected pore sizes and distribution (Gilley 1980) and bulk density (Bauer et al. 1978). The objectives of this research were to compare reclaimed versus undisturbed grasslands (soil series prior to mining of the reclaimed sites) to a) quantify the changes on runoff amounts as affected by slope gradient from known rainfall rates and antecedent

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moisture conditions and b) use these amounts to estimate future runoff amount potential through the development of runoff curve numbers.

METHODS AND MATERIALS

Site Descriptions

Reclaimed stripmined grassland sites were chosen based upon uniformity of cover (first estimation was visual), range of slope gradients, age after reclamation (first year of revegetation was denoted as year one), and availability of native grasslands of similar soil series that were present prior to mining at the reclaimed sites. Age differences between the reclaimed grassland sites resulted in different depths of replaced soil materials (table 1) due to the regulations in effect when permitted. No attempt at estimating replaced depth effects on runoff amounts or calculated curve numbers was attempted in this study.

A brief description of each reclaimed mineland grassland site by age is as follows:

1. 2 yr old (2Y): Soil materials were spread in 1982 to 1983 with the site seeded in 1983. Major species included western wheatgrass (Agropyron smithii Rydb.), Kentucky bluegrass (Poa pratensis L.), smooth bromegrass (Bromus inermis Layss.), intermediate wheatgrass (Agropyron intermedium Beauv.), and numerous forbs. This site was located on the Baukol-Noonan, Inc. mine near Center, ND. The data were collected in 1984.

2. 4 yr old (4Y): Soil materials were spread and the site seeded in 1982. Major species included crested wheatgrass (Agropyron desertorum Schult.), slender wheatgrass (Agropyron trachycaulum L.), and alfalfa (Medicago sativa L.). This site was located on the Basin Electric Cooperative Glenharold mine near Stanton, ND. The data were collected in 1985. This site had been harvested for haylage one time each year in 1984 and 1985 (approximately 30 days before this study).

3. 7 yr old (7Y): Soil materials were spread and the site initially seeded in 1975. Improper seeding resulted in no establishment and it was reseeded in 1979 (year one for this experiment). Major species included western wheatgrass, sideoats grama [Bouteloua ucurtipendula (Michx.) Torr], little bluestem (Schizachyrium scoparius Michx.), and yellow sweet clover [Melilotus officinalis (L.) Lam.]. This site was also located on the Glenharold mine near Stanton, ND. The data were collected in 1985.

The unmined grassland sites consisted of the following soils series:

1. Williams (WL): This soil (fine-loamy, mixed, Typic Argiborolls) site was near Center, ND. The data collected in 1984. Major species

Table 1. Measured characteristics of the reclaimed and undisturbed grassland sites.[1]

	Reclaimed Grassland Sites						Native Grasslands			
	2Y		4Y		7Y		WL[2]		TZ	
Variable[3]	Mean	CV[4]	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Clay (%)	20.2	12.8	21.3	3.6	19.3	3.3	12.9	13.5	6.3	10.9
Silt (%)	33.3	10.0	51.2	3.2	50.3	10.8	44.8	4.9	65.2	3.4
Sand (%)	46.5	9.5	27.5	3.6	30.4	19.8	42.3	1.8	28.5	8.3
Bulk ($Mg\ m^{-3}$) Density	1.3	12.4	1.2	9.9	1.2	9.7	0.8	19.9	0.8	16.4
Vegetative Cover (%)	85.7	21.0	77.3	5.1	99.2	0.8	95.8	0.5	99.8	0.4
Replacement Depths:										
Topsoil (mm)	311.2	27.8	401.3	17.0	190.5	20.2	---	---	---	---
Subsoil (mm)	615.0	18.6	330.2	40.7	220.1	9.4	---	---	---	---
Antecedent moisture[5]:										
Dry (%)	6.6	38.3	11.4	47.0	9.4	47.8	7.8	16.7	19.0	25.1
Wet (%)	25.4	13.4	28.5	7.2	27.1	7.4	41.2	15.8	46.1	11.2

[1] Six replications except where otherwise noted.
[2] Four replications.
[3] 0 to 50 mm depth where applicable. Vegetative cover is live plus litter using a point frame (first-hit technique).
[4] Coefficient of variation (%).
[5] Gravimetric prior to application run for the 0 to 50 mm depth.

included blue grama [(Bouteloua gracilis (H.B.K.)], upland sedges (Carex spp.), green needlegrass (Stipa viridula Trin), western wheatgrass, and numerous other grass and forb species.

2. Temvik-Zahl association (TZ): This soil association (fine-silty, mixed, Typic Haploborolls; and fine-loamy, mixed, Entic Haploborolls; respectively) site was located near Stanton, ND. The data were collected in 1985. Major species consisted of Kentucky bluegrass, upland sedges, blue grama and numerous other species.

Simulator Plots and Measurements

Two replicated plots, 1.8 by 4.9 m were installed at each of three slope gradients of approximately 3, 6, and 9% at each of the grassland sites (no 6% at the WL site). Plots were enclosed with steel borders installed to a depth of 50 mm.

An overhead-rail rainfall simulator (Dunne et al. 1980) was modified and used to apply simulated rainfall at an intensity of 56 mm h^{-1}. A tarp enclosed three sides of the simulator to reduce wind effects. The sequence of simulated rainfall application was an initial (dry) run of 60 min at antecedent soil moisture conditions followed by two 30-min runs (wet and very wet); all runs were separated by 30 min.

Runoff from the simulated rainfall applications was measured using a precalibrated 0.18 m HS flume with an attached stage recorder. Runoff amounts were adjusted to 56 or 28 mm to account for differences in application amounts between plots (Meyer et al. 1970).

Runoff curve numbers (CN) were calculated using the actual field measured values for application and runoff by solving the following equation for S (U. S. Department of Agriculture 1972):

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

where Q is the direct runoff (mm), P is the rainfall amount (mm), and S is the maximum potential difference between P and Q (mm). Once solved for S, the CN values were estimated by solving the following equation:

$$CN = \frac{25400}{254 + S}$$

No adjustments were made to the CN values due to differences in application amounts since this is accounted for in the above equations by the factor P.

Reported CN values are usually standardized to Antecedent Moisture Condition (AMC) II (average case for annual floods). However, since naturally-occurring precipitation in the previous five days was less than 36 mm when the data were collected at the various sites, all dry runs would conform to an AMC I condition (soils are dry but not to the wilting point). All wet and very wet runs would likewise conform to AMC III (greater than 53 mm received during the previous five days with the soils nearly saturated). The values were not adjusted to relate AMC II conditions in this paper.

Particle-size analyses and bulk density for each plot by depth were determined from soil cores removed prior to the dry run. Antecedent soil moisture was also determined prior to the dry and wet runs (table 1). Total porosities of each site were estimated using the measured bulk densities and assuming a specific gravity of 2.65 Mg m^{-3}. Percent cover within the plots was determined with a vertical point frame using a first-hit technique (Hofmann et al. 1983).

Data Analyses

Analysis of variance using a modified randomized block design was used to test slope gradient effects on runoff amounts and CN values within each grassland site. Analysis of covariance using a modified randomized block design with either slope gradient or slope gradient and percent cover as covariant(s) was used to test differences between the reclaimed and their respective undisturbed grassland counterparts. Similarly, analysis of covariance was used to test differences due to age-of-reclamation effect among the reclaimed sites.

RESULTS AND DISCUSSION

Slope gradient had no significant effect on either adjusted runoff amounts or CN values for the two undisturbed grasslands (table 2). However, runoff amounts measured from the WL undisturbed grassland were much more variable than that from the TZ undisturbed grassland as shown by the coefficient of variation (CV) values. Differences within the Stanton location resulting from a soil association rather than a single soil series being used was considered relatively minor when these data were used later for comparisons with the reclaimed grasslands.

Reduced vegetative cover resulting in greater surface sealing was the most probable cause of the significantly greater amount of runoff from the 0.8% slope gradient on the 2Y site as compared to the 4.7% and 6.8% slope gradients for initially dry surfaces. The calculated CN value for the 0.8% plots was also greater than those calculated for the other two slope gradients. While no significant difference for initially dry surfaces was found for runoff amount between the 4.7 and 6.8% slope gradients, their respective CN values (65.5 and 56.5) were significantly different. This may indicate that the Meyer et al (1970) proportionality effect caused by differing

Table 2. Adjusted mean runoff amounts and curve numbers for the reclaimed and undisturbed grassland sites as affected by slope gradient.[1]

Site	Slope	Cover	Dry Runoff	Dry CN	Wet Runoff	Wet CN	Very Wet Runoff	Very Wet CN
	(%)		(mm)		(mm)		(mm)	
					Center Location			
	0.8	63	18.0	81.0	10.0	90.5	11.0	91.5
2Y	4.7	99	4.2	65.5	8.8	90.0	11.4	92.0
	6.8	95	2.1	56.5	4.7	84.0	8.8	88.5
		LSD(.10)[2]	10.4	6.6	1.8	4.3	NS	NS
		CV(%)[3]	44.1	3.4	8.1	1.7	26.8	3.4
WL	3.4	96	2.4	59.5	1.7	74.5	2.6	81.0
	8.0	96	1.7	50.5	2.0	78.5	2.2	79.0
		LSD(.10)	NS	NS	NS	NS	NS	NS
		CV(%)	200.0	40.0	126.0	13.1	41.0	5.0
					Stanton Location			
	3.2	76	6.1	66.5	7.6	87.5	9.3	90.0
4Y	6.1	80	12.0	76.0	8.2	89.0	8.4	90.0
	9.2	76	13.6	75.5	9.2	89.5	10.0	90.5
		LSD(.10)	4.7	NS	NS	NS	0.8	NS
		CV(%)	15.2	4.8	8.6	0.8	3.0	0.4
	3.3	98	<0.1	48.0	4.7	82.0	7.7	87.5
7Y	5.7	100	2.1	55.5	4.5	82.5	12.3	92.0
	9.5	99	<0.1	48.0	4.6	83.5	12.5	92.5
		LSD(.10)	NS	NS	NS	NS	NS	NS
		CV(%)	244.9	14.0	69.1	6.6	27.4	2.3
	3.2	100	<0.1	47.5	<0.1	63.5	<0.1	71.0
TZ	5.8	100	<0.1	47.0	<0.1	64.5	<0.1	65.0
	8.7	100	<0.1	46.5	<0.1	65.5	<0.1	69.0
		LSD(.10)	NS	NS	NS	NS	NS	NS
		CV(%)	0.0	0.9	0.0	0.0	0.0	13.5

[1] Average from two replications.

[2] Least significant difference at the p=0.10 level. NS signifies nonsignificant differences.

[3] Coefficient of variation.

application amounts and averaging over two replications may have affected the data.

For wet soil surface conditions on the 2Y site, the steepest slope gradient (6.8%) consistently (significant only for the wet run data) had less runoff and lower CN values than either the 0.8 or 4.7% slope gradients. The cause of this result could not be adequately determined. However, since under saturated conditions (very wet run data) no significant difference for either parameter existed, it was concluded that the hydrologic properties of the site for the various slope gradients were fairly uniform.

While slope gradient did not significantly affect runoff amounts or CN values for the 7Y reclaimed grassland, slope gradient significantly affected runoff amounts for the dry and very wet runs on the 4Y reclaimed grassland. Since the percent cover values were fairly uniform between plots on this site, the effect of differences due to cover should have been minimal. The calculated CN values using the actual application and runoff amounts were not significant. The significant differences for runoff amounts may have resulted from the adjustments made to the actual runoff amounts due to differences in application amounts, suggesting that the proportionality assumption of Meyer et al (1970) was violated.

Comparisons between the 2Y reclaimed and WL undisturbed grassland sites at Center showed no significant site differences for runoff amounts or CN values for initially dry surface conditions for either analysis of covariant model (table 3). However, once wetted, the reclaimed grassland had significantly greater runoff amounts and CN values than its counterpart undisturbed grassland. These results indicated that the hydrologic properties of the reclaimed grassland profile are dissimilar to those of the undisturbed grassland. The high variability of the dry run data may have "hidden" any significant differences since the reclaimed grassland had runoff amounts 40 to 80% greater than the undisturbed grassland depending upon the analysis of covariant model used.

Age after reclamation also had a significant effect on the Stanton sites. The 4Y reclaimed grassland had consistently greater runoff amounts and CN values for both analysis models than the values for the TZ undisturbed grassland for all three runs and for the dry and wet runs when compared to the 7Y reclaimed site. Under initially dry surface conditions, the 7Y reclaimed grassland had values for runoff amounts and CN values for both models that were not significantly different (although greater than) the TZ undisturbed grassland. Percent cover as a covariant did not result in any changes in significant differences between the two analysis models suggesting that percent cover difference effects among the sites was minimal and that the data was reflecting hydrological property differences among the sites.

Differences in percent cover among the three reclaimed grassland sites did, however, result in significant differences for runoff amounts in the dry and wet runs which were not found when percent cover differences were accounted for in the second analysis model. Likewise, the CN values for the wet run also became nonsignificantly different when percent cover was used as a covariant. The changes reflected in runoff amounts in the dry run in the second analysis model may also reflect the mathematical adjustments made initially to the data (as mentioned previously) since the CN relationships for both analysis models remained significant. No significant differences for either parameter was found for the very wet run data among the reclaimed grassland sites for either analysis model. This indicated that the hydrologic components within the profiles of the three

Table 3. Analysis of covariance results comparing the reclaimed and undisturbed grasslands by location and comparing the reclaimed grasslands among themselves.[1]

Site	Application Run											
	Dry		Wet		Very Wet		Dry		Wet		Very Wet	
	Runoff (mm)	CN	Runoff (mm)	CN	Runoff (mm)	CN	Runoff (mm)	CN	Runoff (mm)	CN	Runoff (mm)	CN
	Covariant: Slope Gradient						Covariants: Slope Gradient and Percent Cover					
						Center Location						
2Y	6.9	65.4	7.5	87.8	10.2	90.3	6.4	65.1	7.5	87.8	10.4	90.5
WL	3.8	58.4	2.4	77.1	2.7	80.6	4.6	58.9	2.4	77.0	2.5	80.2
LSD(.10)[2]	NS	NS	2.6	7.6	2.8	4.3	NS	NS	2.9	7.7	2.9	3.8
CV(%)[3]	91.0	15.2	37.5	7.3	31.3	4.0	69.0	16.1	41.1	8.0	30.8	3.7
						Stanton Location						
4Y	10.5	72.6	8.3	88.6	9.2	90.2	15.9	81.8	7.0	86.8	9.1	90.4
7Y	0.7	50.5	4.6	82.6	10.8	90.6	1.8	46.2	5.2	83.5	10.9	90.5
TZ	0.1	47.1	<0.1	64.6	0.1	68.4	0.8	42.2	0.7	65.5	0.1	68.2
LSD(.10)	2.4	5.2	1.4	2.5	1.8	4.4	2.3	5.2	1.5	2.6	1.9	4.6
CV(%)	61.7	8.9	32.2	3.1	26.5	5.2	59.9	8.9	33.1	3.2	27.5	5.4
						Among Reclaimed						
2Y	7.4	66.4	7.6	88.0	10.6	90.8	7.8	66.9	7.6	88.0	10.6	90.8
4Y	10.9	73.3	8.5	88.8	9.1	90.1	6.4	67.4	7.8	88.1	9.0	90.0
7Y	1.1	51.1	4.7	86.8	10.8	90.6	5.3	56.5	5.3	83.4	10.9	90.7
LSD(.10)	5.5	8.3	2.2	3.6	NS	NS	NS	6.7	NS	NS	NS	NS
CV(%)	83.8	12.7	31.3	4.0	24.7	2.8	59.0	10.3	31.4	4.1	25.8	3.0

[1]Least square mean values. Runoff values adjusted for application amount prior to analysis.

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

[3]Coefficient of variation.

reclaimed grassland sites are similar, especially under wet conditions, and have become dominant.

An indication of the magnitude of the properties that reflect the hydrologic parameters for the reclaimed and undisturbed grassland sites are listed in table 4. Note that the reclaimed grasslands at both locations have significantly smaller total porosities than their counterpart undisturbed grasslands. However, no difference in total porosity was found in the upper 100 mm among the reclaimed sites although differences did exist at deeper depths. These later differences may reflect reclamation technique differences since there seems to be no relationship with age after reclamation. Presumably differences in pore size distribution also existed but they were not measured.

SUMMARY

Artificial rainfall simulation techniques were employed to study slope gradient effects on reclaimed grassland of various ages after reclamation (revegetation), to show differences among the reclaimed grasslands due to age after reclamation, and to show reclamation effect as compared to undisturbed grasslands of soil series present prior to mining on runoff amounts and curve number calculations. Steeper slope gradients generally did not result in significantly higher runoff amounts or curve numbers except where confounded by percent cover differences. Significant differences for runoff within the 4Y reclaimed grassland site were presumably caused by adjusting runoff amounts due to application amount differences since the calculated curve numbers were not significantly affected by slope gradient.

Differences among the reclaimed grassland sites were generally nonsignificant for both runoff amounts and curve numbers. Those differences found were usually not present when percent cover differences among the sites was accounted for through use of analysis of covariance. Differences among the reclaimed sites for total porosity and hydraulic conductivity (assumed for the three sites) showed no significant effect due to age. However, since the oldest site was but seven years old, these nonsignificant differences may change with additional years of vegetative growth.

Significantly lower total porosities and hydraulic conductivities of the reclaimed grasslands resulted in significantly larger runoff amounts and curve numbers for wet surface conditions than for the undisturbed grasslands. For initially dry surface conditions the differences varied between the two locations.

Until such time that the total porosities (in addition to the pore size distributions) and hydraulic conductivities of the reclaimed grasslands approach the values measured for the undisturbed grasslands, reclamation plans must include procedures for managing higher runoff from reclaimed grasslands. This would mean quick establishment of vegetative cover to minimize erosion and, possibly, inclusion of sediment ponds to contain runoff from the reclaimed areas.

Table 4. Total porosity measurements at the reclaimed and undisturbed grassland sites.[1]

Site	Estimated Total Porosity (%) Profile Depth (mm) 0-50	50-100	100-150	150-300
	Center Location			
2Y	50.9	48.1	46.1	42.8
WL	68.4	60.0	56.3	56.6
LSD(.10)[2]	6.4	5.6	3.8	6.1
CV(%)[3]	9.0	8.7	6.1	10.3
	Stanton Location			
4Y	54.6	49.7	52.2	50.8
7Y	54.0	47.0	42.2	41.0
TZ	71.6	60.6	59.6	58.4
LSD(.10)	4.5	4.1	3.3	1.9
CV(%)	7.4	7.6	6.3	3.8
	Among Reclaimed Sites			
2Y	50.9	48.1	46.1	42.8
4Y	54.6	49.7	52.2	50.8
7Y	54.0	47.0	42.2	41.0
LSD(.10)	NS	NS	3.6	3.9
CV(%)	8.3	10.0	7.5	8.5

[1]Average from six replications. Total porosity estimated from bulk density data.
[2]Least significant difference at the p = 0.10 level. NS signifies nonsignificant differences.
[3]Coefficient of variation.

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