Influences of land disturbance and management regime on infiltration and runoff

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Burk, A.R., Chanasyk, D.S. and Mapfumo, E. 1999. **Influences of land disturbance and management regime on infiltration and runoff.** Can. Agric. Eng. **41**:127-134. Infiltration and runoff were measured using a rainfall simulator and runoff frames at five sites. Three sites were located in hayfields and two were in pastures. One of the hayfield sites consisted of reclaimed mineland. Three management treatments (hayed, mowed, and fallow) were applied to the hayfield plots and two treatments (grazed and fallow) were applied to the pasture plots. Runoff volume was measured at 5-min intervals to an elapsed time of 30 min and then infiltration rates and accumulated infiltration were determined. Runoff volumes were low from all treatments (runoff coefficients < 0.50), even under the high intensity used and high antecedent soil moisture conditions. Grazing did not affect infiltration in comparison to fallow. Initially, abstractive losses other than infiltration were also low (< 9 mm). In general, hayed and mowed treatments had higher infiltration rates and accumulated infiltration than the fallow treatment. The reclaimed and unmined soils had similar infiltration variables. Linear relationships between initial abstraction and 5-min infiltration rate with degree of saturation were not significant at 5% significance level.

L'infiltration et le ruissellement ont été mesurés sur 5 sites en utilisant un simulateur de précipitations et des cadres pour la mesure du ruissellement. Trois des sites étaient en foin et deux étaient des pâturages. Un des champs de foin était établi sur un ancien site minier qui avait été réhabilité. Trois traitements furent appliqués aux parcelles en foin (en foin, fauchée et en jachère) et deux traitements furent appliqués aux pâturages (pâturage et jachère). Les volumes de ruissellement étaient mesurés à un intervalle de 5 minutes pendant une période totale de 30 minutes. Ensuite, on déterminait les taux d'infiltration et l'infiltration cumulée. Les taux de ruissellement mesurés sur toutes les parcelles ont été faibles (coefficients de ruissellement < 0.50), même lorsque l'intensité de la précipitation et les conditions d'humidité antécédente étaient élevées. Si on compare avec les parcelles en jachère, le pâturage n'a pas eu d'effet sur l'infiltration. Les pertes attribuables à la rétention initiale, autres que l'infiltration, étaient également faibles (< 9mm). En général, les taux d'infiltration et l'infiltration cumulée mesurés sur les parcelles en foin et fauchées étaient plus élevés que ceux des parcelles en jachère. Le site minier avait des taux d'infiltration et une infiltration cumulée semblables aux autres sites. Les relations linéaires entre la rétention initiale et le taux d'infiltration mesuré aux 5 minutes avec le degré de saturation n'étaient pas significatives au seuil de 5%.

INTRODUCTION

Runoff has often been simply expressed as rainfall minus abstractive losses or abstractions. These abstractions include interception storage, surface storage, infiltration, evaporation, and evapotranspiration (Ponce and Hawkins 1996). For short periods of time, such as those used in rainfall simulation (i.e. up to 30 minutes), the last two factors can be ignored. For large areas, surface storage occurs in ponds, puddles, and other small temporary storage locations (Ponce and Hawkins 1996), while for small areas it is usually a result of surface features.

Soil surface characteristics of importance to infiltration and runoff include vegetation, microtopography or roughness, crust, and stone cover (Morin and Kosovsky 1995). Vegetation affects infiltration and runoff in several ways: the surface cover intercepts rainfall reducing raindrop impacts, which in turn reduces soil crust formation; roots generate macropores and stabilize soil aggregates enhancing infiltration (Morin and Kosovsky 1995). These researchers found that a bare plot generated 25% runoff but a vegetated plot only 9%. Thus, land management practices that control vegetative cover and manipulate the soil surface play a key role in infiltration and runoff.

The term 'initial abstraction' is used to represent the amount of water 'stored' after rainfall begins but before runoff starts and is an integral part of the United States Soil Conservation Service (SCS) Curve Number technique for determining storm runoff (Ponce and Hawkins 1996). Initial abstraction represents interception, surface storage, and infiltration that occur before runoff begins (Rallison 1980). Soils with high initial infiltration rates would have high initial abstraction. Antecedent soil water affects initial abstraction through its effect on infiltration, although its relationship with initial abstraction has not been quantified in the literature. This effect is recognized in the SCS method through variation of the antecedent moisture index (Ponce 1989). The importance of land management in affecting runoff is recognized in the SCS curve number technique by altering curve number based on cover type and hydrologic condition, in conjunction with a hydrologic soil group (Ponce 1989).

Tillage affects soil erosion in that less runoff occurs from rough surfaces than from smooth bare surfaces. The retention of water between clods on rough surfaces contributes to the high depth of water ponding in depressions which produce longer detention times and greater hydraulic gradients (Onstad 1984; Freebairn et al. 1989; Razavian 1990). Under these conditions, infiltration is favored, resulting in the recharge of soil water. However, tillage also creates surface conditions conducive to runoff. Freebairn et al. (1989) concluded that cultivation of a silt loam soil increased runoff generation due to surface sealing and a lack of crop and residue cover. Van Vliet and Hall (1991) reported that annual crop rotations, including fallow periods, had higher overall runoff volume, runoff proportion, and soil loss than rotations which incorporated a perennial grass cover of fescue.

Table I. General site characteristics.

	Site 1	Site 2	Site 3	Site 4	Site 5
Management	alfalfa/grass reclaimed	alfalfa/grass unmined	alfalfa/grass unmined	pasture unmined	pasture unmined
Topsoil depth (mm)	270	180	120	40	90
Slope (%)	16	22	18	18	19
Depth interval (mm)			Soil classification		
0 - 150	loam	silty clay loam	silty clay loam	silt loam	silt loam
150 - 300	clay loam	silty clay	clay	silty clay loam	clay
300 - 450	sandy loam	silty clay	clay	clay	clay

Grazing can reduce vegetative cover, increase bulk density, and increase runoff volume (Naeth et al. 1991). Thurow et al. (1988) found that heavy continuous and high intensity, short duration grazing decreased the infiltration capacity of silty clay soils. Examining three rangeland-soil-vegetation complexes in the Walnut Gulch Experimental Watershed in southeastern Arizona, Tromble et al. (1974) found that vegetation and soil surface condition were key factors in determining infiltration. In plots that were devoid of vegetation or in expanses of bare soil between individual plants, infiltration rates were significantly lower than in vegetated areas. Greater litter accumulation resulted in a higher cumulative infiltration, while pre-wetting of the surface soil lowered infiltration. Increases in bulk density by compaction reduced both accumulated soil water (ASW) and infiltration (Tromble et al. 1974).

Infiltration, runoff and soil water content are affected by soil disturbances such as surface coal mining and subsequent reclamation. Disruption of in situ soil properties is an important consequence of mining and reclamation (Potter et al. 1988). Operations performed in replacing subsoil and topsoil in reclaimed lands generally cause soil compaction which could reduce infiltration, increase runoff, and restrict rooting depth which, in turn, would decrease soil water contents. Silburn and Crow (1984) concluded that runoff from reclaimed profiles would be greater than that from natural soils due to a reduction in depth to the least permeable layer in the profile (reduced by about 50% after mining), a reduction in hydraulic conductivity throughout the profile due to the decreased percentage of large pores and the lower saturated hydraulic conductivity of the spoils compared with the natural subsoils. Jorgensen and Gardner (1987) found that infiltration rates on newly reclaimed mine soils were an order of magnitude lower than those of adjacent, undisturbed soils and that there was a strong temporal variation in these rates. The authors found that in contrast with newly reclaimed soils, most old ($\geq$ 4 y) mine soils exhibited greater vegetation growth and had higher infiltration rates.

The objectives of the study reported herein were: 1) to determine the infiltration rate and accumulated infiltration, resulting from hayed, mowed, and fallowed land treatments in the production of forage hay and providing pasture for cattle; 2) to examine the relationship between initial abstraction and antecedent soil water; and 3) to compare the hydrologic response of reclaimed and unmined lands.

MATERIALS and METHODS

Study area

This study was conducted at five field sites situated near Keephills, Alberta (53° 30' N; 114° 27' W), approximately 90 km west of Edmonton. This region is dominated by rolling topography having slopes of 5-25%. Land use is predominantly cattle grazing and alfalfa hay production with less than half of total agricultural land area being used to produce annual cereal or forage crops.

The climate of this region is characterized by 432-508 mm of precipitation annually, 60% of which falls in the growing season from May-August (Lindsay et al. 1968). The mean annual temperature for the area is 3°C. January is the coldest month with an average temperature of -13.8°C and July is the warmest month with an average temperature of 15.6°C (Lindsay et al. 1968). This area has at least 90 days per year on which the temperature remains above 5.6°C. Soils within the pre-mine study area are dominated by those of the Luvisolic and Solonetzic soil orders (Lindsay et al. 1968), while the reclaimed mine soil is unclassified.

Site selection and plot layout

This study was conducted during 1995 and 1996, beginning during the spring of 1995 when the field sites were selected. Five field sites were selected based on slope position, gradient, and aspect. Slope gradients ranged from 16-22% and aspects were south or southwest for all sites. Three sites (1, 2, and 3) were alfalfa/grass hay fields while two (4 and 5) were grazed pastures. Site 1 was located on reclaimed mine land within Pit 03 at the Highvale Mine. Site 2 and Site 3 were unmined alfalfa/grass hay fields established on privately owned land. Two grazed pasture sites, Site 4 and Site 5, were located on unmined lands in the same area. The greatest distance between any two sites was approximately 12 km, being the distance from the reclaimed site to the nearest off-mine site. General site characteristics are given in Table I. Topsoil depth differed markedly among sites, being deepest at Site 1 and shallowest at Site 4. Soil in the uppermost 150 mm was medium textured (loam, silty clay loam, or silt loam) at all sites.

Management treatments were established in June 1995 and included hayed, mowed, and fallow as forage regimes at Sites 1, 2, and 3. Pasture regimes at Sites 4 and 5 included grazing (moderately heavy) and fallow. Research plots, measuring 3 m by 3 m, were constructed at each site in a randomized complete block design using three treatments (hayed, mowed, and fallow) in triplicate at forage sites and two treatments (fallow and grazed) in triplicate at pasture sites. Each plot was separated from the next by a 1.5-m wide buffer. A series of three randomized plots constituted a block and the three blocks were placed adjacent to each other across the width of the slope to minimize interflow contribution into downslope areas, to maintain constant slope gradient, and to maintain relatively uniform soil conditions hydrologically and physicochemically across the blocks.

Hayed plots were maintained using a Jeri® mower. Standing forage was cut to 40-mm heights and the hay removed from the plot area using hand rakes to prevent mulch formation or the accumulation of organic material on the soil surface. These treatments were conducted at approximately the same time that the farmer-cooperators conducted their haying operations in the fields surrounding the plots.

Mowed regimes were continually maintained to simulate grazing and to increase the amount of bare ground by frequent removal of standing biomass two to three times per week. The impacts of cattle trampling were not realized through this design. Mowing using a 4 kW Ariens® lawnmower was controlled such that foliage was maintained at a height no greater than 20-30 mm above the soil surface, with cut vegetation removed. Thus, no litter was allowed to accumulate on mowed surfaces.

Fallow regimes were established in June 1995 using tractor/rototilling equipment to break the forage cover. Fallow plots were tilled in mid- to late spring and maintained vegetation-free during the growing season using a broad spectrum glyphosate herbicide (Round-up®) at a product rate of 1 L/100 L water, followed by a late fall cultivation at the end of September. These practices were repeated in 1996. Cattle were excluded from the fallow plots.

Pasture plots (both grazed and fallowed) were continuously grazed by cattle already present on the cooperator's land. Grazing intensities were moderately heavy at Site 5 (with about 120 cow/calf pairs per 65 ha) and heavy at Site 4 (with approximately 45 yearling heifers on 8.1 ha.)

Bulk density

Near-surface bulk density (0-75 mm) of all plots was measured using a CPN MC-1 depth moisture/density gauge. It was measured before cultivation, two weeks after cultivation, and then again three months following cultivation in 1996.

Rainfall simulation

A Guelph Rainfall Simulator II (Tossell et al. 1987) and runoff frames were used in this study. Water for simulation was stored in two 250-L fiberglass reservoirs and one 200-L drum. Attached to the water supply was a 1.2 kW electric pump which supplied water to the simulator at a specified rate, determined by a pressure gauge on the simulator. Rainfall intensity was controlled by adjusting pressure output from the pump such that a pressure of 48 kPa was used to provide uniform rainfall at an intensity of 48-55 mm in 30 minutes (greater than a 100-year return period), using a 9.5 mm GG Full-Jet nozzle. Height above the ground surface and runoff frame was kept constant at 2 m for all trials. The effects of wind gusts during simulation trials were eliminated by using a large triangular wind shield and plots were raked a few days prior to simulation to remove surface irregularities.

Runoff volume was measured and recorded every five minutes to an elapsed time of 30 min from a modified 1-m^2 runoff frame having 152-mm deep side walls and a runoff spout. Rubber tubing was attached to the spout, directing runoff downslope and into collection containers. Frames were hammered into the ground to a depth of 25 mm. Infiltration volume was determined by subtracting runoff volume from precipitation volume for a given time interval. Infiltration rates were calculated as infiltration volume divided by the time increment and averaged for a given 5-min interval; e.g. 5-min infiltration rate is the average for the first five minutes of simulation. Initial abstraction (I_a) was recorded as the amount of time elapsed from the start of an infiltration session to the onset of runoff. It was calculated as a depth of water (mm) by multiplying this elapsed time by the simulated rainfall rate.

Simulation runs were conducted twice during 1996 at all five sites, once in late July and then again in late September on an undisturbed portion of the plots. In each of the two sessions, daily simulations were completed for an entire site, ensuring there was no change in site parameters due to overnight rainfall.

Runoff coefficients, expressing the proportion of runoff relative to the amount of incident rainfall, were calculated for all treatments for both simulation sessions. The average value for the two sessions was then compared among sites and treatments.

Near-surface antecedent soil water (0-75 mm) was measured just prior to a simulation run using a Campbell-Pacific Nuclear (CPN) 503 neutron probe and a hydrogenous shield. To express initial water conditions relative to pore space, the antecedent water content was expressed as a degree of saturation using near-surface bulk density.

Statistical analyses of simulation data

The two basic infiltration variables (infiltration rate and accumulated infiltration) were analyzed. Raw data in triplicate from the two sampling periods were grouped into one data file. Statistical analyses were performed on rainfall simulation data obtained from the three forage sites (1, 2, and 3) each comprised of three treatments (hayed, mowed, and fallow) and the two pasture sites (4 and 5) with two treatments (grazed and fallow).

Other variables analyzed included I_a and degree of saturation. Also, linear regression analysis was conducted on I_a and 5-min IR versus degree of saturation. All data were checked for homogeneity of variance using the W-test in SAS (SAS Institute Inc. 1987). The level of significance used for all analyses was $\alpha = 0.05$.

A model was fitted using infiltration rate as the dependent variable. Factors used to separate the IR for each time increment (5, 10,..., 30 min) were treatment, time, and the treatment × time interaction. The statistical analysis for accumulated infiltration by treatment, sites treated individually, was completed using the same model and settings as the GLM procedure used for infiltration rate.

Table II. Infiltration rate (IR) and mean accumulated infiltration (AI) at forage sites.

		Time (min) 5	10	15	20	25	30
				Site 1			
IR (mm/h)	Hayed	95.0 ab	84.3 a	71.6 a	56.2 a	52.7 a	52.7 a
	Mowed	97.8 a	68.1 b	54.1 b	50.6 a	50.5 a	51.9 a
	Fallow	82.9 b	56.0 b	52.2 b	50.3 a	49.4 a	50.2 a
				Site 2			
	Hayed	96.7 a	64.8 a	58.1 a	59.0 a	58.5 a	58.0 a
	Mowed	91.2 a	59.7 a	55.5 a	53.9 a	51.7 a	50.5 a
	Fallow	95.1 a	62.7 a	57.1 a	56.7 a	54.9 a	55.0 a
				Site 3			
	Hayed	100.1 a	99.4 a	90.6 a	80.7 a	74.6 a	71.3 a
	Mowed	97.2 a	89.3 a	79.1 ab	73.7 ab	69.5 ab	67.6 a
	Fallow	90.8 a	68.8 b	58.1 b	52.2 b	48.6 b	49.7 a
				Site 1			
AI (mm)	Hayed	7.9 ab	14.9 a	20.9 a	25.6 a	30.0 a	34.4 a
	Mowed	8.1 a	13.8 a	18.3 ab	22.5 ab	26.7 ab	31.0 a
	Fallow	6.9 b	11.6 b	15.9 b	20.2 b	24.3 b	28.4 a
				Site 2			
	Hayed	8.1 a	13.5 a	18.3 a	23.2 a	28.1 a	32.9 a
	Mowed	7.6 a	12.6 a	17.2 a	21.7 a	26.0 a	30.2 a
	Fallow	7.9 a	13.2 a	17.9 a	22.6 a	27.2 a	31.8 a
				Site 3			
	Hayed	8.4 a	16.7 a	24.2 a	31.0 a	37.2 a	43.1 a
	Mowed	8.1 a	15.6 ab	22.1 ab	28.3 ab	34.1 ab	39.7 ab
	Fallow	7.6 a	13.3 b	18.1 b	22.5 b	26.6 b	30.7 b

* Means within a column for a given infiltration parameter at a given site followed by the same letter are not significantly different ($P \leq 0.05$).
n = 6 per cell

Infiltration rate (IR) for the early time periods (0 - 20 min) was regressed against time (T) on the log-log scale. The general form of the equation fitted:

$$IR = aT^n$$

or

$$\log(IR) = \log a + n \log T$$

Regression analysis using the GLM procedure was conducted on data for each site to determine if the intercepts (log a) and the slopes (n) in the above equation were significantly different among treatments.

RESULTS

Infiltration at forage Sites 1, 2, and 3

Generally, infiltration rates for the hayed, mowed, and fallow treatments decreased with time (Table II). After 30 min, infiltration rates had decreased by 29-47% compared to the initial 5-min IR on all treatments. There were very few significant differences in IR among treatments at either 5-min or 30-min time periods. Although not always significantly different, the hayed treatment had the highest IR while the fallow treatment had the lowest IR. Steady-state infiltration, which was generally achieved after approximately 15 min, was similar among treatments, except at Site 3.

AI generally tended to be highest on hayed treatments and lowest on fallow treatments, except at Site 2 (Table II). Thirty-minute AI was lowest for the fallow treatment at one of the three sites. Thirty-minute AI of hayed and mowed treatments was similar at Sites 1 and 2 but was significantly higher at Site 3 (Table II).

Infiltration at pasture Sites 4 and 5

Infiltration rates of the grazed and fallow treatments at Sites 4 and 5 were similar for all time increments (Table III). Steady state infiltration rates were similar at Sites 4 and 5 for both treatments.

Accumulated infiltration volumes at Sites 4 and 5 were not significantly different between the grazed and fallow treatments at any time (Table III). In addition, there were no significant differences for 30-min AI between treatments at either site.

Variability of surface bulk density

Near-surface soil bulk densities varied depending on the time since cultivation of plots. Generally, surface bulk density tended to increase with time from tillage (Table IV). Except for Site 1, mowed treatments had the highest near-surface densities. At Sites 4 and 5 three months following cultivation, fallow plots had significantly higher near-surface densities than grazed plots: 15% higher at Site 4 and 10% at Site 5 (Table IV). Near-surface average bulk density two weeks after cultivation was 11% lower on Site 4 than that after three months, but only 2% at Site 5.

Table III. Infiltration rate (IR) and mean accumulated infiltration (AI) for Sites 4 and 5.

		Time					
		5	10	15	20	25	30
		Site 4					
IR (mm/h)	Grazed	88.6 a*	68.0 a	55.5 a	50.0 a	48.6 a	49.8 a
	Fallow	97.6 a	67.1 a	53.4 a	47.0 a	43.2 a	43.5 a
		Site 5					
	Grazed	86.7 a	56.5 a	42.7 a	42.5 a	40.9 a	42.9 a
	Fallow	87.7 a	64.6 a	56.2 a	49.2 a	45.2 a	43.7 a
		Site 4					
AI (mm)	Grazed	7.4 a	13.8 a	17.7 a	21.8 a	25.9 a	30.0 a
	Fallow	8.1 a	13.1 a	18.2 a	22.1 a	25.7 a	29.3 a
		Site 5					
	Grazed	7.2 a	12.3 a	15.9 a	19.4 a	22.8 a	26.4 a
	Fallow	7.3 a	12.7 a	17.4 a	21.5 a	25.2 a	28.9 a

* Means within a column for a given infiltration parameter at a given site followed by the same letter are not significantly different ($P \leq 0.05$).
n = 6 per cell

Fallow treatment comparisons

The 5-min IR of fallow treatments tended to be higher, though not consistently significant, on off-mined sites than at Site 1 (Table V). Fallow treatments at the pasture sites generally had lower, but non-significant, 30-min IR means compared to fallow treatments at forage sites. There were no significant differences in 30-min accumulated infiltration (AI) among sites (Table V).

Degree of saturation was significantly higher at Site 1 than at Sites 2, 3, and 5, with Site 2 having the lowest value (Table V). Fallow treatments at forage Sites 2 and 3 tended to show lower means in degree of saturation compared to the fallow treatments at pasture Sites 4 and 5. Mean I_a for the fallow treatments ranged from 3.1 to 8.5 mm and was lowest at Site 1 and highest at Site 4. I_a was generally small for all sites, comprising a maximum 7.7% of total precipitation.

Table IV. Near-surface (0-75 mm) bulk density (Mg/m^3) two weeks and three months after tillage operations at all sites.

	Treatment			
	Two weeks	Three months		
Site	Fallow	Hayed	Mowed	Fallow
1	1.10 A*	1.13 a**	1.17 a	1.17 a
2	1.14 A	1.26 b	1.32 a	1.17 c
3	1.09 A	1.21 a	1.22 a	1.13 b
	Fallow	Grazed	Fallow	
4	1.09 B*	1.06 b**	1.22 a	
5	1.26 A	1.17 b	1.29 a	

* Means within this column followed by the same uppercase letter are not significantly different ($P \leq 0.05$).
n = 6 per treatment per site.

** Means within a row for a given site followed by the same lowercase letter are not significantly different ($P \leq 0.05$).
n = 6 per treatment per site.

Runoff coefficients

Runoff coefficients ranged from 0.18 to 0.54, with 9 of 13 values between 0.43 and 0.49 (Table VI). Treatments that were densely vegetated (hayed and grazed treatments) had the lowest runoff coefficients, while those which had low growing vegetation or bare ground (grazed and fallow treatments) had high coefficients. Runoff coefficients varied little among sites, except for Site 3, where coefficients were lower for all treatments compared to Sites 1 and 2. There was no clear treatment trend at Sites 4 or 5.

Degree of saturation, initial abstraction, and 5-min IR

Degree of saturation ranged from 46.4 to 71.8% and was significantly different among treatments at Sites 3 and 5 (Table VII). The fallow treatment had the higher degree of saturation at Site 5, but lowest at Site 3.

Initial abstractions for Sites 1 and 3 were generally significantly greater for the hayed than fallow treatments (Table VII). At Sites 4 and 5, no significant differences in I_a between treatments were found. Highest I_a was found for the hayed treatment at Site 3, comprising 13.8% of total incident precipitation.

Five-min IR and degree of saturation were not significantly correlated for any of the treatments and there was also a poor correlation between I_a and degree of saturation (Table VIII). Analysis of data obtained in the first 20 minutes of simulation indicated variation in the relationship between IR and time among sites and an excellent fit of data to a log-log relationship (Table IX). For Site 1, the intercepts (i.e. infiltration rate at time of 1 minute) were significantly different among treatments and were in the order hayed > mowed > fallow, but the slopes were identical among treatments. The relationships between IR and time for Site 2 were identical among all treatments. However, for Site 3 the intercepts were identical, but the slopes were different among treatments. The rate of decrease of IR with time was greatest for fallow and smallest for hayed. For Site 4, the intercept for fallow was greater and IR decreased at a faster rate with time in the fallow compared to grazed treatment. For

Table V. Inter-site comparison of infiltration variables for fallow plots.

Site	5-min IR* (mm/h)	30-min IR (mm/h)	30-min AI (mm)	Degree of saturation ** (%)	I_a (mm)
1	82.9 c	50.2 ab	28.4 a	68.8 a	3.1 c
2	95.1 ab	55.0 a	31.8 a	46.4 c	4.3 bc
3	90.8 abc	49.7 ab	30.7 a	54.7 bc	6.7 ab
4	97.6 a	43.5 b	29.3 a	62.9 ab	8.5 a
5	87.7 bc	43.7 b	28.9 a	56.4 bc	6.3 abc

* Means within a column for a given infiltration parameter at a given site followed by the same letter are not significantly different (P≤ 0.05).
** Water content converted to degree of saturation for a surface depth of 75 mm.
n = 6 for each parameter at each site.

Table VI. Mean runoff coefficients over 30 minutes of rainfall simulations.

	Treatment		
Site	Hayed	Mowed	Fallow
1	0.34 b*	0.45 a	0.48 a
2	0.44 a	0.48 a	0.48 a
3	0.18 b	0.23 b	0.43 a
	Grazed	Fallow	
4	0.45 a*	0.49a	
5	0.54 a	0.44 a	

* Means within a row for a given site followed by the same letter are not significantly different (P ≤ 0.05).

Table VII. Treatment comparison of degree of saturation (0-75 mm) and initial abstraction.

	Degree of saturation				I_a (mm)		
Treatment	Site 1	Site 2	Site 3	Treatment	Site 1	Site 2	Site 3
Hayed	71.8 a*	53.7 a	63.6 ab	Hayed	9.4 a	5.3 a	15.2 a
Mowed	68.3 a	57.0 a	68.9 a	Mowed	7.7 a	4.6 a	12.6 ab
Fallow	68.8 a	54.7 a	54.7 b	Fallow	3.1 b	4.3 a	6.7 b
	Site 4	Site 5			Site 4	Site 5	
Grazed	55.1 a*	47.0 b		Grazed	5.3 a	6.3 a	
Fallow	62.9 a	56.4 a		Fallow	8.5 a	6.3 a	

* Means within a row for a given site followed by the same letter are not significantly different (P ≤ 0.05).

Site 5, the intercept for fallow was greater than for the grazed treatment, but the rate of decrease of IR with time was identical between treatments.

DISCUSSION

At one of five sites fallowing reduced infiltration capacity (30-minute IR) and the total amount of infiltrated water; perhaps this was due to the destruction of established pore spaces which reduced the capacity of the plowed layer to conduct water into the soil profile during simulated precipitation. Meek et al. (1989) concluded that infiltration in alfalfa fields was dominated by macropore flow through old root channels. Therefore, a lack of actively transmitting conduits could lead to the rapid saturation of a poorly drained surface soil. This was likely the case for the fallow treatment where biopores were likely destroyed (Dao 1993) and the soil surface compacted by vehicular traffic, potentially leading to a reduction in root growth and root channel formation. With continued compaction of the soil surface, root density and bioporosity were likely reduced.

As hypothesized, mean infiltration rates in hayed treatments exhibited a trend to be higher than those in the fallow treatments. Root channels and biopores are most numerous in soils with surface vegetation, particularly on perennial forages such as alfalfa (Meek et al. 1989). Interception and stem flow may have increased the amount of water being channeled toward the ground where stems and litter then detained water and prevented it from flowing down hill. Water could then enter through pores at the soil surface or just beneath the litter. Dao (1993) found that soil water was recharged through open root channels, biopores, and cracks that were not visible at the soil surface.

Because litter cushions the soil and dissipates energy transferred from above ground activity, the lack of such a protective layer would make the mowed plots more prone to compaction by mowing equipment and foot traffic. Naeth et al. (1990) found that the removal of vegetation exposed soils to the compactive effects of grazing animals. This effect could be similar on any soil surface which has had vegetation removed, whether by grazing, mowing, or harvesting.

Although there was very little difference in any of the measured infiltration variables among treatments at Site 2, trends in IR and AI at this site were different from those at the other sites due to the physical properties of the soils on this hillslope. High soil bulk density at this site may have resulted in poor root penetration, decreased hydraulic conductivity, and an overall reduction in vegetative growth.

Table VIII. Regression results for infiltration parameters.

Regression test	Treatment	R^2	Sample size (n)	Significance level
5-min IR × degree of saturation	Hayed	0.031	18	0.49
	Mowed	0.004	18	0.79
	Fallow (Sites 1-3)	0.133	18	0.14
	Fallow all sites	0.002	30	0.80
I_a × degree of saturation	Hayed	0.037	18	0.45
	Mowed	0.042	18	0.42
	Fallow (Sites 1-3)	0.009	18	0.72
	Fallow all sites	0.016	30	0.50

Table IX. Regression equations for relating infiltration rate (IR) before steady-state to elapsed time (T) for hayed, mowed, fallow, and grazed treatments.

Site	Treatment	Equation	R^2	Significance level
1	Hayed	$IR = 202\ T^{-0.410}$		
	Mowed	$IR = 174\ T^{-0.410}$	0.93	0.0001
		$IR = 202\ T^{-0.410}$		
2	Hayed	$IR = 169\ T^{-0.391}$		
	Mowed	$IR = 169\ T^{-0.391}$	0.89	0.0001
	Fallow	$IR = 169\ T^{-0.391}$		
3	Hayed	$IR = 146\ T^{-0.186}$		
	Mowed	$IR = 146\ T^{-0.225}$	0.96	0.0001
	Fallow	$IR = 146\ T^{-0.333}$		
4	Grazed	$IR = 177\ T^{-0.424}$	0.99	0.0001
	Fallow	$IR = 232\ T^{-0.536}$		
5	Grazed	$IR = 173\ T^{-0.479}$	0.96	0.0001
	Fallow	$IR = 199\ T^{-0.479}$		

The higher bulk density and lower porosity of the fallow treatments compared to the grazed treatments at both Sites 4 and 5 may have been a result of two factors. Compaction by cattle would likely account for most of the increased density. Increases in density at forage sites after cultivation were due to settling, while fallowed pasture plots were subjected to compaction due to both cattle traffic and settling.

Surface cover intercepts rainfall and detains it, allowing more water to infiltrate. Reductions in vegetative cover tended to increase in runoff coefficients as less water was intercepted and detained on the soil surface. However, fallow treatments at Sites 4 and 5 did not consistently have the highest runoff coefficients among treatments as they did on Sites 1, 2, and 3. These differences may have been due to the water content of litter material and surface roughness.

The rainfall rate used in this study was high, allowing quantification of infiltration and runoff for an extreme event, albeit under artificial conditions. The intensity used was not inordinate; Hawkins (1982) indicated that 75 mm /h is a popular choice of intensity used in studies. Jorgensen and Gardner (1987) used an intensity of 75 mm/h for 30 min in their study of the infiltration capacity of disturbed soils, while Hahn et al. (1985) used an intensity of 63.5 mm/h to assess the slope gradient effect on erosion. Given that in this study at most one-half of the applied precipitation occurred as runoff, one could conclude that the amount of runoff that could be expected for storms of shorter return periods would be even less. Coupling this conclusion with the fact that the antecedent moisture conditions at the time of the tests were quite wet, one could conclude that, in general, the runoff potential of the study area is low.

Reclaimed land comparison to unmined land

Sites 1, 2, and 3 had comparable 5-min, 30-min IR, and 30-min AI, indicating that infiltration variables of the reclaimed soil were similar to those of the unmined soils. The much greater topsoil depth and highest degree of saturation for the reclaimed site may have been mitigating factors. These results are contrary to those found by Potter et al. (1988) on reclaimed mine lands (4 and 11 years after reclamation) in North Dakota and those in the Eastern United States by Jorgensen and Gardner (1987). Both studies found that infiltration rates in newly reclaimed mine soils were an order of magnitude lower than those on adjacent undisturbed soil.

Site 1 had the highest degree of saturation and the lowest initial abstraction, indicating that the soil had the smallest absorptive capacity, perhaps due to the low surface roughness and the high antecedent soil water. Burwell and Larson (1969) found that tillage induces increases in random roughness and pore space increases water infiltration into a sandy clay loam soil and that random roughness accounts for most of the variation in infiltration among tillage treatments.

CONCLUSIONS

Hayed and mowed treatments had higher infiltration rates and accumulated infiltration than soils under fallow in two of three sites. Both reclaimed and unmined soils had similar infiltration variables. Functional relationships between initial abstraction and 5-min IR with degree of saturation were poor. The relationship between infiltration rate and time during the first twenty minutes of simulation was influenced by management practices and varied among sites. Grazing did not have a major effect on near-surface soil porosity or infiltration under either grazed or fallow treatments.

Runoff under rainfall simulation was low on all treatments (generally < 50% of incident precipitation), even under a high rainfall intensity. Similarly, initial abstractions were low (3-9 mm) on fallow but were slightly higher under hayed and mowed regimes.

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