Infiltration for Three Rangeland Soil-Vegetation Complexes

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Highlight: *A rotating disk rainfall simulator was used to examine infiltration-runoff relations from selected rangeland sites as influenced by a soil-vegetation complex. The simulator assisted in quantifying infiltration rates for different management practices on different soil types. Infiltration was greater for brush dominated plots than for either grazed plots or grass plots without grazing. Antecedent soil moisture decreased infiltration rates. Crown cover was approximately twice as much on brush plots as on grass plots and significantly influenced infiltration.*

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Soils and vegetation are important parameters in hydrologic models when determining runoff produced by a given rainfall event. However, numerical values of the parameters necessary to quantify the role of the soil and vegetation are difficult to obtain from watershed input-output data because of spatial variability. The watershed response to a given precipitation may be estimated by examining microunits within the watershed. Use of infiltrometers and simulated rainfall on microunits is one of the most convenient methods to evaluate these parameters.

A rainfall simulator developed by Morin (1967, 1970) was used to examine infiltration-runoff relations as influenced by the soil-vegetation complex of three rangeland sites (typical) of southeastern Arizona.

Study Area and Procedure

Three soil-vegetation complexes common to the semiarid Southwest were selected on the Walnut Gulch Experimental Watershed in southeastern Arizona, first, to quantify differences in infiltration and runoff encountered on three major rangeland soils with brush, grass, or no vegetation, and second, to examine infiltration variability encountered on different hydrologic soil groups in the Soil Conservation Service runoff model (Soil Conserv. Serv., 1969).

The hydrologic soil groups represented were characterized as having final constant infiltration rates (f_c) of (Musgrave, 1955):

Soil	SCS hydrologic group	f_c Range, inches/hr
Hathaway	B	0.15 - 0.30
Bernardino	C	0.05 - 0.15
Cave	D	0 - 0.05

The three soils in the infiltrometer tests were Hathaway, a fairly deep soil, Cave with an indurated hardpan at about 15 inches depth, and Bernardino, with a fine textured montmorillonitic subsoil. The Hathaway and Cave soils were medium textured, with all three soils classified as gravelly loams.

Three sites were selected for the infiltrometer tests within the Hathaway soil-vegetation complex: grass-grazing excluded; brush; and grass-grazed. The major grass species on the Hathaway soil were black grama (*Bouteloua eriopoda*) fluffgrass (*Tridens pulchellus*), curly mesquite (*Hilaria Belangeri*), and a limited number of annuals. Shrubs encountered were burroweed (*Haplopappus tenuisectus*), whitethorn (*Acacia constricta*), creosotebush (*Larrea divaricata*), beargrass (*Nolina microcarpa*), yucca (*Yucca* spp.), sotol (*Dasylirion wheeleri*), and ocotillo (*Fouquieria splendens*).

Infiltrometer tests were made on brush, grass, and bare soil at the Cave soil-vegetation complex. Whitethorn, creosotebush, sandpaper bush (*Mortonia scabrella*), tarbush (*Flourensia cernua*), yucca, sotol, Mexican bluewood (*Condalia mexicana*), squawbush (*Condalia spathulata*), burroweed, and various cacti constituted the shrub dominated plots. The grasses included fluffgrass, black grama and sideoats grama (*Bouteloua curtipendula*), wolftail (*Lycurus phleoides*), threeawn (*Aristida* spp.), and annuals.

The Bernardino soil-vegetation complex contained an argillic horizon, which was absent in the other soils. This horizon was postulated to have an effect on infiltration with antecedent soil moisture conditions. Vegetation consisted of blue grama (*Bouteloua gracilis*), curly mesquite, yucca, Mormon tea (*Ephedra trifurca*), and scattered mesquite (*Prosopis juliflora* var. *velutina*).

The data, with three replications per site, were grouped to determine possible infiltration differences using an analysis of variance. The sites were defined as follows:

Soil	Vegetation	Identification
Cave	grass	C-G
Cave	brush	C-B
Cave	bare	C-C
Bernardino	grass	B-G
Hathaway	brush	H-B
Hathaway	grass	H-G
Hathaway	grass w/o grazing	H-GE

After each of the plots was selected and the infiltration run completed, vegetation and soil surface characteristics were measured using the line-point transect method (Levy and Madden, 1933). Observations were recorded to quantify plant species, crown cover, basal area, litter, gravel (2mm-1cm), rock (> 1cm) and soil using 100-pin intersections per plot.

Plot runoff was recorded continuously by a water stage recorder installed on a volumetric tank. Infiltration rates were calculated as the difference between application and runoff rate. Antecedent soil moisture effects on infiltration were determined on selected plots by repeating the infiltration test 48 hours after the initial test.

Variability in simulated rainfall was measured on a test plot with cans placed on an 8-inch grid. Rainfall collected at various points within the test plot averaged 88.34 cc, with a standard deviation of 21.40 cc. The 1.75-inch-per-hour design application rate was checked by placing a plastic sheet over the plot and measuring outflow and agreed with Morin et al.'s (1970) independently determined value.

Results and Discussion

The soil moisture content was low at all locations at the time of the infiltrometer experiment because of below-normal precipitation (< 1 inch) during the preceding 4 months. Limited plant growth reflected the lack of precipitation.

Figure 1 summarizes the infiltration data for the seven different sites with each curve representing the average of three replications from each site.

The Cave infiltration plots had lower infiltration rates than corresponding Hathaway infiltration plots after 150 minutes, but the difference was not as great as expected. The shallow Cave soil had a cemented hardpan at about 1-ft depth, while the hardpan was in excess of 4 ft deep at the Hathaway soil plots. However, close examination of the hardpan at the Cave infiltration plots revealed plant roots following minute fissures or cracks, which suggests that the fissures may form paths for increasing water intake.

Table 1 shows the ranking of the seven sites in order of decreasing magnitude of the mean for the time to beginning of runoff. There were no significant differences among any of the sites examined in this study for the mean runoff beginning time. The lowest runoff (i.e., highest infiltration) was recorded on the Hathaway-brush plots, while the highest runoff was measured on the Bernardino-grass and the Cave-bare-soil plots.

An analysis of variance was made of the cumulative infiltration after specified durations and the results are shown in Table 1. The data in the table show that after 20 minutes of rainfall simulation, only the Bernardino soil with grass dominated cover had lower infiltration than the other sites. After 30 minutes of rainfall simulation, the Hathaway soil with grass cover and the bare Cave soil in addition to the Bernardino-grass site had lower infiltration than the rest of the plot sites. The results are quite obvious visually from the cumulative infiltration curves in Figure 1. Infiltration was higher for brush-covered sites than for grass-covered sites on both the Hathaway and Cave soils.

Calculated water intake rates were what might be expected for the sparse-

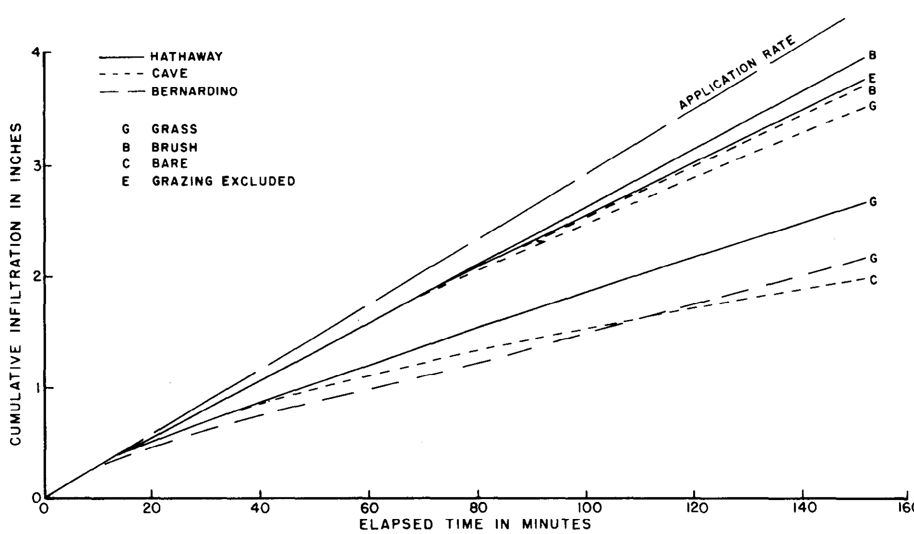

Fig. 1. *Average infiltration rates for the seven sites on Walnut Gulch Experimental Watershed.*

Table 1. Ranking of infiltration sites in order of decreasing magnitude of the mean for (A) the time (min) to beginning of runoff and (B) the cumulative infiltration (inches) after specified time periods.

	Rank						
Measurements	1st	2nd	3rd	4th	5th	6th	7th
A. Time to beginning runoff							
Site*	C–G*	H–GE	C–C	H–B	B–G	H–G	C–B
Elapse time	15.5+	14.3	10.7	10.3	10.0	9.1	8.0
B. Infiltration							
At 20 min.							
Site	C–B	H–GE	C–G	H–B	H–G	C–C	B–G
Inches	0.57^{a}** ++	0.56^{a}	0.56^{a}	0.55^{a}	0.52^{a}	0.52^{a}	0.46^{b}
At 30 min.							
Site	C–B	H–GE	C–G	H–B	H–G	C–C	B–G
Inches	.84^{a}	.82^{a}	.82^{a}	.82^{a}	.70^{b}	.70^{b}	.61^{b}
At 60 min.							
Site	C–B	H–GE	C–G	H–B	H–G	C–C	B–G
Inches	1.63^{a}	1.59^{a}	1.59^{a}	1.59^{a}	1.21^{b}	1.12^{b}	1.00^{b}
At 150 min.							
Site	H–B	H–GE	C–B	C–G	H–G	B–G	C–C
Inches	3.92^{a}	3.71^{a}	3.66^{a}	3.48^{a}	2.64^{b}	2.12^{b}	1.98^{b}

* Infiltration sites are as follows: C–G = Cave-grass; C–B = Cave-brush; C–C = Cave-bare; B–G = Bernardino-grass; H–B = Hathaway-brush; H–G = Hathaway-grass; H–GE = Hathaway-grass w/o grazing.

**Numbers in a given row with letters in common were not significantly different.

\+ Elapsed time in minutes from t = 0 to beginning of runoff.

++Infiltration in inches at the end of specified times.

covered, gravelly, coarse-textured soils.

The antecedent soil moisture tests indicated infiltration was lower when soils were moist (Fig. 2). The percentage change of infiltration rates as influenced by antecedent soil moisture was least for the Cave soil. Infiltration on the Hathaway soil for both the dry and moist runs was higher where grazing was excluded than on the grazed area. The Hathaway ungrazed site had been protected from livestock use for the past 9 years. Annual forage production was 3.5 times greater on the Hathaway ungrazed than on the Hathaway grazed site. The results from this current test illustrate the magnitude of increased infiltration as a result of protection. Gardner [1] (unpublished data) found that infiltration rates were higher on areas not being grazed by livestock. Lassen et al. (1952) reported that trampling by grazing animals compacts the soil, which reduces total porosity and thus would decrease infiltration rates.

Plot Surface Characteristics

Plot surface characteristics, expressed in percentages for each parameter measured, are presented in Table 2. Litter and crown cover were greater on the brush plots than on corresponding grass plots. Accumulation of litter and organic matter under the plant crown may explain the higher infiltration on the brush plots (Fig. 1). The decomposing organic matter aids in the development of a highly permeable soil surface (Coleman, 1953). Further, some precipitation intercepted by vegetation flows down the stems, increasing infiltration as well as reducing raindrop splash erosion.

Average plot infiltration for the three replications on the Hathaway grass-grazed and grass-ungrazed plots was 1.21 and 1.59 inches in 60 minutes, respectively. Similar basal area percentages on the Hathaway grazed and ungrazed plots indicated that the plant density was approximately the same for both treatments (Table 2). Reduction in crown cover by grazing, even though the grass basal area was similar, left the soil unprotected, with the postulated soil compaction and enhanced runoff. Thatcher[2] estimated annual forage production to be 1807 and 525 lb/acre for the ungrazed and grazed sites, respectively. The amount of forage removed by grazing is also indicated by the crown cover percentage which was more than three times as much on the ungrazed as on the grazed plots.

Rauzi and Fly (1968) report from 670 tests that "Among all variables measured, the amount of both new and old vegetation showed the greatest general correlation with water intake rates." Their results also showed that the infiltration rate in the second 30 minutes of simulated rainfall was most highly correlated with total vegetal cover or total weight of herbage.

Linear regression analysis was performed to evaluate the effect of the measured characteristics on infiltration after 120 minutes (Table 3). Data show that litter and crown cover were highly correlated with increased infiltration. Gravel and rock plus gravel showed negative high correlations with infiltration. However, there wasn't enough rock alone to make a significant difference.

A highly significant decrease in infiltration resulted from bare soil. Basal area of plants was not significantly correlated with infiltration.

These data indicate that soil surface protection provided by increased plant material resulted in increased infiltration. Conversely, with expanses of bare soil between widely spaced individual plants infiltration decreased. This suggests that where greater onsite water retention is desired, one general solution would be to try to increase plant cover.

The high cumulative infiltration on the brush plots may reflect a permeable soil surface and increased litter accumulation under the individual brush plants. This increase in infiltration may also be a result of less soil compaction from livestock trampling in the area adjacent to or under individual shrubs.

The small infiltrometer plot size (51 inch square) may affect the sampling of water intake rates on rangeland soils, particularly when brush is present. Placement of small plot borders to include shrubs might exclude much of the open areas between plants because of plot size

[1] J. L. Gardner, 1971, personal communication, Las Cruces, New Mexico.

[2] A. P. Thatcher, unpublished report, Walnut Gulch Infiltration Studies, 1971.

Table 2. Average surface characteristic values (%) for each of the seven soil-vegetation complexes.

Soil-vegetation complex	Rock	Gravel	Soil	Litter	Basal area	Crown cover
Hathaway-brush	8.3	20.3	24.7	43.3	3.3	46.3
Hathaway-grass	3.0	25.0	33.7	20.3	13.0	7.0
Hathaway-grass (ungrazed)	11.3	19.0	23.0	33.0	13.7	23.7
Cave-bare	3.7	55.0	35.3	4.0	2.0	3.3
Cave-brush	6.3	15.3	23.0	50.3	4.7	68.3
Cave-grass	7.7	16.3	28.3	37.0	10.7	30.3
Bernardino-grass	11.0	33.3	34.0	24.3	7.3	14.3

Table 3. Regression equation and correlation coefficient of runoff vs characteristics for the infiltration plots.

Characteristic	r*	Equation
Rock	0.23	$y = 0.057x + 2.657$
Gravel	−0.83	$y = -0.048x + 4.333$
Soil	−0.54	$y = -0.085x + 5.404$
Litter	0.85	$y = 0.044x + 1.737$
Basal area	0.21	$y = 0.036x + 2.791$
Crown cover	0.78	$y = 0.027x + 2.320$
Rock + gravel	−0.83	$y = -0.051x + 4.779$

*r must be 0.41 and 0.53 to be significant at the 0.05 and 0.01 level, respectively.

restrictions. Water intake could be much larger with the shrub canopy than the surrounding sparsely vegetated area because of litter cover. Increasing the plot size on shrub-dominated sites could improve the representativesness of the infiltration measurements for each sites.

Conclusions

For the Hathaway soils, infiltration was higher on brush than on ungrazed grass plots, and higher on the ungrazed grass than on the grazed-grass plots. Similar ranking of infiltration rates by cover type were observed for the Cave soil sites.

Infiltration on moistened plots was less than on the dry control plots. The percentage infiltration decrease with antecedent soil moisture was least on the Cave-grass site. The Bernardino soil, with a fine textured B_2 horizon, had the lowest infiltration rate of all sites.

Gravel and rock plus gravel showed a significant negative correlation with infiltration, whereas rock alone was not significant. Infiltration decreased significantly with bare soil.

The amount of litter measured on brush-dominated plots was higher than on grass-grazed plots, providing soil surface conditions more amenable to infiltration. Approximately twice as much crown cover was measured on brush plots as on grass plots, providing protection to the soil surface and significantly improving infiltration.

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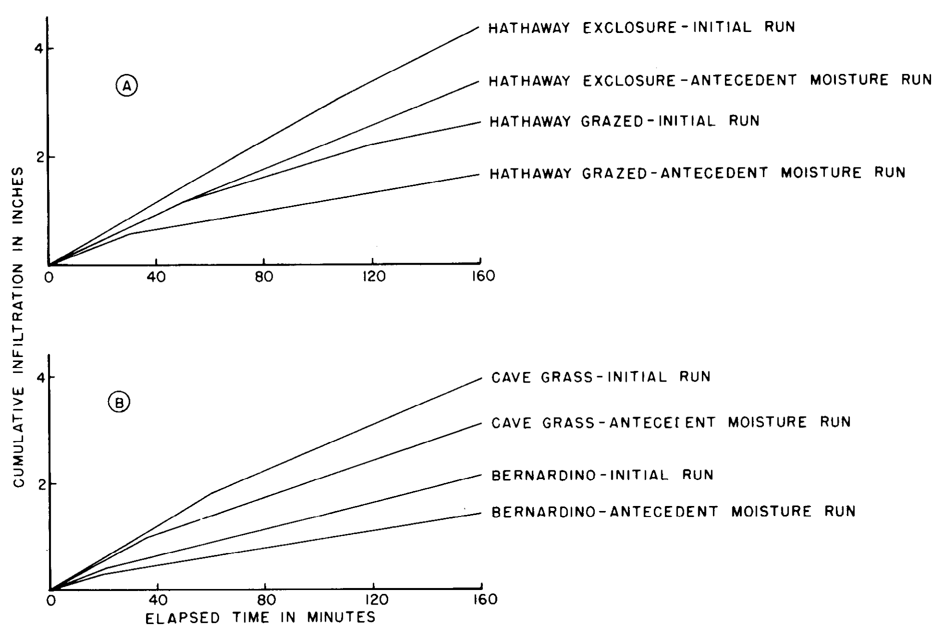

Fig. 2. *Infiltration versus time curves for (A) Hathaway grazed and ungrazed plots and for (B) the Bernardino and Cave-grass plots.*