

Runoff and Sedimentation Potentials Influenced by Litter and Slope on a Chaparral Community in Central Arizona¹

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The chaparral type is an important watershed resource in Arizona where it covers about 3-1/2 million acres at mid-elevations throughout the central part of the state (Hibbert and others 1974). These brush-covered areas are potential sources of increased streamflow when the deep-rooted brush plants are replaced with shallower-rooted grasses and forbs (Hibbert 1979). The possibility of large-scale treatments of this vegetation type makes it essential to better understand the potential on-site runoff-sedimentation relationships. This study reports the results of infiltrometer trials which were used to establish the effect of different litter and slope conditions on runoff and associated on-site sediment movement in an undisturbed stand of Arizona chaparral.

Several factors affect the runoff-sedimentation relationships in chaparral, including vegetation cover and density, litter, slope, and the infiltration capacity of the soil. In chaparral areas receiving 22 inches or more of precipitation annually the brush cover is usually moderate to dense with a sparse understory of native herbaceous plants (Hibbert and others 1974). The amount of litter on the soil surface varies widely depending partly on the brush density. For example, in an oak-mountain mahogany stand the weight of L- and F-material (current and partly decomposed litter) on the forest floor varied from 9.2 to 27.1 metric tons per ha (Pase 1972).

The physical properties and infiltration characteristics of the chaparral soils vary widely depending upon the parent rock material. In many areas the parent rock is granite which weathers into a coarse-textured soil having a high infiltration capacity but which can be highly erosive on steep slopes because it lacks soil structure.

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Abstract: Runoff and sediment was measured for a chaparral community on the Prescott National Forest in the summer of 1979. Simulated rainfall intensities of 12.5 cm/hr were applied to steep, moderate, and gentle sloped plots covered with none, light, moderate and heavy litter. Infiltration capacity was highest (10.8 cm/hr) on heavy litter plots giving low runoff potentials. Highest sediments (1466 kg/ha) were from bare soils. Litter cover significantly reduced sediment losses and decreased runoff potentials.

Although the infiltration capacity in chaparral soils is usually high, it may be restricted by water-repellent substances present in the litter and underlying soil. Water repellency is most likely a problem after fire although it may also be present in unburned chaparral litter and soil (DeBano and others 1979).

When fully vegetated, chaparral watersheds seldom show overland flow (Rice 1974). Both surface litter and plant canopy promote infiltration by reducing raindrop impact and impeding overland flow, thereby providing temporary storage for periods of high-intensity rainfall. Litter material in an oak-mountain mahogany stand in Arizona was found to retain from 4.8 to 5.1 mm of precipitation against free drainage (Pase 1972). High infiltration rates and the storage capacity of the chaparral soil and litter leave little water available for overland flow (DeBano and others 1979).

METHODS

The study area was located in a chaparral community about 2 miles S.W. of the Goodwin, Arizona, townsite on the Prescott National Forest. The cover on the study area was composed mainly of shrub liveoak (*Quercus turbinella*) and Wright mountain mahogany (*Cercocarpus breviflorus*). These species are typical of much of Arizona chaparral (Cable 1972, Carmichael and others 1978).

Twelve study sites were selected on different slopes and litter conditions in the area. Three slope categories selected were (1) gentle 0-19 percent, (2) moderate 20-39 percent, and (3) >40 percent. Within each slope category, four different litter conditions were selected for study. The litter classes included (1) none, (2) light, (3) moderate, and (4) heavy amounts on the soil surface. The litter was visually classified into these four classes when study sites were selected; amounts of litter were measured after completion of the infiltrometer trials. Two replicates of each slope-litter combination were used for the study.

Infiltrometer trials were run on each of the twelve plots. Infiltration rates were measured using a drip infiltrometer (Blackburn and others

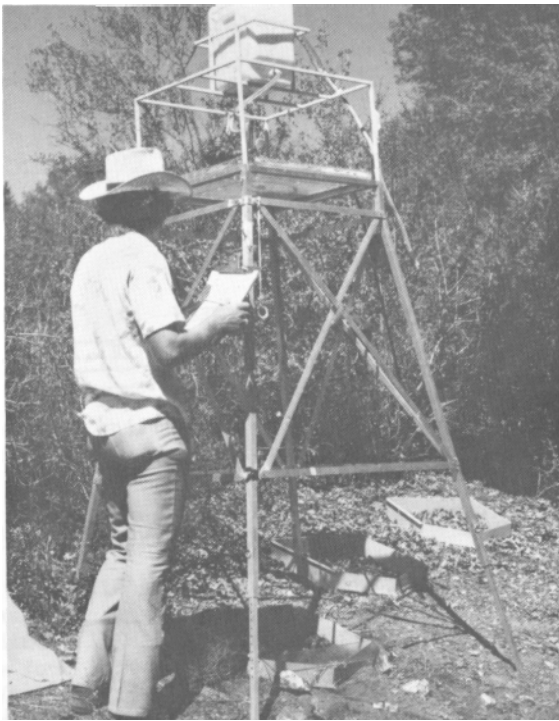


Figure 1--Modified rainfall infiltrometer.

1974) modified to improve portability in rugged terrain (fig. 1). Simulated rainfall was applied from 0.36 m² modules to a 0.25 m² sample plot at a rate of 12.5 cm/hr for 30 minutes. The four litter plots within each slope category received simulated rainfall from the infiltrometer in a single day. Following the initial application, the plots were covered with plastic to retard evaporation, and after six hours of drainage the plot received simulated rainfall with the soil in a wet condition.

Antecedent soil water was determined gravimetrically from samples of surface soil (0-5 cm) taken immediately adjacent to the plots. Following each wet soil infiltrometer trial the litter was removed from the plot using a fine rake, and oven-dried at 80°C for 48 hours. Rocks were removed, and litter weighed. A soil sample from the surface 0-5 cm depth was collected for subsequent analysis. Soil organic matter was determined by chromic acid oxidation (Jackson 1958) and soil texture by the hydrometer method (Day 1965).

Runoff water drained through a miniature flume and was collected in a 10-liter plastic bottle. The quantity of runoff was measured in a 1-liter graduated cylinder at 5-minute intervals and recorded to the nearest milliliter. Data was converted to centimeters of runoff per area and used to calculate infiltration rates for 5-minute time intervals. The infiltration rates reported

in this paper are for wet soils during peak runoff.

After runoff stopped, a 1-liter aliquot of the runoff water was saved for sediment analysis. The amount of sediment lost in the runoff water was determined by filtering it through No. 41 filter paper and oven-drying the residue at 105°C for 24 hours before weighing. Sediment losses are reported in kilograms per hectare.

The sediment yield data were normalized by using a common logarithmic transformation prior to statistical analysis. The data was analyzed using the Statistical Analysis System (SAS) software package (Barr and others 1976). Analysis of variance (Steele and Torrie 1960) was used to test for differences in runoff, sediment, litter and soil characteristics. Duncan's new multiple range test (P = 0.05) was performed when F-values were significant. Stepwise multiple regression analyses were used to isolate the effect of slope, litter classes, and soil characteristics on infiltration rates and sediment production. Variables included in the regression models if significant at P = 0.10.

RESULTS AND DISCUSSION

Litter and Soil Conditions

The slope of the individual plots selected for study ranged from 6 to 67 percent (table 1). Mean litter ranged from none on the bare plots to 36074 kg/ha on the sites having heavy litter accumulations (table 2). The quantities of litter measured in this study were similar to those reported by Pase (1972) in Arizona and DeBano and Conrad (1978) in California where both the F- and H-layers (humus) were reported as litter. In the study area about 10 percent of the surface was bare soil, 17 percent covered with light, 31 percent moderate, and 42 percent with heavy accumulations of litter. The average amounts of litter on the gentle, moderate and steep slopes were 14073, 11326, and 14600 kg/ha, respectively, but were not statistically different at the 0.05 level. Soil organic matter was greater on the heavy litter plots, as expected, but only significantly different from plots having no litter (table 2).

Table 1--Slope (percent) characteristics of plots used for studying runoff and sedimentation potentials of a chaparral community in central Arizona.

Category Data	Slope Category		
	Gentle	Moderate	Steep
Category Limits	0-19	20-39	>40
Observed Ranges	6-15	20-33	55-67
Mean Slope	8.9	25.0	58.2

Table 2--Surface soil properties of a chaparral community in central Arizona.

Soil Cover	Litter (kg/ha)	Organic Matter Percent	Sand	Percent Silt	Clay
None	¹ 0c	2.2b	51.9a	31.0b	17.0a
Light	3,804c	3.2ab	52.0a	33.5ab	14.4ab
Moderate	13,454b	4.8ab	50.7a	34.3ab	14.9ab
Heavy	36,074a	8.5a	49.2a	36.6a	14.0b

¹Means followed by the same letter are not significantly different at P = 0.05 percent.

Generally, organic matter increased in the soil as the thickness of the litter layer increased.

The surface soils were classified as silt loams for all slope and litter combinations. There were no significant differences in the sand fraction among the four litter classes. In contrast, the silt and clay fractions were statistically different (table 2). Silt increased with increasing amounts of litter. Clay content was 2.6 percent higher in soils on bare plots compared to those having some litter cover.

Infiltration Rates

The terminal infiltration rate, or infiltration capacity, is defined as the stable rate which is attained during a 30-minute infiltrometer trial. The terminal infiltration rate for the dry soil averaged 9.4 cm/hr and was significantly greater (P = 0.05) than the 8.4 cm/hr rate in the wet soils.

No significant differences in terminal infiltration rates were found in the wet soils among the different slope classes (fig. 2). The steep slopes had the highest infiltration rates (9.1 cm/hr). This may have occurred because the steep slopes had shallow soils which contained numerous fractures in the unweathered granitic parent material. On the more gentle slopes, the surface soils probably developed from colluvial material which produced a deeper soil containing more clay and silt than those on steeper slopes (table 3). Consequently, infiltration rates were slower on the gentle and moderate slopes compared to the steep slopes (fig. 2). The major feature governing infiltration into chaparral soils appears to be the amount of litter accumulating on the soil surface. The infiltration capacities of plots having the greatest amounts of litter (36074 kg/ha) was 10.8 cm/hr after 30 minutes of simulated rainfall (fig. 3). Moderate quantities of litter (13454 kg/ha) had an average infiltration capacity of about 2 cm/hr less than those plots covered with a heavy litter accumulation.

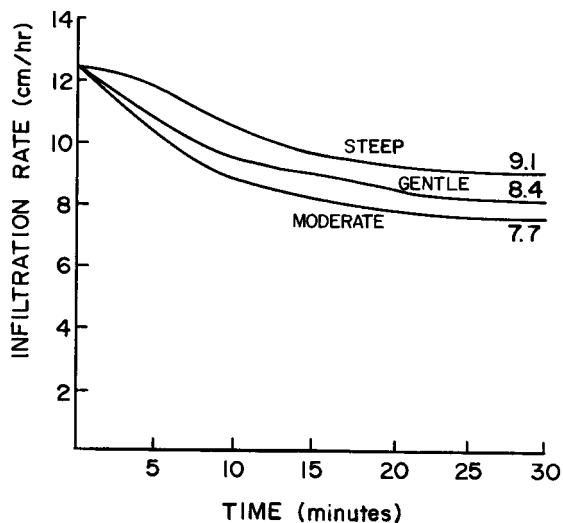


Figure 2--Terminal infiltration rates (cm/hr) for wet soils as influenced by slope in a chaparral community in central Arizona.

On plots having light amounts of litter, or no litter, the infiltration capacities were 30 to 40 percent less (and statistically significant) than on plots having heavy amounts of litter.

The influence of litter, or its decomposed counterpart--soil organic matter, on water movement into chaparral soils was further verified by the regression analysis. The best three-variable equation describing the infiltration capacity of dry soils (Y_1) was:

$$Y_1 = 13.0388 + 0.3325 \text{ organic matter} - 0.0564 \text{ silt} - 0.2234 \text{ clay}$$

This model accounted for 75 percent of the variation observed in the infiltration capacity of the dry soil. The first variable in the model, organic matter, yielded a coefficient of determination of 0.48. In the wet soil, slightly more of the variation in infiltration capacity (Y_2) was accounted for by a three-variable model. The equation for the wet soil was:

$$Y_2 = 0.4457 + 0.0008 \text{ litter} + 0.02287 \text{ organic matter} + 0.1123 \text{ sand}$$

This equation had a coefficient of determination of 0.84 and the first variable in the model, litter, accounted for 66 percent of the variation observed in infiltration capacity.

Table 3--Soil textural properties of soils on gentle, moderate and steep slopes in an Arizona chaparral community.

Slope Category	Sand Percent	Silt Percent	Clay Percent
Gentle	¹ 52.4a	33.5a	14.1b
Moderate	44.6b	36.2a	19.1a
Steep	55.9a	31.9a	12.2b

¹Means in columns followed by the same letter are not significantly different at P = 0.05 percent.

Sediment Production

The sediment losses from the three slope classes were not statistically different. However, sediment losses were significantly different among the four litter classes. The greatest loss (1466 kg/ha) was from bare soils that were wet (fig. 4). Even small amounts of litter on the soil surface significantly decrease the sediment lost in the runoff water. The lowest sediment loss (20 kg/ha) was measured on plots having a heavy litter layer.

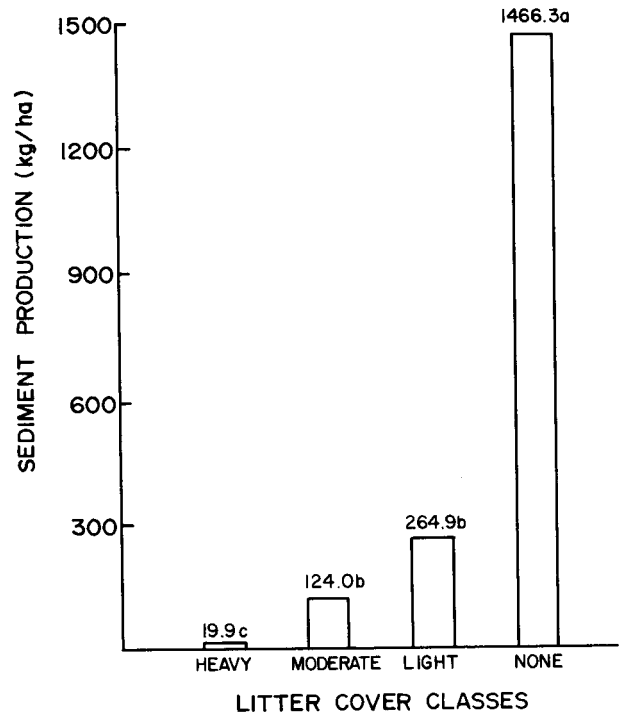


Figure 4--Sediment production from wet soils after 30 minutes at 12.5 cm/hr rainfall intensity as influenced by litter class. Column means with the same letter are not significantly different at P = 0.05 percent.

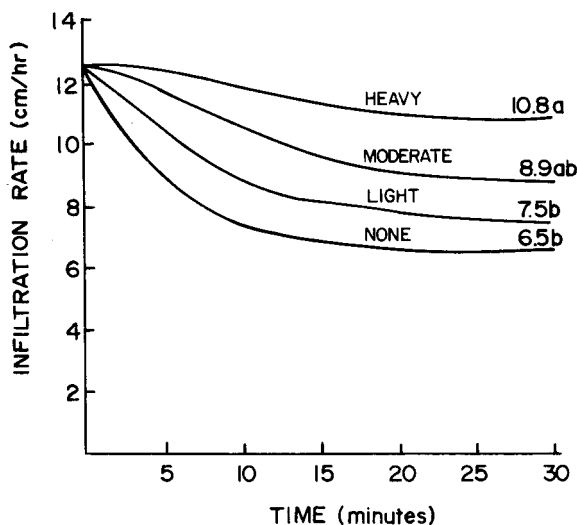


Figure 3--Infiltration capacity (cm/hr) for wet soils as influenced by litter class. Means for terminal infiltration rate followed by the same letter are not significantly different at P = 0.05 percent.

The on-site movement of sediment measured during the infiltrometer trials reported here are comparable to a long-term sediment rate of 0.7 m³/ha reported for a nearby watershed (Hook and Hibbert 1979). If the volume-weight of the sediment is assumed to be 1121 kg/m³ (Megahan 1972), then the mass of sediment moving off this watershed was 812 kg/ha per year. The sediment rates measured in this study were also comparable to those reported on other small plots or infiltrometer trials. In southern California, on-site sediment movement rates of 210 kg/ha were measured on small plots in untreated chaparral on a 50 percent slope (DeBano and Conrad 1976). Recent studies on Texas grasslands using a similar type infiltrometer showed that maximum sediment losses from untreated short-grass ranges were 252 kg/ha (Brock and others 1981), 196 kg/ha on heavily continuously grazed pastures during years of favorable moisture (Woods 1980), and over 1000 kg/ha following a summer drought on heavily grazed areas (Knight and others 1980).

Sediment production rates measured by infiltrometers, or on small plots, should be used with extreme caution when assessing the long-term erosion rates from large watersheds. The measurements may not be comparable because many of the on-site erosional processes are altered down-slope or completely different in the channels draining

larger watershed areas. However, small plots and infiltrometers are useful tools for isolating some of the factors affecting on-site erosion such as litter, soil physical properties, localized slope conditions, effect of fire, water repellency, and a host of other small-scale processes. These small-scale studies provide a much better chance of rigorously testing some variables while controlling others.

Sediment losses were also related to organic matter, litter and soil properties in dry and wet soils by regression analysis. Litter and soil organic matter were related to sediment loss as was the case for infiltration capacity, but the regression coefficients were reversed in sign. The prediction equation for the log of sediment losses (Y_3) from dry chaparral soil was

$$Y_3 = -2.8797 - 0.2614 \text{ organic matter} \\ + 0.0962 \text{ sand} + 0.02706 \text{ clay}$$

This three-variable model accounted for 65 percent of the variation observed in the log of sediment yield. When only one variable, organic matter, was used, only 48 percent of the observed variation was accounted for in the regression. The regression model for the log of sediment losses of wet soils (Y_4) was

$$Y_4 = 6.2423 - 0.0006 \text{ litter} - 0.1841 \\ \text{ organic matter} + 0.0417 \text{ clay}$$

The coefficient of determination for the three variables was 0.76 and litter accounted for 67 percent of the variation.

CONCLUSIONS

Infiltration capacity of chaparral soils was found to be influenced more by soil surface characteristics than by steepness of slope. The infiltration capacities were lowest on bare soils and increased when litter and soil organic matter content increased. Sediment losses were greatest on unprotected soils. However, even small amounts of litter on the surface greatly reduced the on-site erosion potential of these chaparral soils. The results of this study provided some information concerning the important site factors that affect on-site erosion, particularly if they are affected by chaparral treatments. For example, treatments in chaparral communities which bare the soil and leave it unprotected should be avoided. When mineral soil is exposed by mechanical treatments or overly intense fires, revegetation or surface modifications such as contour furrowing and revegetation should be undertaken immediately to reduce potential soil movement and loss.

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