Infiltration and Soil Erosion as Influenced by Vegetation and Soil in Northern Utah[1]

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Highlight

The influences of vegetation, soil properties, and slope gradient on infiltration capacity and soil stability of high-elevation herbland on the Wasatch Front in northern Utah were investigated under simulated rainfall conditions. Results emphasize the importance of vegetation and litter cover in maintaining infiltration capacity and soil stability. Infiltration is also affected significantly by soil properties, notably bulk density, aggregation, and moisture content.

Control of overland flow and soil erosion is a basic requirement for effective watershed protection. Such control is particularly important on herbaceous high-elevation rangelands of Utah, where summer floods not only cause damage to the range itself but also inflict severe damage to cities and towns at the mouths of flood-producing watersheds.

The importance of vegetative cover in maintaining soil stability and permeability is well known. For example, on the Davis County Experimental Watershed, Marston (1952) found that amounts of summer storm overland flow and soil erosion, during 15 years of observation, were slight on sites where vegetation and litter covered 65% or more of the soil surface. Overland flow and erosion from plots with less than this amount of cover were judged to be excessive. There is, however, considerable uncertainty about the amounts of vegetative cover needed to prevent excessive overland flow and erosion under diverse topography and soil characteristics. For instance, soils that have high inherent erodibility need more protective cover than do soils that have low inherent erodibility.

The quantitative effects of certain soil properties on infiltration and soil erosion have been presented by Packer (1963) for the Gallatin elk winter range in southwestern Montana, by Dortignac and Love (1961) for ponderosa pine ranges of Colorado, and by Meeuwig (1965) for a subalpine range in central Utah. Similar information was developed on the Davis County Experimental Watershed in northern Utah during the summer of 1962.

Study Area and Methods

The Davis County Experimental Watershed is situated on the Wasatch Front, midway between Salt Lake City and Ogden, Utah. Study plots are located on ungrazed, herbaceous sites at an elevation of approximately 9,000 ft in the headwaters of Farmington and Parrish Creeks. Soils are derived from parent rock materials varying from metamorphic gneisses and schists to conglomerates, sandstones, and shales.

The rainfall-simulating infiltrometer described by Dortignac (1951) was used to apply approximately 2.5 inches of simulated rain to each of eighty 20- by 30-inch plots during a 30-min period. Resultant overland flow and soil erosion from each plot were measured. The difference between applied rainfall and overland flow in area inches closely approximates infiltration capacity, but includes plant canopy storage and ground depression storage as well. The weight of soil washed from each plot by raindrop splash and overland flow during the 30-minute period is considered an index of soil erodibility.

To obtain a wide difference in initial soil moisture, half (40) of the plots were pre-wet the day before infiltration tests were made by applying 0.5 inch of simulated rain during a 15-min period. Initial moisture content of the surface 2 inches of soil was determined from two 240 cc soil samples taken just outside the boundaries of all the plots a few minutes before the infiltration tests.

Protective cover in each plot was measured with a point analyzer (Levy and Madden, 1933). First strikes of 100 mechanically spaced points were recorded as plants (by species), litter, stone, or bare soil. A day or two after the tests, all vegetation on the plots was clipped flush with the soil surface and all litter was removed. Litter and vegetation were air-dried for 2 weeks and weighed.

Two days after the application of simulated rain, when the soil moisture had approached field capacity, two 120 cc cores were obtained from the 0- to 1-inch and the 1- to 2-inch depths of the soil mantle. Also, two 240 cc cores were obtained from the 2- to 4-inch depth and one 240 cc core was obtained from the 4- to 6-inch depth. Soil bulk density and 0.06 bar moisture content of each of these cores were measured. Bulk soil samples were obtained from the surface inch of soil concurrently with the soil core samples. Texture of the soil was measured by the hydrometer method. The dichromate method (Peech et al., 1947) was used to determine organic matter content. Size distribution of soil particles and aggregates was determined by wet-sieving.

The above data were analyzed by a series of multiple regressions to determine which combinations of the measured site variables were most closely associated with infiltration and eroded soil.

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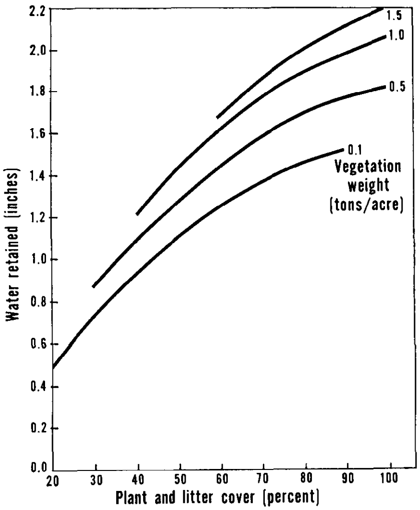

Fig. 1. Inches of water retained during application of 2.5 inches of simulated rain in 30 min in relation to plant and litter cover and vegetation weight. Initial soil moisture, soil bulk density, and soil particles and aggregates are held constant at their sample means.

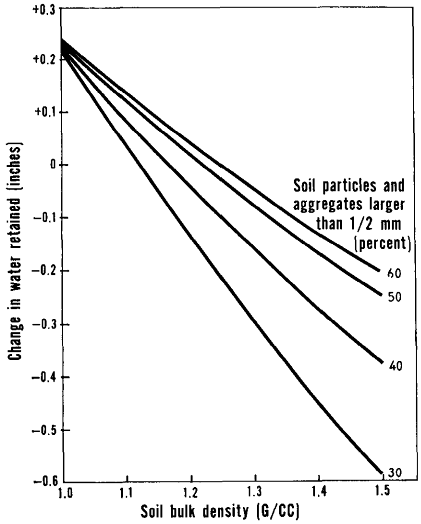

Fig. 2. Changes in inches of water retained due to variations of bulk density of the surface 4 inches of soil and percentage of particles and aggregates larger than 0.5 mm in the surface inch of soil.

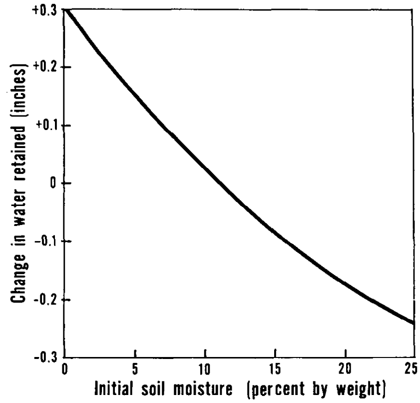

Fig. 3. Effects of changes in initial soil moisture on inches of water retained.

Results

Infiltration

Plant and litter cover accounted for 73% of the variance in the amount of water retained by the study plots during the 30-min simulated rainfall tests. No other single measured variable was this highly correlated with retained water.

Four other site factors in combination with plant and litter cover density accounted for 82% of the variance in water retained. These factors are: bulk density of the surface 4 inches of soil, proportion of particles and aggregates larger than 0.5 mm in diameter in the surface inch of soil, initial moisture content of the surface 2 inches of soil, and air-dry weight of live vegetation.

The multiple regression equation is:

$$\hat{y} = 4.44 - 8.74A + 7.25A^2 - 4.45B + 0.316B^2 + 9.20AB - 7.64A^2B + 3.03C - 1.46C^2 + 0.362V - 0.192V^2 + 0.419CV - 3.35M - 4.55M^2$$

in which $\hat{y}$ is the difference between applied rain and resultant runoff in inches, A is the proportion of the surface inch of soil composed of aggregates and particles larger than 0.5 mm, B is bulk density of the surface 4 inches of soil in grams per cc, C is the proportion of the soil surface protected from direct raindrop impact by vegetation and litter, V is air-dry weight of live vegetation in tons per acre, and M is the initial moisture content of the surface 2 inches of soil expressed in grams of water per gram of ovendry soil. This equation is expressed graphically in Figures 1, 2, and 3.

Shown in Figure 1 are the influences of plant and litter cover and of vegetation weight on amount of water retained when soil bulk density, soil particles and aggregates larger than 0.5 mm, and initial moisture content are held constant at their respective averages of 1.22 g/cc, 50%, and 11%. These results are in general agreement with findings of other studies; the amount of water retained decreases as cover and vegetation weights decrease. However, the rate at which water retention increases as vegetation weight increases is small when vegetation weight exceeds 1 ton per acre.

The changes in water retention associated with variations from average values of soil bulk density, proportion of particles and aggregates larger than 0.5 mm, and soil moisture content are shown in Figures 2 and 3 as deviations from the values in Figure 1. Water retention decreases with increasing bulk density. However, this relation is strongly affected by the coarseness of the soil as expressed by the proportion of particles and aggregates larger than 0.5 mm in diameter (Fig. 2). When a large proportion of the soil is composed of particles and aggregates larger than 0.5 mm the effect of bulk density is minimal, but when the soil is fine and poorly aggregated, water retention decreases sharply as bulk density increases. One might expect soil bulk density and aggregate distribution to be closely related, but such was not the case on this study area. The correlation between bulk density and percentage of particles and aggregates larger than 0.5 mm was not significant ($r = -0.04$).

Initial moisture content exerts a small, but significant, effect on amount of water retention (Fig. 3). Retained water decreases about 0.1 inch for each 5% increase in initial moisture content of the surface 2 inches of soil.

Inches of water retained by sites during the 30-min simulated rainfall can be estimated if values for the five site factors are known. For example, if 70% of the soil surface is protected by plants and litter, and vegetation weight is 0.5 ton per

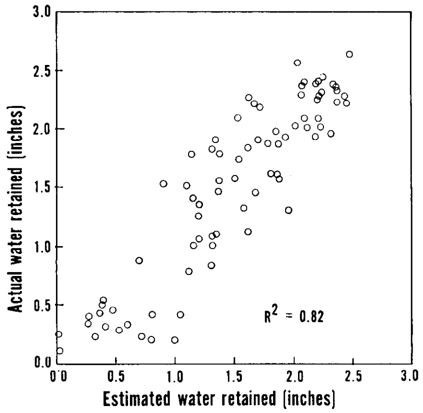

FIG. 4. Inches of water retained as estimated by regression and as actually measured.

acre, 1.58 inches of water are retained without correction for bulk density, aggregate distribution, or initial moisture (Fig. 1). If 30% of the surface soil consists of particles and aggregates larger than 0.5 mm and bulk density is 1.3 g per cc, the depth of water retained is reduced by 0.29 inch (Fig. 2), changing the total to 1.29 inches. Finally, if initial moisture content is 5%, the depth of water retained is 0.15 inch greater (Fig. 3), increasing total water retention to 1.44 inches. This is the same value that would be obtained by solving the regression equation upon which these curves are based.

The standard error of estimate of this equation is 0.343 inch of water. The relation between water retention actually measured on the 80 plots and estimated by the regression equation is shown in Figure 4.

Soil Erosion

The weights of soil eroded during the 30-min simulated rainfall tests were related exponentially to influential site factors. Accordingly, logarithms of eroded soil weights were used as the dependent variable in regression analyses rather than actual tons per acre of eroded soil.

As in the case of infiltration or retained water, plant and litter cover is the single site factor most closely correlated with eroded soil ($r = -0.87$). Differences in cover explain 76% of the variance of the logarithm of eroded soil.

Three other site factors—litter weight, slope gradient, and soil organic matter—in combination with cover, account for 83% of the variance of the logarithm of eroded soil. The multiple regression equation is:

$$\hat{y} = 0.553 - 0.0621C - 1.91C^2 - 0.341L + 0.194CL - 5.24H - 1.41H^2 + 0.0183T$$

in which $\hat{y}$ is the common logarithm of weight in tons per acre of soil eroded during the 30-min simulated rain test, C is the proportion of the soil surface protected from direct raindrop impact by plants and litter, L is air-dry weight of litter in tons per acre, H is organic matter content (in grams) of the surface inch of soil per gram of soil, and T is plot slope gradient in percent. The curves in Figures 5, 6, and 7 were calculated from this equation to show the relations graphically.

The effect of differences in cover percentage and litter weight (tons per acre) when organic matter content of the surface inch of soil is at its average of 5% and slope gradient is at its average of 20% are shown in Figure 5. The rate at which soil erosion increases as cover decreases is reduced substantially by increasing weights of litter.

Organic matter content is the most important *soil* factor influencing soil erosion. Variations of organic matter content from 5% alter the relations shown in Figure 5. The amount of such alteration is shown by the curve of correction factors in Figure 6. For example, if organic matter content is 10%, the weights of soil eroded are only one-half of those indicated in Figure 5.

Variations of slope gradient from 20% alter the plant cover-litter weight-soil erosion relation shown in Figure 5. The magnitude of such alteration due to variations in

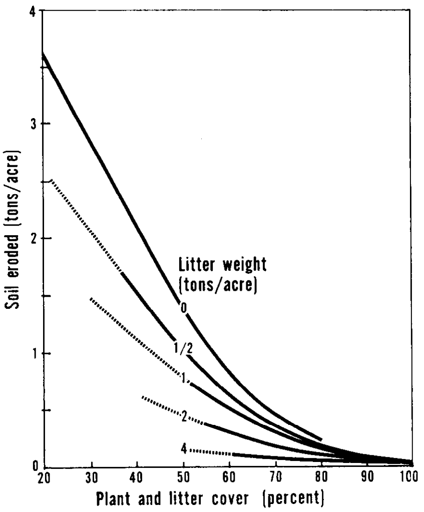

FIG. 5. Weight of soil eroded during application of 2.5 inches of simulated rain in 30 min as a function of plant and litter cover and air-dry weight of litter on 20% slopes with 5% organic matter in the surface inch of soil.

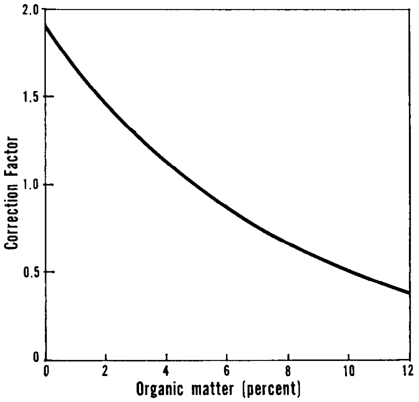

FIG. 6. Correction of estimated soil eroded for variations in organic matter content of the surface inch of soil.

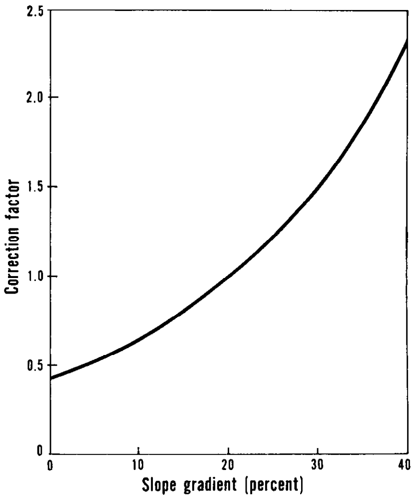

FIG. 7. Slope correction of estimated soil eroded.

slope gradient is shown by the curve of correction factors in Figure 7. Values from the curves in Figure 5 should be multiplied by the correction factors obtained from the curve in Figure 7 to correct for slope. For instance, at a slope gradient of 2%, the weights of soil eroded are only one-half of the weights indicated by the curves in Figure 5. Similarly, at a slope gradient of 36%, the weights of soil eroded are twice those indicated in Figure 5.

Weights of soil eroded under conditions similar to those of the simulated rainfall tests can be estimated from the curves in Figures 5, 6, and 7. If, for example, a site is characterized by a plant and litter cover of 60%, litter weight of 1 ton per acre, 2% organic matter in the surface inch of soil, and slope gradient of 10%, the expected weight of eroded soil is estimated as follows: a combination of 60% cover and 1 ton per acre of litter, holding soil organic matter content and slope gradient constant at 5% and 20%, respectively, yields 0.50 ton per acre of eroded soil (Fig. 5). However, the correction factor for 2% organic matter content is 1.46 (Fig. 6), and the correction factor for 10% slope is 0.66 (Fig. 7). Applying these correction factors, the estimated weight of soil eroded is $0.50 \times 1.46 \times 0.66 = 0.48$ ton per acre.

The standard error of estimate of this equation is 0.455 log unit. The

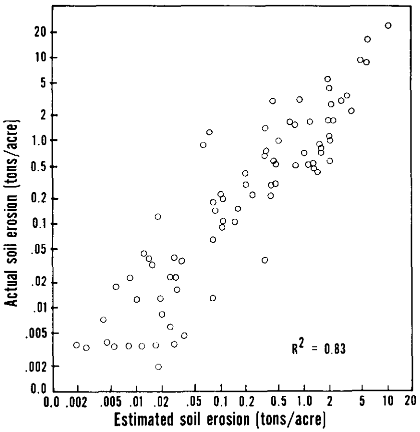

FIG. 8. Soil eroded as estimated by regression and as actually measured, plotted logarithmically.

relation between soil erosion actually measured on the 80 plots and estimated by the regression equation is plotted logarithmically in Figure 8.

Application

Results of this study do not provide absolute values of flood and sedimentation potentials of a watershed under natural rainfall conditions. However, they identify those site factors that exert important influences on both detention of precipitation and soil erodibility, define these relations quantitatively, and indicate how these factors interact. They provide quantitative criteria for estimating site-by-site infiltration and erosional behavior of high-elevation herbaceous watershed lands that are subjected to natural rainstorm conditions approximating those of the simulated rainfall tests. They furnish a basis for comparing the relative flood and erosion potentials of different sites. They also provide a basis for determining the changes in influential site factors that must be achieved by management to insure that flood and erosion potentials considered to be "acceptable" are not exceeded.

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Summer Meeting

The Board of Directors and Advisory Council will hold their official midyear meeting immediately prior to the AIBS Interdisciplinary Meeting, University of Wyoming, Laramie, June 26–27, 1970.