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SOIL STABILITY ON HIGH-ELEVATION RANGELAND IN THE INTERMOUNTAIN AREA

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ABSTRACT

Measurements were taken of the amount of soil eroded from small plots under the impact of a fixed amount of simulated rain. Under these conditions, erosion is more closely related to amount of cover than to any other site characteristic. However, the relation between erosion and cover is strongly influenced by slope gradient. Regression analyses indicated that erosion is about the same on a 5-percent slope with 40-percent cover as it is on a 35-percent slope with 80-percent cover. Organic matter is the most important soil parameter affecting erodibility, but the direction and magnitude of its effects depend on soil texture. Organic matter decreases erosion of clay soils, but tends to increase erosion of sandy soils.

INTRODUCTION

During the past decade, the author has studied infiltration and erosion potentials of seven diverse summer ranges and has related these to cover, soil, and topographic parameters by means of multiple regression analyses. Acceptable regression equations relating infiltration to site factors were developed for three of the areas (Meeuwig 1969, 1970a), but the regression equations developed for the other four lacked precision and contained anomalous relations.

Satisfactory regression equations relating erosion to site factors were developed for each of the seven areas (Meeuwig 1970b). Unlike the infiltration equations, the general relations defined by these equations did not differ greatly from area to area. In essence, these equations indicate that erosion potential (as measured in these studies) depends chiefly on cover and slope gradient; and that differences in the cover-slope-erosion relations, both within and among study areas, are attributable to variations in soil properties, notably organic matter content and texture of surface soils.

This paper reports the results of combining the data from all seven study areas to determine the general influences of cover, slope, soil texture, and organic matter on soil stability over the range of conditions encompassed by these studies.

STUDY AREAS

All the study areas have herbaceous cover and all are grazed by livestock during the summer, except the Davis County Experimental Watershed from which grazing has been prohibited for more than 30 years. Their locations are shown in figure 1. Areas studied were:

1. — *Great Basin Experimental Range*, Manti-LaSal National Forest, central Utah. Elevations of the 162 study plots varied from 7,000 to 10,000 feet. This sheep range has a wide variety of grass and forb species. Soils are mostly silty clay loams and clay loams derived from limestone, shale, and sandstone.

2. — *Davis County Experimental Watershed*, Wasatch National Forest, northern Utah. Elevations of the 80 study plots varied between 8,000 and 9,000 feet. This area was the source of serious floods during the period 1923 through 1930. Much of it was contour trenched and seeded with grass from 1933 through 1936. Grazing has been prohibited since 1933. Soils are mostly silt loams and loams derived from gneiss, schist, conglomerate, sandstone, and shale.

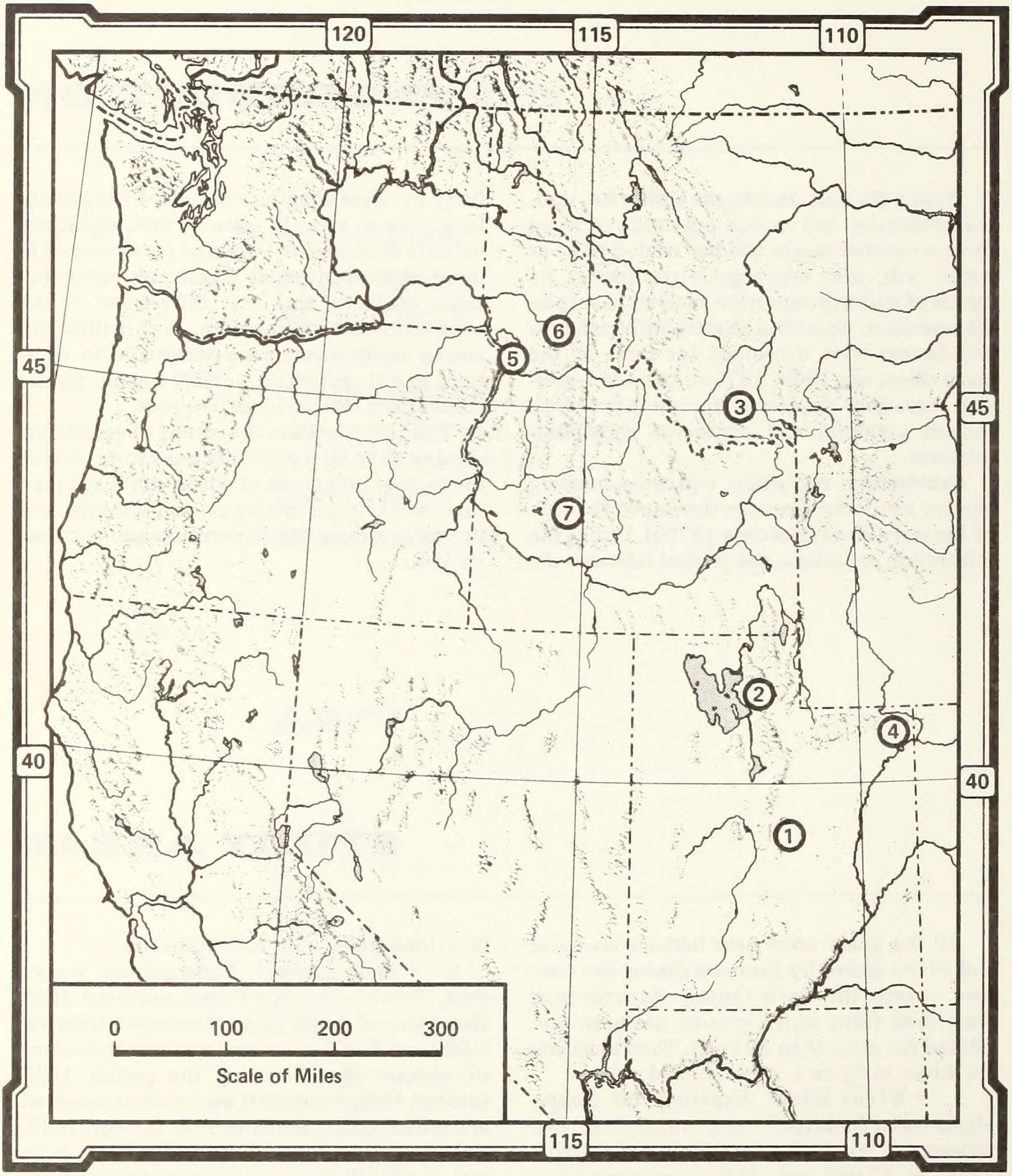

Figure 1. — Locations of study areas.

3. — *Vigilante Experimental Range and Monument Ridge* in the Gravelly Range, Beaverhead National Forest, southwestern Montana. Elevations of the 84 study plots varied between 7,000 and 9,500 feet. This is cattle and sheep range dominated in many parts by Idaho fescue (*Festuca idahoensis*) and in others by native forbs or seeded grasses (mainly *Agropyron desertorum*). Soils are mostly silt loams and silty clay loams derived from red shale, siltstone-shale, and glacial till.

4. — *Diamond Mountain Cattle Allotment* near Flaming Gorge, Ashley National Forest, eastern Utah. This is an experimental grazing area where portions of the native sagebrush-grass vegetation has been replaced by introduced grass species. Soils are loams and sandy loams derived from sandstone. Elevations of the 34 plots were about 8,000 feet.

5. — *The basalt study area* north of Seven Devils, Nezperce National Forest, central Idaho. Forty-five study plots were located in grassy openings in open ponderosa pine stands at about 5,000 feet elevation. Soils are loams and silt loams derived from basalt.

6. — *Coolwater Ridge*, Nezperce National Forest, central Idaho. Elevation of the 15 plots was about 6,000 feet. Vegetation on this deteriorated subalpine range is predominantly forbs of low value insofar as palatability and protection are concerned. The granitic soils are sandy loams and loams.

7. — *Trinity Mountains*, Boise National Forest, southern Idaho. Forty study plots were located in large and small openings in coniferous forest at elevations of about 7,000 feet. The granitic soils, typical of much of the Idaho Batholith, are sandy loams and loamy sands.

MEASUREMENTS

Uniform procedures were followed on all 460 plots involved in this analysis. The plots were 20 inches wide and 30.5 inches long; approximately 1/10 milacre in area. Dortignac's (1951) rain simulator was used to apply 2.5 inches of water to these plots at a constant intensity of 5 inches per hour for 30 minutes. The raindrops produced by this simulator tend to be larger than those of actual thundershowers, but have lower impact velocities. All runoff from the plots was collected and measured. All eroded mineral and organic material, including that deposited in the collecting trough at the bottom of the plot frame and that suspended in the runoff, was ovendried and weighed.

Density of cover on each plot was measured with a point frame (Levy and Madden 1933). First strikes at 100 evenly-spaced points were recorded as plants by species, litter, stone, or bare soil. A day or two after the simulated rain test, vegetation was clipped at the soil surface and litter removed. Vegetation and litter were air-dried and weighed.

The following soil parameters were among those measured:

1. — Antecedent moisture content of the surface 2 inches of soil;
2. — bulk density and capillary porosity of the surface 6 inches of soil;
3. — organic matter content of the surface inch of soil by the dichromate method (Peech 1947);
4. — particle-size distribution (Bouyoucos 1962) and aggregation (Middleton 1930) in the surface inch of soil.

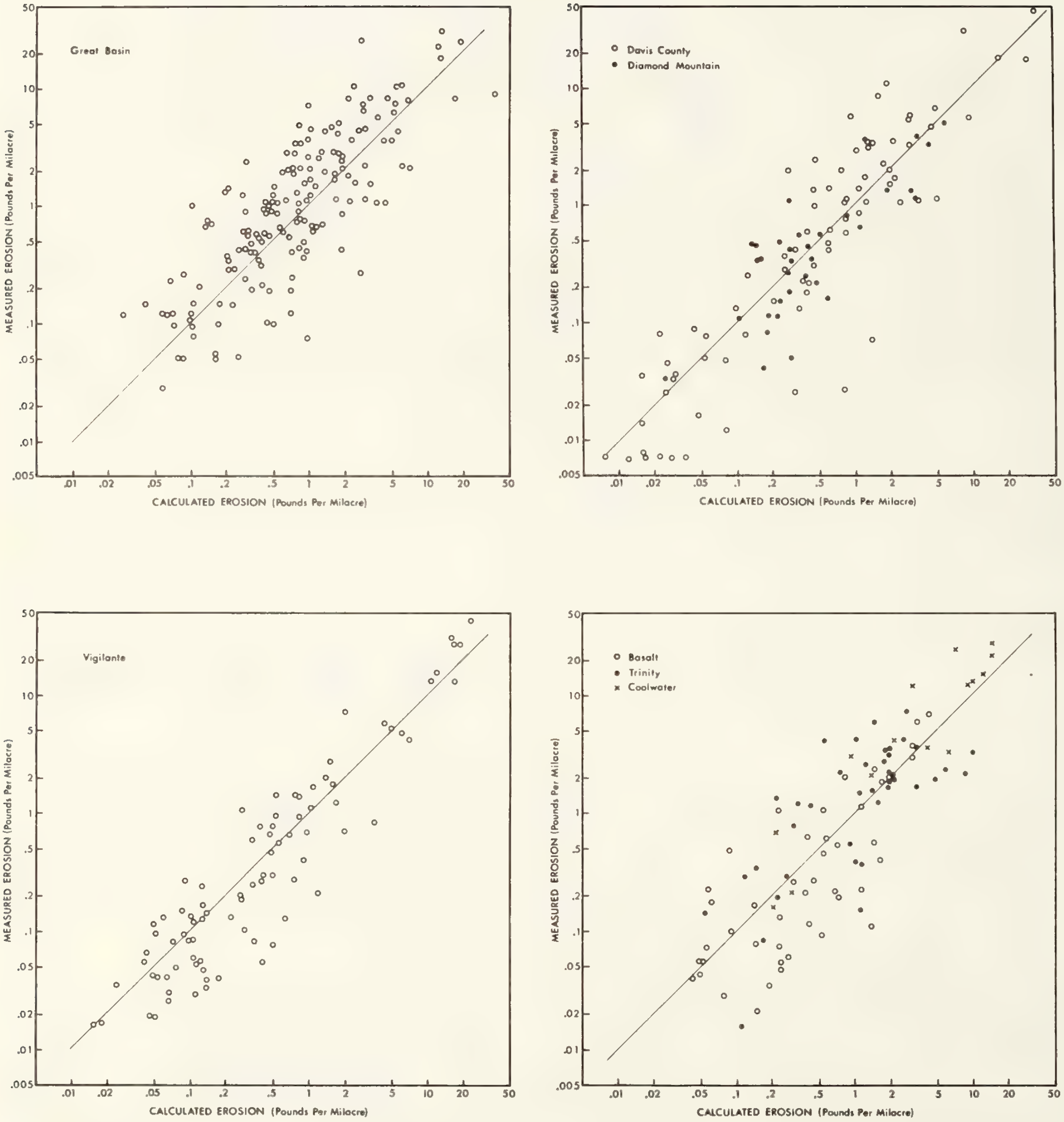

Figure 2. — Calculated and measured erosion of the 460 plots. Study areas are identified to show variation associated with each area.

ANALYSIS

Variables were subjected to preliminary screening during the development of the seven regression equations for the individual study areas. Several site variables that were expected to have a definite influence on erodibility (e.g., aggregation and antecedent soil moisture content) did not appear in any of these equations, and so were not included in the present analysis. Although stone cover materially affected erosion on some of the study areas, it did not prove to be important when the combined data were screened.

Final screening of the combined data was limited to the following parameters, their interactions, and transforms:

- A. — Proportion of the soil surface covered by plants and litter, as determined by first strikes of the point analyzer. It is equivalent to the proportion of soil surface protected from direct impact by raindrops.
- L. — Air-dry weight of litter in pounds per milacre.
- G. — Slope gradient of plot in percent.
- C. — Proportion of the surface inch of soil composed of clay.
- D. — Proportion of the surface inch of soil composed of sand.
- M. — Proportion of the surface inch of soil composed of organic matter.

Variable	Mean	Standard deviation	Correlation with Y
A	0.687	0.247	−0.755
L	1.87	2.22	−.533
G	18.4	8.5	.291
C	.240	.108	.063
D	.295	.210	.059
M	.075	.038	−.473
Y	−.239	.803	--

The dependent variable Y is the common logarithm of the weight (pounds per milacre) of material eroded from the plots during the 30-minute simulated rainstorm. Its average of −0.239 is equivalent to a geometric mean of 0.577 pound per milacre. The logarithmic transformation was used because the distribution of erosion values was skewed. The transformation resulted in a more nearly normal distribution and more nearly homogeneous variance.

Taking into consideration the curvilinear and interactive nature of the relations among the parameters as observed during preliminary analyses, the following regression model was assumed:

$$\hat{y} = \beta_o + \Sigma\beta_i X_i$$

in which the X_i were: A, A^2, A^3, A^4, A^5, A^6, L, L^2, AL, A^2L, A^3L, G, G^2, AG, A^2G, A^3G, C, C^2, D, D^2, M, M^2, CD, CM, DM, M/C, MD/C, MC^2, M^2C, MD^2, M^2D.

These components were screened in a computerized regression analysis designed to select those that contributed materially to the regression model. The following equation resulted:

$$\begin{aligned}\hat{y} = & -.6935 - 6.456\,A^3 + 17.483\,A^5 \\ & -12.403\,A^6 - .0582\,A^3L + .0306\,G \\ & -.0217\,A^3G + 8.21C - 10.59C^2 \\ & -8.45M + .651\,M/C - 1.38CD + 35.48\,M^2D.\end{aligned}$$

The equation explains 74 percent of the variance of the log of erosion. The standard error of estimate (0.42) is difficult to interpret because it is logarithmic. A clearer picture of the deviations from regression is derived when actual erosion and calculated erosion are plotted on logarithmic scales (fig. 2).

This empirical equation should not be applied indiscriminately to specific situations because, after all, it is derived from measurements of erosion caused by a fixed amount of simulated rain on small plots in a few selected areas. In spite of its limitations, this equation provides some indications as to the combined effects of cover, slope, and basic soil properties on soil stability.

COVER AND SLOPE

As found in other studies of a similar nature, erosion on the seven study areas is influenced more by cover than by any other site variable. The magnitude of the effect of cover on erosion depends on slope gradient. The curves in figure 3 are derived from the above regression equation; sand, clay, and organic matter contents of the surface inch of soil are fixed at their respective averages of 30, 24, and 8 percent. Unfortunately, it was necessary to ignore the litter weight term in calculating these curves, but the effects of litter weight will be quantified shortly.

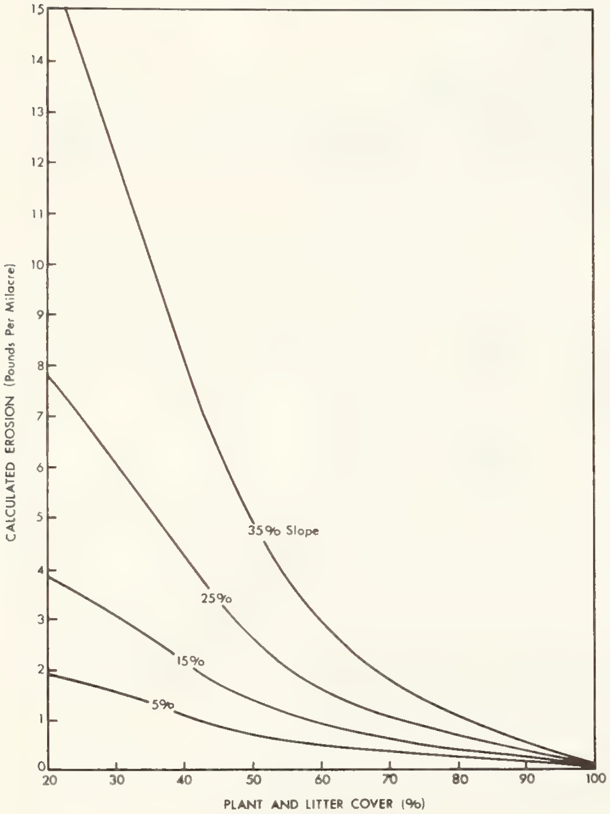

Figure 3. — Erosion calculated as a function of slope gradient and percentage of the soil surface protected by plants and litter. Sand, clay, and organic matter are fixed at their respective averages of 30, 24, and 8 percent.

The effects of cover are greater on steeper slopes. Similarly, slope becomes increasingly important as cover decreases. At less than 50-percent cover, erosion rates double for each 10-percent increase in slope. The amount of cover needed to hold erosion within some specified limit varies widely with variation in slope. For example, 40-percent cover on a 5-percent slope apparently is as effective as 80-percent cover on a 35-percent slope because calculated erosion is about 1 pound per milacre in both cases.

The regression term for litter weight ($-0.058A^3 L$) indicates that weight of litter is not important unless cover is virtually complete (table 1). At 60-percent cover, the presence of 1 pound of litter per milacre reduces estimated erosion to 97 percent of the value shown in figure 3. At 100-percent cover, the same amount of litter reduces erosion to 87 percent. Twelve pounds of litter per milacre with 100-percent coverage reduces estimated erosion to one-fifth that shown in figure 3. Thus, litter weight serves mainly to explain variations in erosion when cover is complete or nearly so. So far as soil stabilization is concerned, however, ground coverage provided by litter is much more important than its weight.

Table 1. — Correction factors for litter weight

Cover (percent)	Air-dry weight of litter				
	Pounds per milacre				
	1	2	4	8	12
	- - - Correction factors - - -				
60	0.97	0.94			
70	.96	.91	0.83		
80	.94	.87	.76	0.58	
90	.91	.82	.68	.46	0.31
100	.87	.76	.58	.34	.20

SOIL TEXTURE AND ORGANIC MATTER CONTENT

Sand, clay, and organic matter contents of the surface inch of soil were arbitrarily fixed at their average values to calculate the curves in figure 3. Variation within these parameters can cause estimated erosion to vary from less than half to more than twice the values shown in figure 3. Effects on erodibility are produced by these soil components operating together in a complex manner only approximated by the regression model presented in this paper. However, some general trends can be detected (see fig. 4) and are listed below:

1. — If organic matter is low, clay is more erodible than sand.
2. — Erodibility of clay is inversely related to organic matter content.
3. — Erodibility of sand tends to increase with increasing organic matter, especially if the soil contains less than 10-percent clay.
4. — If organic matter content is high, sand can be more erodible than clay.

Of particular interest is figure 4A which shows relative erodibility as a function of organic matter and sand contents at a constant clay content of 10 percent. Erodibility is about half that of average soil if organic matter does not exceed 8 percent or if sand does not exceed 30 percent. When both sand and organic matter exceed these percentages, a further increase in either sand or organic matter results in increased erodibility.

The apparent adverse effects that organic matter has on stability of sandy soils are believed to be real because comparable relations appeared in the three individual regression equations for Diamond Mountain, basalt, and Trinity Mountains study areas. This phenomenon is believed to be linked with water repellence, which has been observed to occur mostly in sandy soils and to be related to organic matter (Krammes and DeBano 1965). Organic coatings profoundly affect the interfacial energy of soil particles. Organic coatings on soil particles reduce the affinity those particles have for water to such a point that positive pressure may be required to force water into the soil (Fink 1970). These coatings may also reduce the forces of attraction between sand particles to such an extent that they repel one another and increase their erodibility.

Clay tends to reduce or eliminate the adverse effects of organic matter on sand. One or more of the following mechanisms may be responsible:

1. — Organic matter is known to favor aggregation of clay. Perhaps the stabilizing effects of organic matter on clay compensate for its deleterious effects on sand.
2. — Clay reduces the amount of organic matter available for binding to sand particles because it has a much greater surface area per unit weight than sand and a greater capacity to bind organic matter.
3. — Clay may form the necessary link for the aggregation of sand particles. Although the organic molecules on adjacent sand particles form no bonds with each other, they may form weak bonds with adjacent clay particles.

The foregoing is, of course, pure speculation but it points out the need for further research into these phenomena and suggests the possibility of the use of soil amendments to stabilize organic sands.

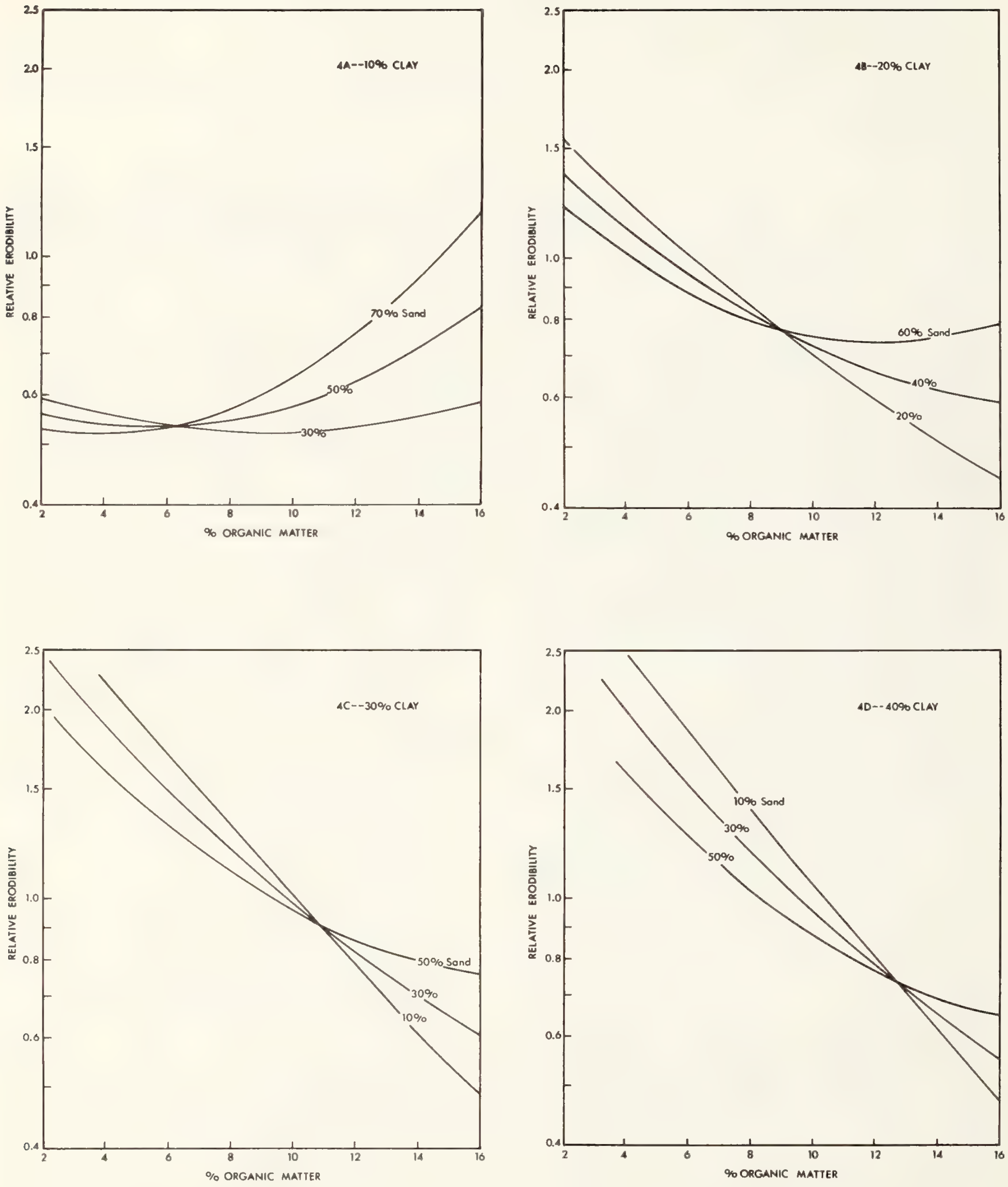

Figure 4. — Relative erodibility as influenced by variations in sand, clay, and organic matter content of the surface inch of soil. Relative erodibility is the ratio of calculated erosion corrected for sand, clay, and organic matter to calculated erosion at average sand, clay, and organic matter.

CONCLUSIONS

Unless plant and litter cover is virtually complete, erosion potential is strongly affected by slope gradient and the amount of cover required to limit potential erosion to some specified amount is substantially greater on steep slopes than on gentle slopes.

Soils vary in their susceptibility to erosion. The most erodible soils are those with high clay, low sand, and low organic matter contents. The combinations that appear to be least erodible are soils that have:

1. — High clay, low sand, and high organic matter contents;
2. — low clay, high sand, and low organic matter contents; or
3. — low clay and low sand contents, regardless of organic matter content.

Apparently, the generalization that organic matter favors soil stability is not universally true. Erodibility may increase with increasing organic matter content in very sandy soils. This poses a difficult problem for management of such soils; sufficient cover must be maintained but at the same time, excessive accumulation of soil organic matter discouraged.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
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