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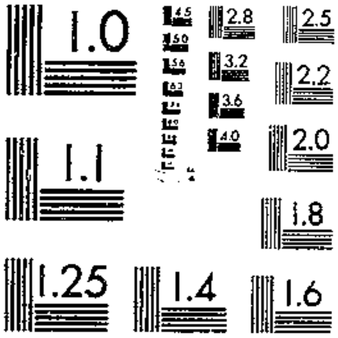

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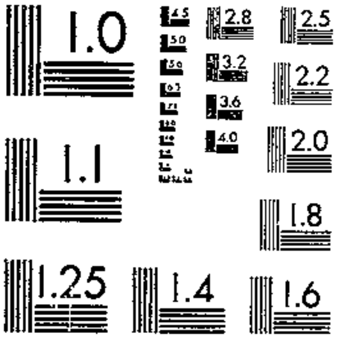

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Erodibility Investigations on Some Soils of the Upper Gila Watershed[1]

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CONTENTS

INTRODUCTION

In the course of an erosion survey of the upper Gila watershed of Arizona and New Mexico, it was noted that soils from granite and recent sedimentary materials were damaged much more by accelerated erosion than the soils developed from quartzite. It was noted further that in the higher parts of the watershed soils originating from both basalt and limestone were resistant to erosion whereas in the lower parts of the watershed soils from basalt were moderately damaged and those from limestone were severely damaged.

Because this area is and has been under the management of a number of different ranches and public agencies and because the soils occur on a variety of slopes and in scattered and interspersed bodies, it is assumed that the range vegetation has been utilized similarly, and that the major variations are due to either soil properties or topography. Because of the similar treatment and occurrence of these soils it was concluded that the differences in erosion were due to inherent soil properties or those very closely associated with the soil. This study was undertaken in an effort to determine what soil factors were chiefly responsible for these differences in erosion and to formulate a

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standard by which the erodibility[3] of the soils of this area might be compared.

PREVIOUS WORK

In 1911, McGee *(28)*[4] concluded after a study of erosion that it might vary as some power of the slope (about the eighth is suggested) but that no one equation would fit all soils.

Duley, Ackerman, Hays, and Miller (*17, 18, 19, 20*) working with soils from the Middle West found: That in intense rains a barren soil spaded to a depth of 4 inches gave less run-off and more soil loss than the unspaded soil, but that both run-off and soil loss decreased when the soil was spaded to a depth of 8 inches; that on slopes under 10 percent a sandy loam is less erodible than a silty clay loam but more erodible on steeper slopes; that if soil loss in tons per acre is plotted against slope the resulting curve is of exponential form; that in rains of high intensity on these soils run-off was greater from the short plots and erosion was greater from the long plots, whereas in rains of low intensity both the run-off and erosion were greater from the short plots. They stated that erosion of these soils caused a relative increase in the concentration of silica, iron, manganese, and phosphorus, and a loss of calcium, sulfur, potassium, and sodium.

Middleton, Byers, and Slater *(30, 31, 32, 33)* found in studying soils from all over the United States that the soil characteristics giving the best correlation with erodibility were: Dispersion, ratio of colloid to moisture equivalent, erosion ratio, and the silica sesquioxide ratio. They decided that none of these characteristics was infallible as a criterion of erodibility but that the erosion ratio was probably the best derived relation and the most potent single factor was probably the dispersion ratio. They studied the relations of these factors to the soils from the erosion experiment stations together with other properties such as kind and amount of colloid, settling volume, and saturation capacity. Saturation capacity they defined as the water content of the soil at settling volume.

Miller and Krusekopf *(34, 35)* confirmed the results of Duley and Miller *(20)* and showed that there is a greater loss of sand from uncropped plots than from those in vegetation.

Breazeale *(10)* in his study of the Colorado River silt showed that the silt was in a dispersed condition, containing a fairly large amount of replaceable sodium. He observed that the silt was probably in this dispersed condition in the soil even before it got into the river, and that the quality of the water as well as the velocity should be taken into consideration in estimating its load-carrying capacity.

Conner, Dickson, and Scoates *(13)*, and Bennett *(3)*, showed that cultivation, or anything that tends to reduce the compaction of the soil, decreases the surface run-off, but in rains of high intensity cultivation increases the amount of erosion. In addition Conner, Dickson, and Scoates *(13)* stated that erosion plotted against slope gives a curve that is somewhat linear below slopes of 3 percent but that run-off is not linear over the same slope range. Besides, Diseker and Yoder *(15)* found that continuous storms of a given intensity cause more erosion than intermittent storms, and that aggregates more

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[3] In this paper erodibility (erosibility) is the relative ease with which one soil erodes under specified conditions of slope as compared with other soils under the same conditions. This applies to both sheet and gully erosion.

[4] Italic numbers in parentheses refer to Literature Cited, p. 20

often than single grains are removed from Cecil clay by erosion. Bennett (*4*) states that in the tropics, a low silica sesquioxide ratio goes with a stable physical structure whereas a high ratio is associated with structural instability.

Bouyoucos (*8*) suggested the use of the "clay ratio," sand plus silt divided by the clay, as a possible criterion of erodibility of soils and calculates these ratios for the erosion experiment station soils from the results of Middleton, Slater, and Byers (*28, 30, 31*) to substantiate his contention.

Lutz (*25, 26*) concluded that the nonerodible character of Davidson clay is due to the high degree of aggregation of the B horizon, and that the erodible character of Iredell clay is due to its ease of dispersion and to the impervious nature of the B horizon; that all Davidson colloids are flocculated regardless of what cation is in the complex; that hydration and not charge is responsible for the difference in properties of Davidson and Iredell colloids; and that any physical property that influences permeability or dispersion is a paramount factor in erodibility.

Lowdermilk (*23, 24*) showed that debris or erosion pavement decreases erosion damage on any soil and in addition he gave a criterion for judging erosion damage.

Murphy and Daniel (*36*) showed that Solonetz soils in Oklahoma give a dispersion coefficient[5] averaging 4.29 as compared to the value 0.96 for normal soils. They attributed the erodible nature of the Solonetz soils to the impervious nature of the B horizon, which results in the rapid supersaturation of the loose A horizon, its becoming comparatively fluid and its moving off as a mud flow.

Musgrave and Free (*37, 38, 39, 40*) stated that infiltration is an inherent property of the soil but that it may be altered by treatments such as cultivation. They give the factors that may influence the infiltration rate as follows: Porosity per unit of soil in any one soil, and the ease with which the soil is dispersed in water. They stated that for low-intensity rains, short slopes give a greater percentage of run-off and less erosion than long slopes. In highly intense rains the run-off and erosion are both greater on the long slopes.

After a survey of the Boise River watershed Renner (*44*) concluded that coarse-textured soils erode most easily.

Slater and Byers (*46, 47*) found that the suspension percentage,[6] the percentage of silt, and the percolation ratio[7] follow the inverse order of the permeability. They found that the base exchange capacity of the colloids from the erosion experiment station soils increases as the amount of leaching in nature decreases, the capacity varying from 9.7 milliequivalents per 100 g. of colloid in the Cecil C horizon to 88.1 milliequivalents per 100 g. in the Houston clay subsoil. The base capacity of the organic matter extracted from these soils by dilute ammonia was very high, but it did not vary with the climate under which the soil was developed.

In studying the soils of the Cecil series, Yoder (*50*) found that the size distribution on aggregate analysis follows series lines but that the

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[5] The dispersion coefficient is defined as the number of centigrams of soil per 100 cc. left in suspension in the top 5 cm. after settling 24 hours, if 4 gm. of soil had originally been shaken in 400 cc. for 24 hours with distilled water.

[6] The suspension percentage is the percentage of silt plus clay in suspension in distilled water after being shaken end over end 20 times where the soil-water ratio is 1 of soil to 100 of water.

[7] The percolation ratio is the suspension percentage divided by the ratio of the colloid to the moisture equivalent.

coarser members of the series are more highly dispersed. From Yoder's data the dispersion ratios of the soil washed from the different slopes can be calculated. Their values are:

Slope of —	*Dispersion ratio of soil from*
0 percent	65.4–75.4
5 percent	38.6–41.8
10 percent	25.0–27.2
15 percent	31.3–32.0
20 percent	32.1–32.5

It might be noted that the dispersion ratio on the flatter slopes is high and that there is no great change for slopes greater than 10 percent. This slope probably approximates what Nichols and Sexton (*41*) term the critical slope for the Cecil soil studied by Yoder.

Nichols and Sexton (*41*) confirmed the findings of earlier workers that decreasing the compaction of a given soil increases the erosion and decreases the run-off in intense rains. They suggest that all soils have a critical slope above which the rate of soil lost per unit of slope increases greatly. This suggestion is borne out by Yoder's data above.

Hendrickson (*21*) found that if silty water is applied to a soil, the infiltration rate is lowered in proportion to the fineness of the silt. The silty water also causes an increase in erosion.

PROCEDURE

This investigation is divided into two parts: (1) An examination of erosion-survey data in an attempt to correlate the erodibility of soils with their field characteristics and to set up a standard for evaluating the erodibility, and (2) laboratory investigations of the physical and chemical characteristics of the soil types that were selected for special study.

EXAMINATION OF EROSION-SURVEY DATA

Field Observations

A survey of the upper Gila watershed revealed that, aside from the extremely mountainous parts, most of the soils are members of one of two great groups by Marbut's classification (*29*). Soils of the lower elevations are members of the southern Gray Desert group and those lying above 3,500 to 4,000 feet are of the southern Brown soil group.[8] Because the soils may be classed in more than one soil group, it is desirable to have some means of comparing the soils of the area as a whole without undue emphasis on the soils of either group. With this in view, a number of methods were tried with little success until the mean percent erosion[9] for each soil type was plotted against the slope on which the soil occurred. Measuring the areas of Mangus stony loam shown in figure 1 with a planimeter showed that on slopes from 0 to 3 percent, 1.18 square miles had little or no erosion, 0.56 square miles had up to 5 percent erosion, and 1.95 square miles had 5 to 15 percent erosion. On slopes from 3 to 10 percent, 0.12 square miles had 0 to 5 percent erosion and 4.24 square miles had 5 to 15 percent erosion.

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[8] Southern Gray Desert soils have been renamed Red Desert soils; southern Brown soils have been renamed Reddish Brown soils (*1*, pp. 989 and 993).

[9] Percent erosion is equal to the percentage of soil removed from the solum (A, B, and C horizons) whether in a mature or an incipient stage, or not well-defined.

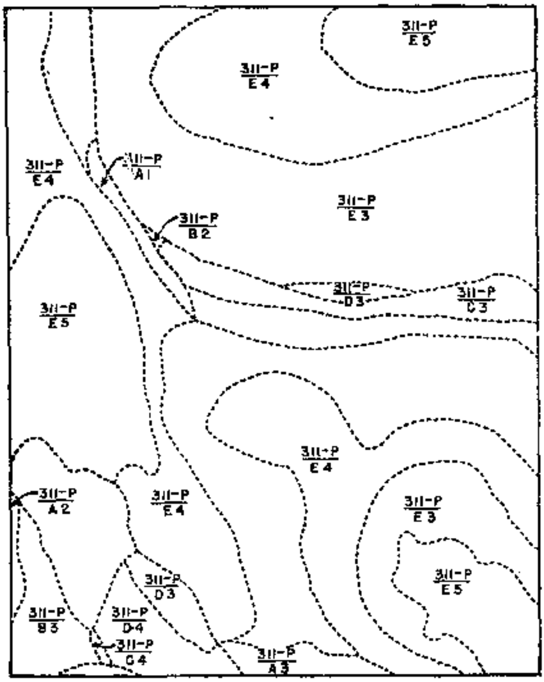

FIGURE 1.—Hypothetical map of a pasture- or range-land area on Mangus stony loam: The capital letters represent slope: A, 0–3 percent; B, 3–10; C, 10–20; D, 20–35; and E, 35 percent and over. The numbers represent percent erosion: 1, no erosion; 2, 0–5 percent; 3, 5–15 percent; 4, 15–60 percent; and 5, 60–100 percent.

The midpoint of both the slope and erosion classes was chosen to represent the class. The mean percent erosion was calculated as follows:

For the slope range of 0 to 3 percent—

$$\frac{(1.18\times 0.00)+(0.56\times 2.5)+(1.95\times 10)}{1.18+0.56+1.95}=5.66$$

For the slope range of 3 to 10 percent—

$$\frac{(0.12\times 2.5)+(4.24\times 10)}{0.12+4.24}=9.79$$

The mean percent erosion for the other slopes was calculated in identical manner. These means were plotted against the mean slope as in figure 2. The curves obtained for Whitetail gravelly loam, Karro gravelly loam, Chualar gravelly sandy loam, and Catron gravelly loam and clay loam are shown in figure 3. These curves take the same general form as those obtained by Duley and Hays (*19*), Conner, Dickson, and Scoates (*13*), and Yoder (*51*) in plotting tons per acre of soil loss against slope.

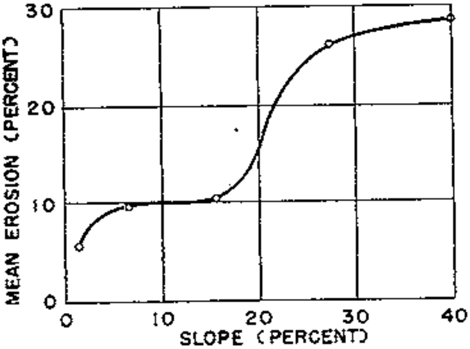

FIGURE 2.—Mean percent erosion compared with slope on Mangus stony loam.

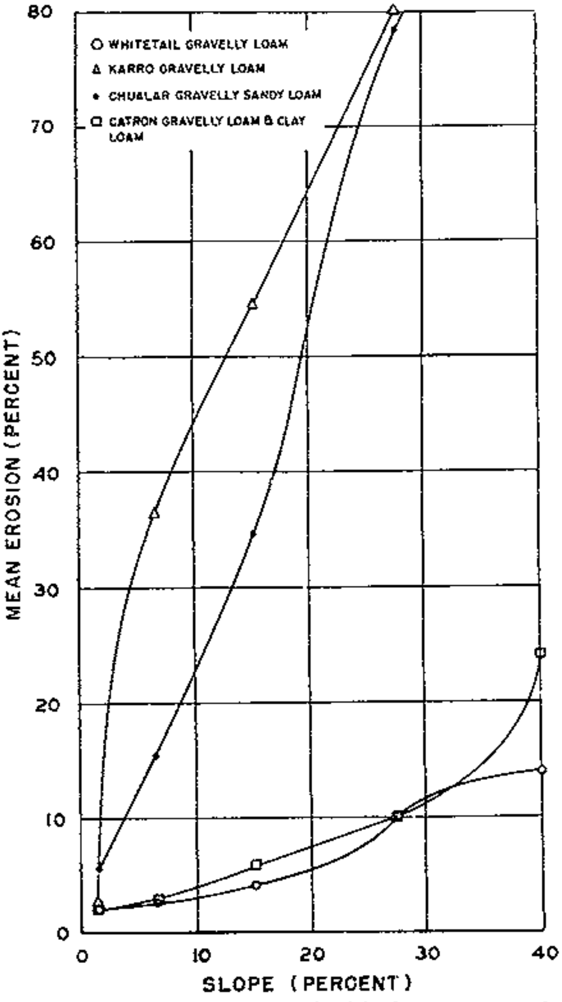

FIGURE 3.—Mean percent erosion compared with slope on several representative soils.

ERODIBILITY INTEGRALS

The term erodibility (erosibility) has been widely used to mean susceptibility to erosion, but no units or means of expressing this quantitatively have been used. Loose usage of the terms erodible and nonerodible makes difficult a quantitative correlation of various factors with erodibility. For this investigation the definition of erodibility (*E*) shall be: The percent erosion per unit of slope over a specified range of slopes. Although this value *E* can be determined from curves (figs. 2 and 3), it is not so readily nor so accurately determined as the area under the curve. Since the area under a curve is the integral, the area under the erosion-against-slope curve will be called the erodibility integral throughout this paper. The erodibility integral (*EI*) may be found by measuring the area under a curve with a planimeter. In this study the integral is expressed in units: 10-percent slope × 10-percent erosion=1 unit. It is readily seen that whenever the slope is held constant, *E* is equal to a constant times *EI*. In other words, the erodibility integral is just as much an index to the behavior of the soil as the erodibility under these conditions.

PROPERTIES INFLUENCING ERODIBILITY

Study of a large number of curves similar to figures 2 and 3 and their integrals brought out several interesting relationships between soil properties as observed in the field and erodibility as expressed by the integrals. It emphasized the influence of parent material on erodibility. By plotting the average percent erosion on all soils from the same parent material against the slope, these relations are clearly shown. The curves are shown in figure 4 and their erodibility integrals in table 1.

TABLE 1.—*Erodibility integrals of soils from different parent materials*

Parent material	Erodibility integrals	
	Desert soils	Brown soils
Quartzite	6.8	3.7
Basalt	12.8	3.4
Rhyolite	10.0	4.8
Limestone	14.8	3.2
Granite	9.9	9.9
Mixed	12.5	----------

The drop in erodibility as soils develop under more humid conditions will at once be seen. In soils developed from limestone, all the difference cannot be attributed to climate since the particular limestones studied differ in composition. The limestone in the Brown-soil area is very high in sesquioxides and low in lime, whereas the reverse is true for the limestone from the Desert-soil area. In line with past work on erodibility and the results of this investigation, this difference in composition alone would account for much of the difference in the erodibility of the limestone soils from the two soil groups. The parent materials from which the other soils were derived are very similar in both areas.

This variance of soil erodibility with parent material is in agreement with Musgrave's findings (*37*), which reveal that infiltration is an inherent property of the soil and has marked influence on the amount of erosion.

The curves for the individual soils indicated that coarse-textured were more erodible than finer-textured soils. To investigate this relationship, the soils were divided into two classes based on (1) the size of the rock particles contained in them, and (2) on difference in texture.

Of the 24 pairs of class 1, in which one member of the pair was rocky and the other was gravelly,[9] 22 showed less erosion in the gravelly member than in the rocky member, and 2 pairs showed equal or more erosion in the gravelly member. The averages of the erodibility integrals of this group classed according to the soil texture are shown in table 2. These differences in the erodibility integrals with rock and gravel are highly significant[10] and they are in accord with the indications cited in the past by Lowdermilk (*23*) and others.

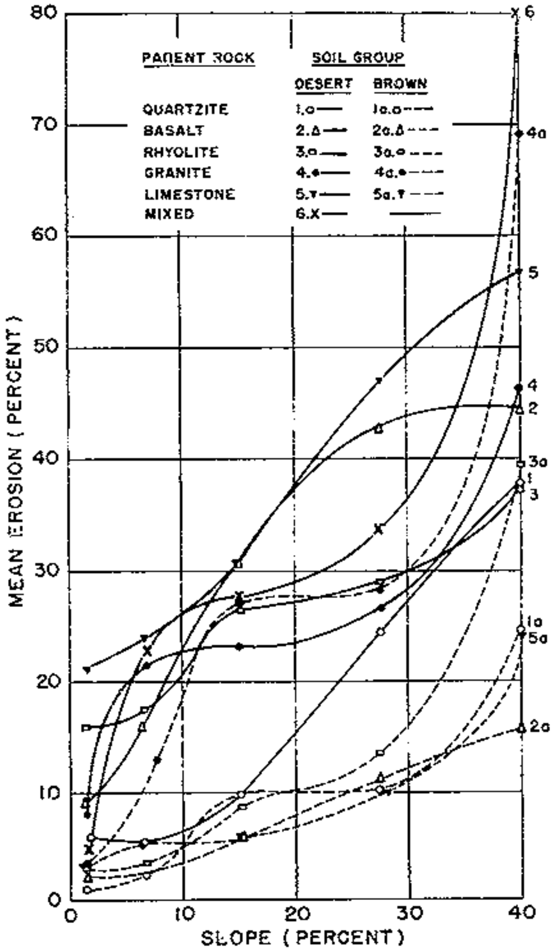

FIGURE 4.—Mean percent erosion compared with slope for soils derived from different parent rock materials.

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[9] Soil having rock particles larger than 4 cm. in diameter was classed as rocky and soil having particles between 4 cm. and 2 mm. was classed as gravelly.

[10] Significance was tested by Brandt's method (*9*).

The type of erosion pavement formed by gravel and rock might offer an explanation for the difference in erodibility for soils covered by them. The effect of this pavement has been outlined by Lowdermilk.

TABLE 2.—*Erodibility of soils of different textural classes*

Textural class	Erodibility integrals	
	Gravelly soils	Rocky soils
Sandy loams	7.2	9.3
Loams	5.8	7.5
Clay loams	1.7	3.1
Average, all textures	6.0	7.9

Of the 11 pairs of class 2 in which one member of the pair was sandy loam and the other loam, the sandy loam member of 9 pairs showed more erosion than the corresponding loam, and the loam member of only 2 pairs showed equal or more erosion than the sandy loam. In all 6 pairs of class 2 in which one member was clay loam and the other loam, the clay loam member showed less erosion than the loam. The erodibility integrals averaged for each class are shown in the following tabulation:

Erodibility integrals for—	
Sandy loams	10.6
Loams	7.4
Clay loams	5.8

Apparently these soils increase in erodibility as the texture becomes coarser. This observation is substantially in agreement with the findings of other investigators (*19, 30, 32, 33, 43, 44*). The use of the "clay ratio" as a criterion for judging erodibility from laboratory analyses by Bouyoucos (*8*) agrees with these findings.

Further examination showed that the curves for the individual soils fell into two definite groups, those with erodibility integrals much above 8.0 and those with integrals much below 8.0. Because such a marked separation was apparent and because the terms erodible and nonerodible have been much used, it was decided arbitrarily to call all soils with erodibility integrals above 8.0 erodible and those with integrals below 8.0 nonerodible. It is recognized that under other slope ranges and other soil and climatic conditions this limit would probably change.

LABORATORY INVESTIGATIONS

The soil types chosen for investigation in the laboratory and their erodibility integrals are as follows: Whitetail gravelly loam, 2.6; Karro gravelly loam, 24.2; Chualar gravelly sandy loam, 19.8; Catron gravelly loam and clay loam, 3.2. These soils were chosen because they represented (1) the two great soil groups of the area, (2) those soils high in lime and those low in lime, (3) those soils high in iron and those low in iron, and above all, (4) those soils erodible and those nonerodible (figs. 5 and 6).

The samples were obtained on locations that were as representative of the respective soils as possible. The locations are shown in figure 7, and samples were taken on the following dates: Whitetail gravelly loam, August 24, 1936; Karro gravelly loam, September 5, 1936; Chualar gravelly sandy loam, February 25, 1937, and Catron gravelly loam and clay loam, February 25, 1937.

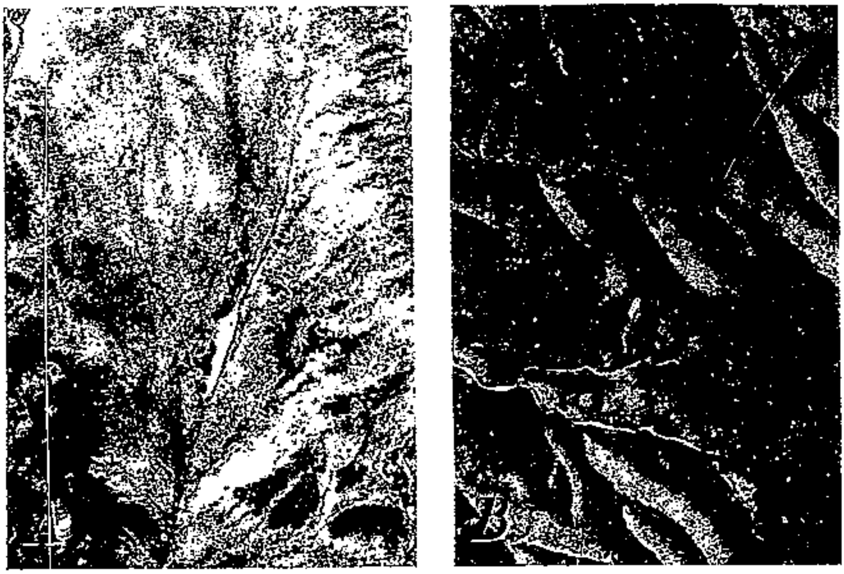

FIGURE 5.—*A*, Area containing body of Whitetail gravelly loam in upper and central part of picture. Smooth relief and lack of finger gullies are to be noted. *B*, Areas of Catron gravelly loam and clay loam. Steeply rolling topography with rounded hills indicate little erosion. Aerial photographs by Fairchild.

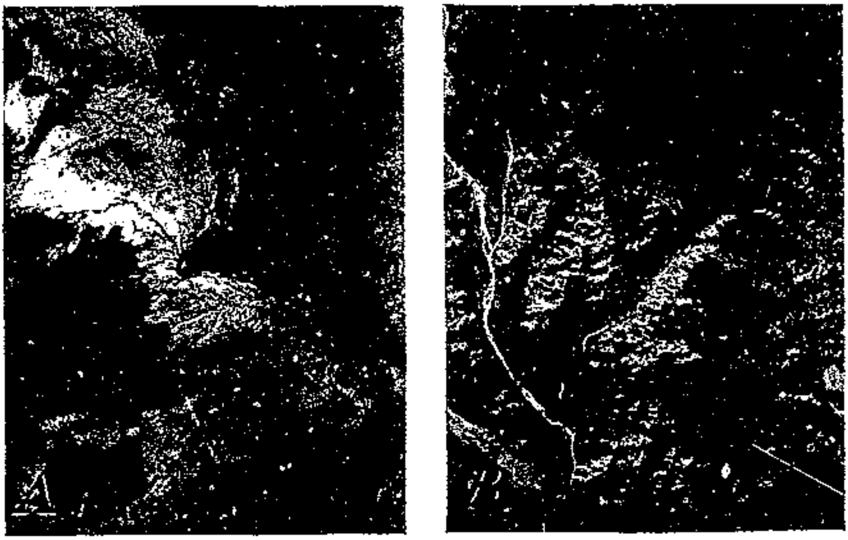

FIGURE 6.—*A*, Karro gravelly loam is shown in light-colored areas along alluvial flats of drainageways. Note the severe finger gullies of recent origin throughout the soil body. *B*, Area of Chualar gravelly sandy loam. Note the angular relief developed as a result of rapid erosion. Aerial photographs by Fairchild.

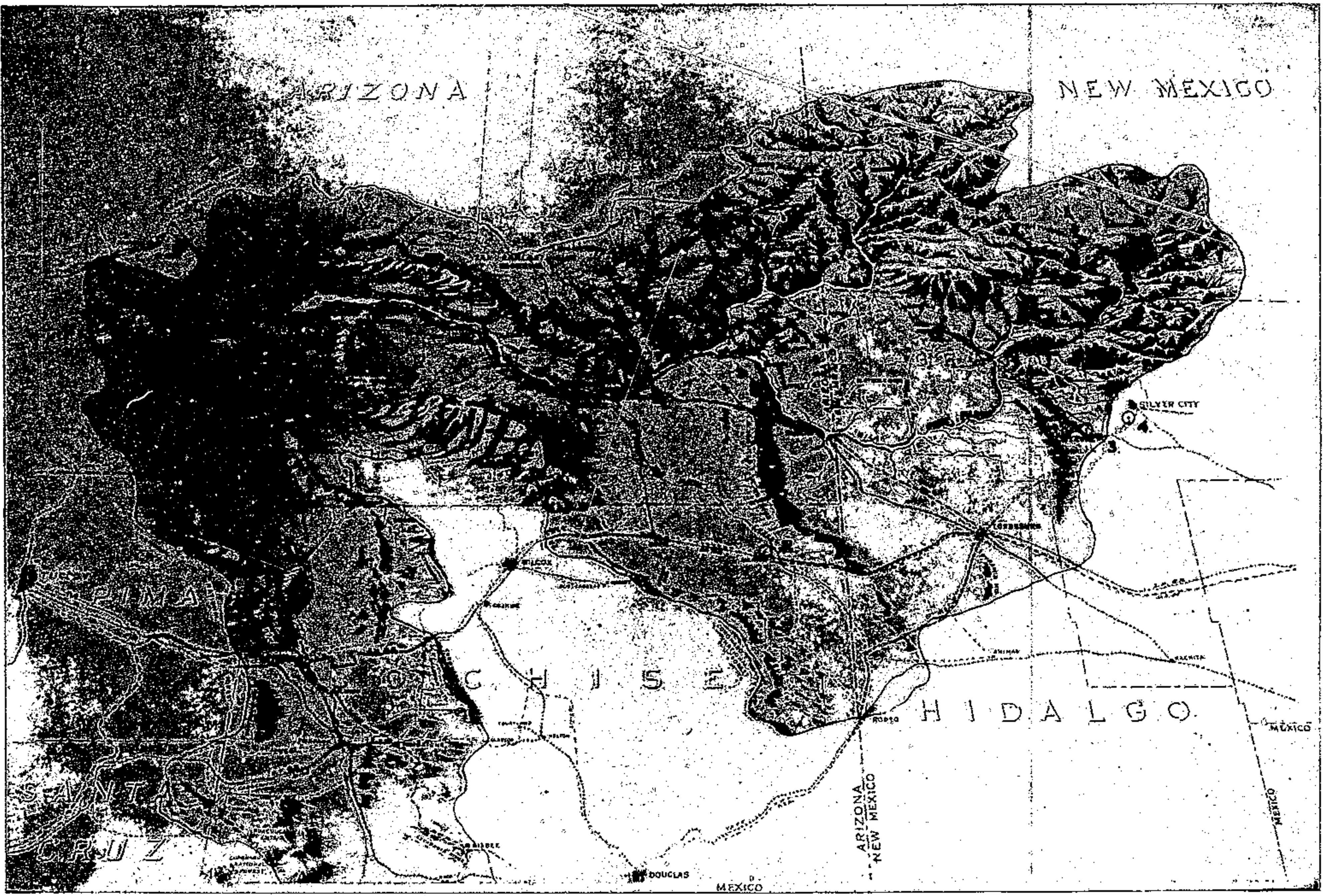

FIGURE 7.—Watershed of the Upper Gila and San Pedro Rivers showing location of samples (1) Whitetail gravelly loam; (2) Karro gravelly loam; (3) Chualar gravelly sandy loam; and (4) Catron gravelly loam and clay loam.

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On June 6 and 7, 1937, two or more samples were taken of each soil in the undisturbed state. These samples were obtained by use of brass cylinders of different lengths, machined on the outside to a long bevel to prevent compaction or disturbance of the soil as the cylinder was being forced by use of a hydraulic jack into the profile to the desired depth. The cylinders were dug out with a shovel and lids fitted snugly on each end to insure safe transport to the laboratory.

DESCRIPTION OF SAMPLES

WHITETAIL GRAVELLY LOAM

The Whitetail gravelly loam soils were formed on old alluvial fans from valley-filling materials derived mainly from quartzite rock and under semidesert conditions and mixed shrub and desert grassland type of vegetation (fig. 8, *A*). In occurrence and general character of profile they resemble the White House series, from which they are differentiated by geologic origin and by the deeper surface soil and brown subsoil and by the less massive and calcareous character of the deeper red materials. The sample consists of:

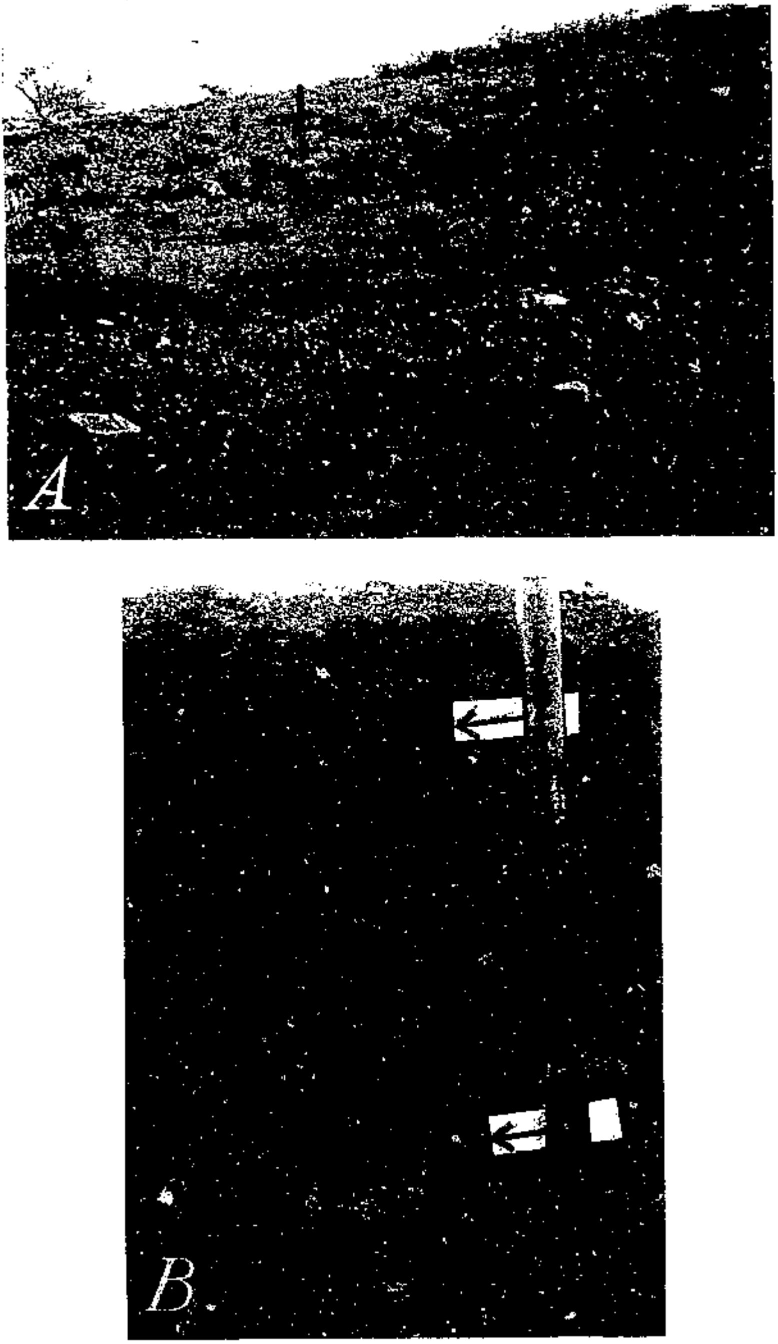
1. Pale reddish brown gravelly loam, noncalcareous, friable, and low in organic matter. This layer in the sample was 4 inches in depth, which is slightly less than typical for this soil (fig. 8, *B*).
2. Compact, brown, noncalcareous loam with prismatic structure. This layer extends to a depth of 18 inches.
3. Dark dull-red clay loam, calcareous and gritty in texture, intermixed with quantities of small angular fragments of parent rock. Its structure is compact but breaks down readily into small nutlike clods. At 24 inches this layer grades into:
4. Red-brown gravelly material of looser character that is generally calcareous.

The relief at the locality where the sample was taken is smooth, but incised stream channels give the appearance of gently rolling hills. The native vegetation consists of desert grasses, mainly black grama and rothrocks grama with annuals and a few shrubs. The soil is used only for grazing for which it is quite well adapted.

KARRO GRAVELLY LOAM

The Karro gravelly loam has developed from old valley filling deposits that were laid down in a playalike area and have been greatly modified by weathering and accumulation of lime. This soil type is confined to the lower terraces and comparatively flat parts of the valley troughs. The surface is smooth and gently rolling to flat and is badly cut in places by sheet and gully erosion. Under natural conditions surface drainage is poor, and internal drainage is retarded by the impervious nature of the subsoil (fig. 9). The sample consists of:

1. Light, brownish-gray gravelly loam, low in organic matter, and highly calcareous, with here and there small nodules of lime; the surface has a mulchy structure overlain with a thin crust commonly saline. The loam extends in two similar layers to a depth of 12 inches.
2. Light-gray, granular clay loam, very highly calcareous with lime nodules disseminated throughout, and slightly more compacted than the surface. This layer extends to a depth of 24 inches.



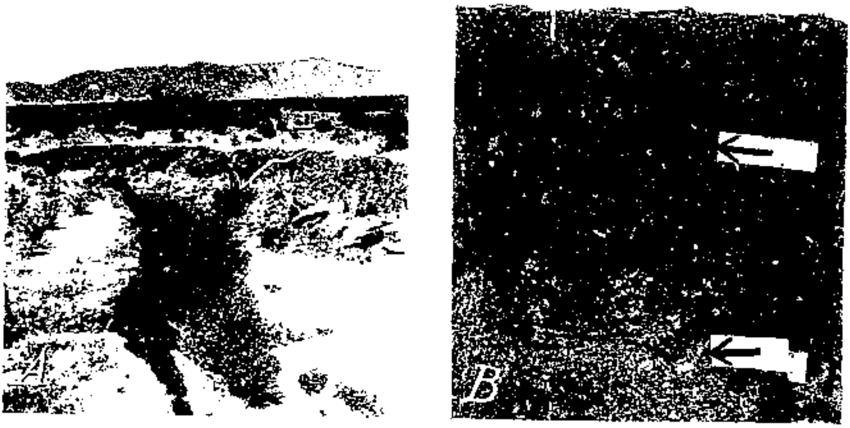
ARIZ-R-143; ARIZ R-142

FIGURE 8. *A*, Erosion on Whitetail gravelly loam. Note the protective erosion pavement formed on this soil. *B*, Profile development on Whitetail gravelly loam.

3. Very light-gray almost white granular clay loam that is more than half lime. This layer is of low compaction even though it is very impervious to water. It extends to a depth of over 36 inches. The native vegetation of this soil consists of various salt bushes, mesquite, crucifixion thorn, three-awn grasses, and annual weeds and grasses of various kinds. The land is utilized for grazing, for which it is poorly suited.

CHUALAR GRAVELLY SANDY LOAM

The soils of the Chualar series developed on the upper fans from pinkish-colored granite and under a cover of mixed grasses and shrubs (fig. 10, *A*). The soils are generally shallow and often stony. The sample is as follows:



ARIZ-3477. ARIZ-R-44

FIGURE 9. *A*, Erosion on Karro gravelly loam. Note the severe gullying. *B*, Profile development on Karro gravelly loam.

1. Dull reddish-brown, noncalcareous sandy loam that has a small organic-matter content and contains a quantity of fine gravel. The surface soil grades rather abruptly into the subsoil at a depth of 3 inches (fig. 10, *B*).

2. Dull brownish-red, very compact, noncalcareous gravelly clay loam, extending to a depth of 7 inches.

3. Dull brownish-red, very compact, calcareous, gravelly clay loam, extending to a depth of 21 inches.

4. Pinkish-brown decomposed granitic material that is mildly calcareous and similar in texture to the surface soil.

The topography is rolling to hilly and mountainous and is marked by sheet erosion and moderate gullying. The native vegetation consists of blue, hairy, and side-oats grama grasses, beargrass, juniper, and several species of oak. The land is utilized for grazing for which it is only fairly well suited.

NM R J. NM-R-4

FIGURE 10.—*A*, Erosion on Chualar gravelly sandy loam. Note the beginning of small shallow gullies in the foreground. *B*, Profile development on Chualar gravelly sandy loam showing very compact B horizon.

CATRON GRAVELLY LOAM AND CLAY LOAM

The soils of the Catron series developed on a bedrock substratum of limestone in elevated desert grassland and juniper areas (fig. 11, *A*). The soils generally are shallow and frequently stony and the soil profile in many places is imperfectly developed. The sample is as follows:

1. Dark purplish-brown loam with some organic matter incorporated in it. Its gravel is made up to some degree of ferromanganite concretions residual from the parent rock. It is mildly calcareous and very friable. It extends to a depth of 2 inches (fig. 11, *B*).
2. Dark reddish-brown gravelly clay loam. Compact, calcareous, and containing concretions and angular fragments of the underlying bedrock, it breaks into a cloddy structure. At a depth of about 16 inches it grades into the parent bedrock of purplish ferromanganiferous limestone.

The topography is rolling to hilly and mountainous with gentle to steep slopes broken occasionally by rock outcrops or ledges. The native vegetation is beargrass, curly mesquite grass, juniper, acacia, aster, and grama grasses. It is utilized for grazing, to which it is very well suited.

PREPARATION OF SAMPLES

The samples for chemical analyses were prepared in the manner suggested by the Association of Official Agricultural Chemists. The samples for physical analyses were divided into two groups, those which of necessity must maintain their original structure for analyses, such as aggregate analysis, and those prepared similarly to those for chemical analyses. Samples in the first group were treated sufficiently to remove rocks larger than 4 mm. in diameter; otherwise they were in their original state of division. All samples when taken were very near the air-dry state, making the usual period of drying almost unnecessary.

METHODS OF ANALYSES

Aggregate and mechanical compositions were determined by both the elutriator [11] and hydrometer methods. It was found that if special care was taken to get the soil properly wetted the pipette and hydrometer gave very similar aggregate and mechanical compositions for the soils. Because of this similarity and the greater speed of the hydrometer method, it was used to determine aggregate composition of size ranges below those which the elutriator could handle conveniently. The same procedure was used for determining the mechanical composition of the samples. The method adopted was briefly as follows: 30 g. of air-dry soil were placed in the smallest of the elutriator bulbs evacuated, and allowed to slake completely, the time usually required ranging from about 8 to 24 hours. After complete slaking the sample was elutriated until the elutriate from the largest of the bulbs was free of suspended material. The water was shut off, and the soil separate in each bulb was removed, dried, and weighed. The same procedure was used for mechanical analysis of the coarser separates except that the soil was completely dispersed with sodium hydroxide

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[11] Lutz (*27*) has shown that the sieve and elutriator methods are in substantial agreement.

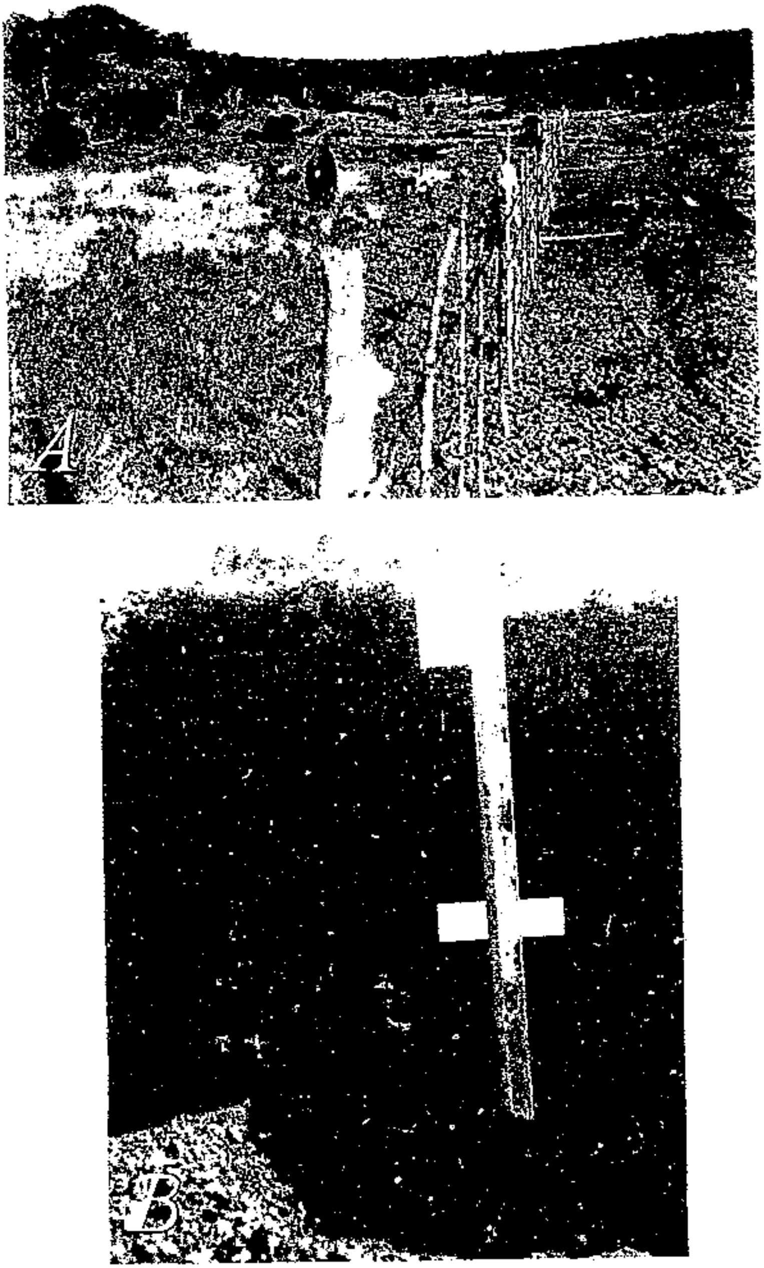

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FIGURE 11. *A*, Catron gravelly loam and clay loam, resistant to erosion. *B*, Profile development on Catron gravelly loam and clay loam. Note dark color and white lime mottling.

as a peptizing agent before it was placed in the elutriator tube. The Bouyoucos stirrer was used to aid in dispersing the sample.

For particles smaller than 0.02 mm. in diameter the method suggested by Bouyoucos (*5*) was used for aggregate-size determinations, and the hydrometer method suggested earlier by the same author (*5*) was used for small mechanical separates.

Dispersion was determined by the methods of Middleton (*30*), Lutz (*25*), and Volk (*48*). Middleton's method: A 10-g. sample of soil is placed in a tall cylinder of approximately 1,200-cc. capacity, and enough distilled water is added to make the volume a liter. The mixture is shaken end over end 20 times. The suspension is then allowed to settle until a 25-cc. sample pipetted at a depth of 30 cm. contains particles of a maximum diameter of 0.05 mm. From the dry weight of this fraction the total percentage of particles in suspension is calculated. This value is called the suspension percentage. The suspension percentage divided by the total percentage of silt plus clay, obtained by mechanical analysis and multiplied by 100, is the dispersion ratio. Lutz's method: A 10-g. sample of soil in the state in which it left the field is placed in the smaller of the elutriator tubes and is allowed to elutriate until the largest tube no longer loses soil in suspension. The water is shut off, and the soil is washed out of the tubes and dried and weighed, and the percentage of silt plus clay calculated. This percentage is divided by the percentage of silt plus clay from mechanical analysis which gives the percent dispersion.[12]

Volk's method: A 50-g. sample of the air-dry soil is wetted in a vaccum with 200 cc. of distilled water and allowed to slake for at least 1 hour. The suspension is washed into a tall cylinder and 800 cc. more water is added. The cylinder is shaken end over end 30 times and allowed to settle until only particles smaller than 0.005 mm. remain in suspension above a depth of 10 cm. Then 100 cc. is carefully pipetted out and dried and weighed. The percentage of particles smaller than 0.005 mm. in diameter suspended by this treatment is divided by the percentage in suspension by mechanical analysis and the result is called the degree of dispersion.

Air-dry moisture was found by drying in the oven at 105° C. water-vapor absorption over 3.3-percent sulfuric acid was found by Robinson's (*45*) method. Moisture equivalent was determined by both Bouyoucos' (*6*) suction method and Briggs and McLane's (*11*) centrifuge method. Because no significant difference was noted only one set of results was recorded. Water-saturation capacity was found by the method of Middleton and Byers (*31*). Structural stability was found by Bouyoucos' (*7*) settling volume method. Volume weight, pore space, water-holding capacity, specific gravity, and volume expansion on wetting of the laboratory sample were determined after the procedure of Keen and Raczkowski (*22*). These same properties were determined on the undisturbed samples by following the same procedure as suggested by Keen and Raczkowski except that the original cylinder in which it was taken was used to hold the soil, employing a perforated lid with filter-paper on the lower end to prevent the loss of soil as saturation was taking place. The large volume of soil was somewhat awkward to work with, but the additional accuracy warranted its use.

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[12] See footnote 11.

Colloid was determined by three different methods. (1) Sedimentation of all particles larger than 0.002 mm. in diameter, considering those still in suspension as the colloidal fraction. (2) Water-vapor absorption over 3.3 percent sulfuric acid, which consists of:

$$\text{Percent colloid} = \frac{\text{water absorbed per gram of soil}}{\text{water absorbed per gram of colloid}} \times 100.$$

(3) Copper adsorption, as follows: A 25-g. sample of a loam soil is placed in a Büchner funnel and washed with normal copper ammonium sulfate, which has previously had the excess ammonia removed by precipitation with ethanol, until it is saturated. The excess is removed by washing with dilute ammonia. The adsorbed copper is then measured by replacing with normal ammonium acetate. The same procedure is followed on a smaller amount of colloid.

$$\text{Percent colloid} = \frac{\text{copper adsorbed per gram of soil}}{\text{copper adsorbed per gram of colloid}} \times 100.$$

Total silica, alumina, manganese, calcium, magnesium, and loss on ignition were determined by Association of Official Agricultural Chemists' methods. Iron was separated from the sesquioxides iodometrically. Free iron oxide was estimated by the method of Drosdoff and Truog (*16*). Potassium was estimated by the cobaltinitrite-permanganate method and sodium by the magnesium-uranyl-acetate method. Available PO_4 and NO_3 were estimated colorimetrically in CO_2 extracts. Total soluble salts were determined conductometrically with the bridge, and pH value was found with the glass electrode and Beckman pH meter.

Base-exchange capacity and replaceable bases were estimated by leaching an alcohol-washed soil with normal ammonium acetate and removing the excess by again leaching with alcohol. The base-exchange capacity was found by distilling the ammonia from the soil and the replaceable cations by analysis of the leachate.

Results of the aggregate and mechanical analyses are given in table 3. The percentage dispersion at each of the particle-separate sizes is recorded, but no definite correlation with erodibility is noted. Attention is called to the increased percentage of fine material in the lower horizons of each of the soils.

The results of a number of physical tests are given in table 4. It will be noted that none of these factors other than the moisture equivalent and the water-holding capacity shows any obvious relation to the erodibility of these soils. Comparison of the water-holding capacity of the undisturbed samples with the moisture equivalent of the laboratory samples reveals that both erodible soils give abnormal relationships if the nonerodible soils are taken as a standard. This is better shown in figure 12. The water-holding capacity of the undisturbed No. 2 layer of the Chualar is definitely lower than the moisture equivalent for the same layer. This would indicate that the No. 2 layer in situ is so compact that pore space available to infiltration water is very low, preventing the possibility of a rapid infiltration rate for the whole of the Chualar soil. This observation is borne out by a scrutiny of the volume weight and pore space as given in table 4. Such an impervious subsoil would cause the coarse-textured topsoil to become supersaturated even in light rains, rendering the soil incapable for holding rainfall and thus permitting excessive erosion.

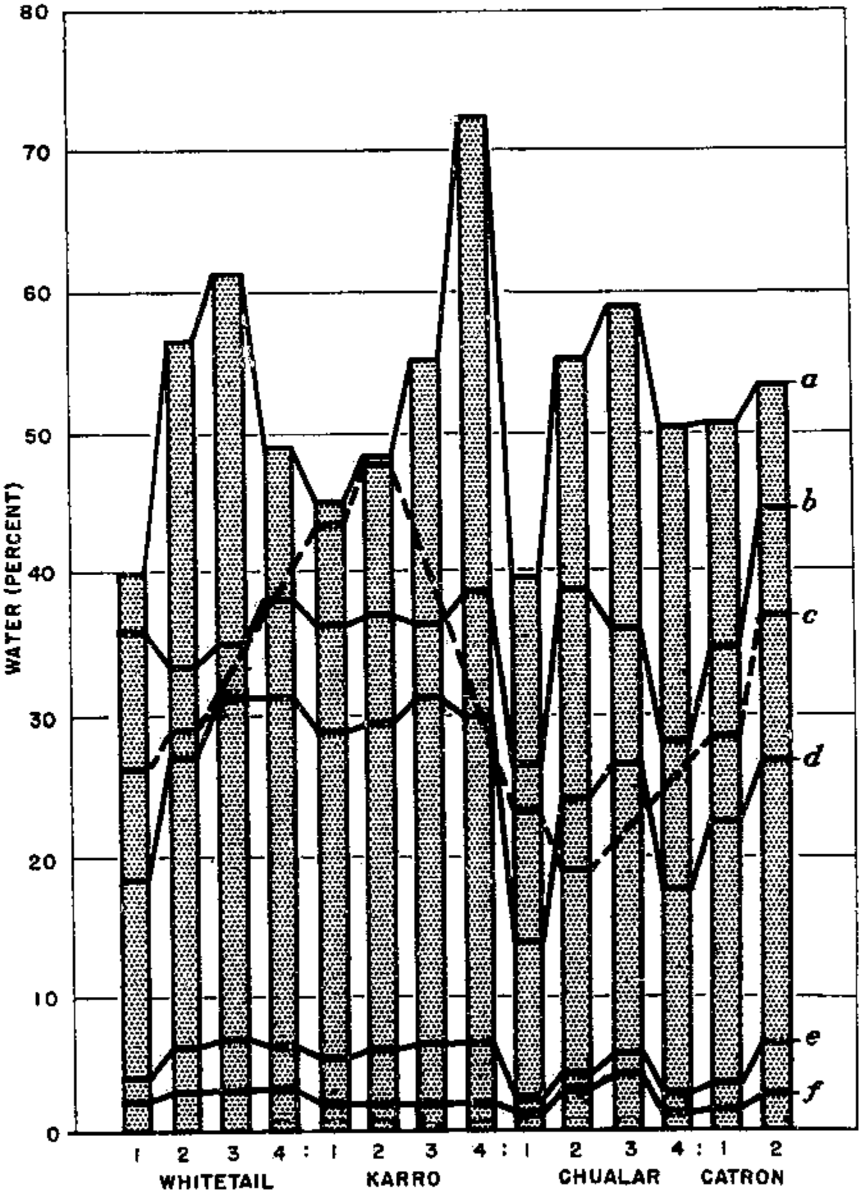

FIGURE 12.—Water relations of the soil: *a*, water-saturation capacity; *b*, water-holding capacity; *c*, water-holding capacity, undisturbed; *d*, moisture equivalent; *e*, moisture over 3.3 percent H_2SO_4; *f*, air-dry moisture.

TABLE 3. *Mechanical and aggregate analyses and dispersion ratios of the four soils studied*

Soil type and horizon	Soil particle size of—																										Erodibility integral
	0.1 mm. and greater			0.05-0.1 mm.			0.04-0.05 mm.			0.03-0.04 mm.			0.02-0.03 mm.			0.01-0.02 mm.			0.005-0.01 mm.			0.002-0.005 mm.			Less than 0.002 mm.		
	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	Dispersion ratio	Mechanical analysis	Aggregate analysis	
Whitetail gravelly loam:	*Pct.*	*Pct.*		*Pct.*	*Pct.*		*Pct.*	*Pct.*		*Pct.*	*Pct.*		*Pct.*	*Pct.*		*Pct.*	*Pct.*		*Pct.*	*Pct.*		*Pct.*	*Pct.*		*Pct.*	*Pct.*	
Horizon 1	38.67	40.57	97.00	10.83	24.43	69.30	2.90	0.14	73.20	8.67	14.50	52.30	6.90	7.33	40.68	2.53	9.03	13.55	7.00	3.80	0.89	11.50	0.20	0.00	11.00	0.00	2.6
Horizon 2	25.70	32.40	85.62	12.20	33.60	54.72	1.27	.67	54.76	9.33	12.67	40.13	2.73	5.66	30.72	10.47	8.50	16.90	6.00	6.00	1.55	20.30	.50	0	12.00	0	
Horizon 3	28.17	28.67	99.30	9.83	20.33	67.72	1.34	10.07	52.65	17.66	14.76	39.90	7.70	3.70	38.16	3.30	7.97	17.18	4.00	5.50	0	16.00	0	0	12.00	0	
Horizon 4	17.17	30.83	83.50	17.83	29.67	60.80	.84	2.06	58.35	15.50	15.23	45.66	7.83	8.00	34.82	7.83	8.21	18.18	4.00	6.00	0	15.00	0	0	14.00	0	
Karro gravelly loam:																											
Horizon 1	45.00	53.40	84.80	19.00	15.57	86.10	4.93	.43	98.40	.23	8.17	72.65	10.23	4.00	89.30	.11	8.90	46.30	4.00	6.00	21.20	6.50	2.50	10.00	10.00	1.00	24.2
Horizon 2	52.00	63.50	78.13	9.00	12.00	65.20	7.50	2.67	72.55	.17	5.66	54.80	8.33	3.00	61.82	5.00	4.67	52.80	8.00	5.50	40.00	1.00	3.00	11.11	9.00	1.00	
Horizon 3	39.77	63.00	61.40	14.23	16.00	45.65	1.60	.83	45.40	.17	.50	44.45	6.40	7.93	31.04	8.83	6.74	17.25	9.00	4.00	5.00	12.00	1.00	0	8.00	0	
Horizon 4	18.90	54.67	56.00	11.10	22.83	32.13	.73	.27	32.10	0	.33	31.60	3.87	7.47	22.68	21.40	7.33	17.05	9.00	6.00	4.20	21.00	1.50	0	11.00	0	
Chualar gravelly sandy loam:																											
Horizon 1	55.27	74.90	56.10	15.23	8.80	55.25	.54	4.70	40.05	0	.50	38.33	6.43	2.10	39.90	13.03	9.00	0	4.50	0	0	1.00	0	0	4.00	0	10.8
Horizon 2	59.93	72.47	57.63	.07	14.53	32.50	.26	.34	31.85	6.20	1.13	34.38	1.00	5.37	18.92	4.54	6.61	0	3.00	0	0	11.00	0	0	14.00	0	
Horizon 3	59.73	70.23	74.00	8.77	10.77	80.80	.40	1.20	57.22	0	2.47	49.30	.83	5.40	33.12	.77	9.93	0	8.50	0	0	9.00	0	0	12.00	0	
Horizon 4	75.80	80.41	80.90	.70	.39	81.56	1.23	.41	84.36	3.27	9.90	46.81	3.60	.80	52.50	9.90	4.19	70.90	3.00	3.90	0	.50	0	0	2.00	0	
Catron gravelly loam and clay loam:																											
Horizon 1	47.60	48.67	98.00	7.40	14.53	80.80	2.83	1.74	83.20	7.53	9.10	75.00	8.33	8.07	68.00	.31	7.09	41.55	15.00	6.40	44.00	7.00	4.40	0	4.00	0	3.2
Horizon 2	52.00	58.47	86.52	0	17.13	46.90	.17	1.03	44.80	11.63	.60	62.90	2.47	11.27	34.10	1.73	7.10	13.57	9.00	4.40	0	9.00	0	0	14.00	0	

TABLE 4.—*Physical measurements of soils studied*

Sample	Horizon No.	Volume-weight	Specific gravity	Pore space	Volume expansion per 100 cc.	Water-holding capacity	Moisture equivalent	Moisture absorbed over 3.3 H_2SO_4	Settling volume per 50 g.	Saturation capacity	Density of suspension	Structural stability	Suspension percentage	Erodibility integral
				Pct.		*Pct.*	*Pct.*	*Pct.*	*Cc.*	*Pct.*				
Whitetail gravelly loam	1	1.590	2.70	41.10	6.96	36.20	17.98	3.89	38.50	40.0	1.30	12.5/12.5	33.0	2.6
	2	1.498	2.70	41.55	9.64	33.50	26.88	5.96	46.70	56.5	1.07	16.5/16.5	38.0	
	3	1.418	2.72	47.80	7.10	35.30	30.75	6.36	49.0	61.2	1.02	17.0/17.0	51.0	
	4	1.400	2.69	47.90	11.45	38.18	30.70	6.05	43.2	49.3	1.16	16.5/16.5	49.0	
Whitetail gravelly loam, undisturbed	1	1.594	----	42.00	1.72	25.77	----							
	2	1.662	----	30.61	3.51	28.75	----							
Karro gravelly loam	1	1.367	2.61	47.70	5.06	36.70	28.50	5.34	42.5	44.7	1.18	14.0/13.0	29.0	24.2
	2	1.401	2.65	47.05	6.21	37.17	29.25	6.00	43.0	48.2	1.16	13.5/13.5	29.0	
	3	1.390	2.03	47.15	4.03	36.40	31.10	6.66	46.5	54.9	1.06	14.0/14.0	25.0	
	4	1.302	2.72	52.08	1.90	38.78	30.12	6.60	54.5	72.2	.98	16.5/16.0	21.0	
Karro gravelly loam, undisturbed	1	1.217	----	53.40	.19	43.15	----							
	2	1.102	----	56.15	1.62	47.90	----							
Chualar gravelly sandy loam	1	1.540	2.72	43.40	4.19	26.50	13.64	2.75	38.0	39.4	1.32	11.5/11.0	25.0	19.8
	2	1.300	2.67	51.35	9.02	39.20	23.41	4.20	46.0	54.7	1.09	14.0/11.0	15.0	
	3	1.350	2.74	50.75	6.67	36.00	26.42	5.63	47.2	58.0	1.06	14.0/13.0	20.5	
	4	1.391	2.05	47.50	1.16	28.00	17.25	2.02	44.0	50.3	1.14	13.0/12.5	16.5	
Chualar gravelly sandy loam, undisturbed	1	1.658	----	39.00	4.40	23.03	----							
	2	1.798	----	32.60	.97	18.93	----							
Catron gravelly loam and clay loam	1	1.493	2.90	48.50	6.18	34.80	22.18	3.53	42.5	50.5	1.18	15.0/14.0	33.0	3.2
	2	1.242	2.93	57.60	7.13	44.60	26.26	6.75	43.7	53.3	1.14	17.0/16.0	17.0	
Catron gravelly loam and clay loam, undisturbed	1	1.632	----	13.70	0	28.58		----	----	----	----	----	----	----
	2	1.600	----	35.37	5.79	36.90		----	----	----	----	----	----	----

The other erodible soil, Karro gravelly loam, typifies the other extreme. It is so loosely compacted that the water-holding capacity of the No. 1 and 2 undisturbed layers is almost as high as the saturation capacity, in which state this soil is fluid. Such high fluidity at the water-holding capacity results in very great soil losses whenever even slight run-off occurs.

The high degree of correlation between the various moisture percentages has already been mentioned by other investigators (*31*, *33*) and therefore will not be discussed here.

The results of the chemical analyses of the soils are given in table 5. Apparently the degree of base saturation and the base capacity bear no relation to erodibility in these soils. There is no noticeable relation between the apparent fertility of the soils and their erodibility. It is recognized, however, that good fertility is needed to support a good growth of vegetation, and the vegetation has an influence on the erodibility of range soils. It appears that the mineral constituents (CaO, K_2O, Fe_2O_3, and Na_2O) are in some way related to erodibility, the calcium and iron oxide contents being particularly important.

In relation to erodibility the kind of colloid seems to overshadow the quantity of colloid, even though there seems to be a relationship between quantity of colloid and erodibility.

TABLE 5—*Chemical analysis of horizons of the four soil types studied*

Soil type	Horizon	Total SiO_2	Fe_2O_3	Al_2O_3[1]	Mn_2O_3	CaO	MgO	K_2O	Na_2O	Ignition loss[2]	Combined SiO_2	Free Fe_2O_3	Organic carbon	Available nutrients			pH[3]	Base exchange (milliequivalents per 100 gm.)						
														NO_3	PO_4	Soluble salts		Base capacity (NH_4Ac)	Replaceable calcium	Replaceable magnesium	Replaceable sodium	Replaceable potassium	Colloid (Cu adsorption)	Colloid (H_2O absorption p.)
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P.p.m.*	*P.p.m.*							*Pct.*	*Pct.*
Whitetail gravelly loam (erodibility integral 2.6).	1	68.40	6.20	10.05	0.08	0.90	2.94	4.09	2.06	5.90	11.70	3.12	0.63	2.0	17.0	545	7.35	12.85	8.57	3.58	0.00	0.60	12.75	13.05
	2	61.80	6.69	13.76	.08	.95	3.02	5.65	1.95	6.30	16.92	4.00	.35	5.0	3.7	310	7.38	20.72	13.10	7.16	0	.46	18.3	20.00
	3	62.75	6.69	13.81	.08	1.05	2.96	3.93	1.95	6.20	16.97	3.97	.35	3.0	17.4	320	7.50	23.90	16.06	7.16	0	.68	21.6	21.35
	4	63.60	6.50	13.82	.08	2.89	1.22	3.64	1.19	6.80	17.75	3.50	.31	4.0	12.4	375	7.90	22.76	16.64	5.38	0	.74	23.0	21.00
Karro gravelly loam (erodibility integral 24.2).	1	48.04	3.10	9.08	.08	18.10	2.94	3.06	2.63	13.30	14.03	1.19	.65	9.0	13.6	470	8.40	17.80	13.82	2.00	(4)	1.08	9.9	18.51
	2	46.72	2.72	7.43	.08	19.80	3.10	2.43	2.42	15.80	15.09	1.34	.70	9.0	8.0	575	8.46	16.94	11.22	3.58	(4)	2.14	15.5	20.78
	3	34.78	2.91	7.25	.07	24.45	3.53	2.20	3.09	21.50	13.56	2.01	.50	15.0	6.5	1,390	8.45	14.00	7.58	2.85	1.57	2.00	15.4	23.14
	4	30.65	2.34	7.79	.07	20.83	1.17	1.37	3.96	22.11	12.27	1.25	.42	15.0	7.3	2,250	8.40	16.03	9.51	2.43	2.61	1.48	15.8	22.89
Chualar gravelly sandy loam (erodibility integral 19.8).	1	70.00	4.00	12.20	.05	2.01	1.66	1.93	5.52	3.45	7.90	3.80	.87	5.0	3.6	330	7.00	9.94	5.96	3.43	0	.55	4.0	8.95
	2	65.00	4.19	16.42	.05	1.99	2.05	1.92	5.06	4.13	14.46	4.09	.84	6.0	3.5	510	7.00	13.57	8.95	4.07	(4)	.55	11.5	14.55
	3	64.60	4.68	16.17	.04	1.95	2.26	2.03	4.67	2.64	14.90	4.23	.52	6.0	3.4	680	8.05	22.85	15.81	6.43	(4)	.61	12.9	19.55
	4	67.00	3 43	12.75	.05	2.70	1.52	5.15	4.95	2.94	10.25	3.40	.14	4.0	3.0	560	8.50	9.14	5.80	2.86	0	.48	9.9	10.15
Catron gravelly loam and clay loam (erodibility integral 3.2).	1	40.68	16.75	17.66	2.42	2.97	2.10	4.49	4.13	9.39	12.00	12.35	.87	5.0	9.4	520	8.30	10.55	15.14	3.43	0	.98	10.3	12.25
	2	42.10	13.92	20.12	2.06	3.60	2.48	3.82	3.82	6.70	14.88	7.85	.66	3.0	3.0	440	8.16	21.81	16.96	4.00	0	.85	15.8	23.40

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[1] Alumina includes all of the sesquioxides except iron.

[2] Roughly equal to the CO_2 from carbonates.

[3] 1 part soil to 5 parts water.

[4] Trace.

DISCUSSION AND CALCULATED DATA

The work of Duley and Miller (*20*), Musgrave and Free (*40*), Conner, Dickson, and Scoates (*13*), Dickson (*14*), Diseker and Yoder (*15*), Miller and Krusekopf (*35*), Weaver and Noll (*50*), Nichols and Sexton (*41*), Bennett (*3*), and others have shown that in any one soil, the looser the soil the less the run-off and the greater the erosion caused by any run-off producing precipitation. The observations for soils in situ in this area are in agreement with these findings. For example: The impervious subsoil of the Chualar gravelly sandy loam prevents infiltration to any marked extent, the loose surface soil is too thin to absorb much water, resulting in large erosion losses from this loose topsoil, losses that in many places leave only the resistant subsoil.

Duley and Hays (*19*) state that no laboratory criterion can correlate very well with erodibility, as they used the term, because erodibility varies with the slope. The fault appears to lie with the ordinary expression of erodibility in the field, since these findings are nearly always from only one slope. The variation with slope need not always be a limiting factor if it is recognized that erodibility is a function of slope, and that the range of slopes on which the soils are to be compared is specified. It is logical, however, that no set of criteria derived for a set of slopes should be applied to another slope range without due consideration of the variability of such an extrapolation.

In the statistical study of these soils, the correlations were divided into two groups. Those correlating erodibility with criteria mentioned by other workers, and those suggested by the data obtained in this study. The values of the calculated criteria to be correlated are given in table 6. Several of the ratios are calculated by using different methods of determining the properties from which they are calculated. For example, the erosion ratio is calculated using two different methods of determining colloid, making four values of the erosion ratio in all. Some of the ratios, such as the erosion ratio using colloid at 0.002-mm. diameter, which are obviously very far from correlating with erodibility, are not shown in the table but have in every instance been calculated.

It is evident from an examination of table 6 that some ratios suggested in the past as criteria of erodibility are no more than roughly qualitative on these soils. It is recognized that the soils of this area were formed under radically different conditions from any on which previous studies have been made, and divergent results are not surprising. Few of the properties suggested as criteria seem to be reliable as such on these soils. The relation of these properties to erodibility of soil is shown statistically by the correlation coefficients in the following tabulation (*49*).

TABLE 6.—*Calculated ratios for the four soil types studied*

Soil type	Horizon	Erosion ratio				Dispersion ratio			Ratio of colloid to moisture equivalent			Percolation ratio		Clay ratio	Base pacity colloid		Molecular ratio									Removal: slope
		Middleton's method	Lutz' method	Suspension percentage (Middleton): Colloid (Cu adsorption): Moisture equivalent	Suspension percentage (Lutz): Colloid (Cu adsorption): Moisture equivalent	Middleton's method	Lutz' method	Volk's method	Colloid by water absorption	Colloid by Cu adsorption	Colloid 0.002	Middleton's method	Colloid by Cu adsorption		Colloid by water-vapor absorption	Colloid by Cu adsorption	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Bases}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{Fe_2O_3}{Bases}$	$\frac{Fe_2O_3}{Na_2O}$	$\frac{Fe_2O_3}{CaO}$	$\frac{K_2O}{Na_2O}$	
Whitetail gravelly loam.	1	89.0	100.27	91.5	97.7	65.0	73.2	0.9	0.73	0.71	0.61	45.2	47.5	3.44	0.98	1.01	8.25	29.38	11.54	6.89	0.39	0.23	1.17	2.42	1.31	0.56
	2	82.7	73.9	90.0	80.5	61.2	54.8	1.5	.74	.68	.45	51.3	55.9	2.10	1.04	1.13	5.81	24.64	7.63	5.63	.31	.23	1.35	2.46	1.91	.58
	3	121.2	98.1	119.4	96.2	83.6	67.7	0	.69	.70	.39	73.9	72.9	2.57	1.12	1.11	5.87	24.95	7.70	6.32	.31	.25	1.35	2.24	1.35	.81
	4	111.0	89.4	100.7	81.4	75.5	60.8	0	.68	.75	.46	72.0	65.3	2.45	1.08	.99	5.98	26.04	7.79	7.55	.30	.29	2.14	.78	2.05	1.07
Karro gravelly loam	1	123.8	132.5	230.0	248.2	80.5	86.1	21.2	.65	.35	.35	44.6	82.9	5.06	.96	1.80	7.35	41.24	8.98	1.70	.22	.04	.46	.06	.76	7.50
	2	104.8	91.8	140.4	123.6	74.4	65.2	40.0	.71	.53	.31	40.8	54.7	9.00	.82	1.09	8.61	45.76	10.69	1.57	.25	.03	.44	.05	.67	8.04
	3	73.5	61.6	111.0	92.2	54.4	45.6	5.0	.74	.49	.26	33.8	51.0	4.00	.60	.91	6.45	31.81	8.14	.97	.26	.03	.36	.04	.46	4.50
	4	46.4	42.4	67.9	80.5	35.3	32.2	4.3	.76	.52	.87	27.6	40.4	1.86	.70	1.01	5.59	33.00	6.69	.80	.19	.02	.23	.03	.23	3.00
Chualar gravelly sandy loam.	1	53.5	83.6	121.7	188.4	35.3	55.2	0	.66	.29	.29	37.9	86.2	19.0	1.11	2.48	8.04	46.60	9.74	6.26	.21	.13	.28	.70	.22	5.36
	2	81.5	52.4	103.0	66.3	50.5	32.5	0	.62	.49	.60	24.2	30.6	3.00	1.17	1.18	5.77	41.30	6.72	5.69	.16	.14	.32	.74	.26	2.60
	3	87.8	109.2	132.7	123.7	65.0	80.8	0	.74	.49	.45	36.0	41.8	2.72	.93	1.77	5.73	36.85	6.79	5.72	.18	.15	.39	.84	.29	2.29
	4	118.8	138.4	122.8	135.6	70.0	81.6	0	.59	.57	.12	28.0	28.9	39.00	.90	.92	7.61	52.10	8.93	4.85	.17	.09	.27	.44	.62	2.86
Catron gravelly loam and clay loam.	1	133.1	146.9	155.7	175.8	73.2	80.8	40.0	.55	.47	.18	60.0	70.2	8.90	1.59	1.90	2.32	6.49	3.93	3.09	.62	.48	1.65	1.97	.72	1.00
	2	40.0	52.7	59.3	84.4	35.6	46.9	0	.89	.60	.53	19.1	28.3	3.55	.93	1.38	2.36	8.05	3.55	3.06	.44	.38	1.41	1.35	.66	0.62

*Correlation coefficient ** of erodibility and—*	
Erosion ratio:	
Middleton's method	0.062
Lutz' method	.101
Suspension percentage (Middleton): colloid (Cu adsorption): moisture equivalent	*.605
Suspension percentage (Lutz): colloid (Cu adsorption): moisture equivalent	*.571
Dispersion ratio:	
Middleton's method	.055
Lutz' method	−.079
Volk's method	−.472
Ratio of colloid to moisture equivalent:	
Colloid by water absorption	−.161
Colloid by Cu adsorption	**−.735
Colloid 0.002	−.278
Percolation ratio:	
Middleton's method	−.254
Colloid by Cu adsorption	.319
Clay ratio	.216
Ratio of base capacity to colloid:	
Colloid by water-vapor absorption	−.376
Colloid by Cu adsorption	.262
Molecular ratio:	
$SiO_2 : R_2O_3$	*.573
$SiO_2 : Fe_2O_3$	**.658
$SiO_2 : Al_2O_3$	.475
$SiO_2 : K_2O$	.301
SiO_2 : Bases	*−.545
$Fe_2O_3 : CaO$	**−.756
$Fe_2O_3 : Al_2O_3$	*−.503
$Fe_2O_3 : Na_2O$	**−.633
Fe_2O_3 : Bases	**−.728
$K_2O : Na_2O$	−.455
Fe_2O_3	*−.581
CaO	*.604
Na_2O	.133
K_2O	*−.512
Organic carbon	.287

**Highly significant; *signifiant.

The correlation coefficients for the erosion ratios and erodibility indicate that erosion ratios by the methods of Middleton and Lutz are not reliable criteria for quantitatively judging erodibility of these soils. Even Middleton (*30*), who suggested the use of the erosion ratio, expected it to be far from perfect in judging erodibility of soils and stated it to be only the best calculated criterion discovered at that time. The lack of a more significant correlation with the erosion ratios is attributed to the high degree of dispersion found in these soils (*2*).

No significant correlation is shown with any of the dispersion ratios, but it is rather surprising to note that these ratios give a negative correlation coefficient. Since these statistics are not significant these results may be due to other properties completely overshadowing the action of dispersion.

The higher correlation between the ratio of colloid to moisture equivalent when the colloid by copper adsorption is used in its calculation than when colloid by water-vapor absorption is used, might be expected when the calcareous nature of these soils is considered. The difference is greatest in the instance of the Karro gravelly loam, which is the most calcareous of the group.

In the other highly significant correlations the elements, iron, sodium, or potassium, are in some way associated. All significant correlations involve one or more of the four elements, potassium, sodium, calcium, or iron in the value or in the calculation of the ratio to be correlated with erodibility.

Peele (*42*) has shown that calcium salts increase the erodibility of soils in the Piedmont by decreasing the size and permeability of the aggregates in inorganic soils. These findings are borne out on soils of the upper Gila watershed. From the work of Lutz (*27*) one would assume that the role of free iron oxides in the soil was to aid in forming large, porous, water-stable aggregates. In this area percent of free iron does not correlate with dispersion nor does dispersion correlate with erodibility. The explanation of the effect of the aggregates on erodibility then, must lie in the structure of the aggregate rather than its size. Study of figures 13 and 14 seems to support such a theory. It will be noted on figures 13, *B* and 14, *A* that the aggregates consist of a central particle surrounded by very fine single-grained particles in a densely packed lump, whereas in figures 13, *A* and 14, *B* the aggregates are packed in porous groups in which the size range is not sorted to cause impermeability. These photomicrographs were taken of the soils under water and the aggregates shown are those that are water stable, the dispersed particles being single grains whenever they are large enough to be seen.

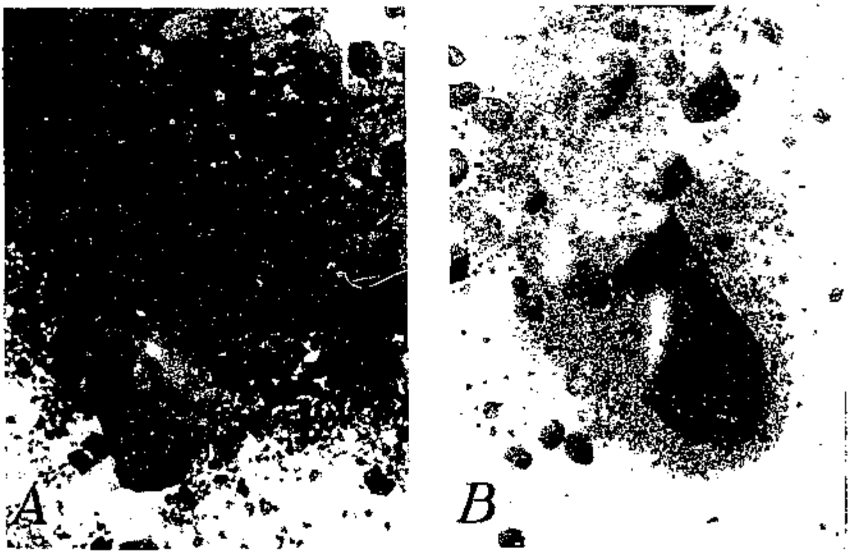

FIGURE 13. *A*, Whitetail gravelly loam sample No. 2. Note the angular structure of the smaller aggregates as structural units of the larger aggregates. *B*, Karro gravelly loam sample No. 2. Note the coating of fine particles which make up the contact surface of the aggregates, acting as a lubricant for the aggregates one on another. Photomicrographs by H. R. Reynolds, Utah State Agricultural College.

The role of potassium and sodium in erodibility can be only surmised, but it is suggested that they are perhaps intimately associated with the weathering and colloid content of the soil. It is well known that grinding a soil increases the amount of replaceable potassium. Cobb (*12*) has shown that weathered soils are richer in iron and poorer in sodium than unweathered soils and apparently this process is inseparably tied to erodibility.

It has been impossible to date, in laboratory studies of erodibility, to avoid the problem of differences in soil properties due to rainfall. The merit of a separation of soil properties and erodibility from rainfall differences is questionable. In the field, rainfall differences affect the erodibility only as they affect soil properties since profile depth is dependent on rainfall. In the light of this fact it is suggested that even the most resistant soil in the Desert group if placed in the Red and Yellow soil belt would be rapidly eroded or changed to an entirely different soil within a comparatively short time. This would explain some of the apparent disagreements received in the past from laboratory analyses.

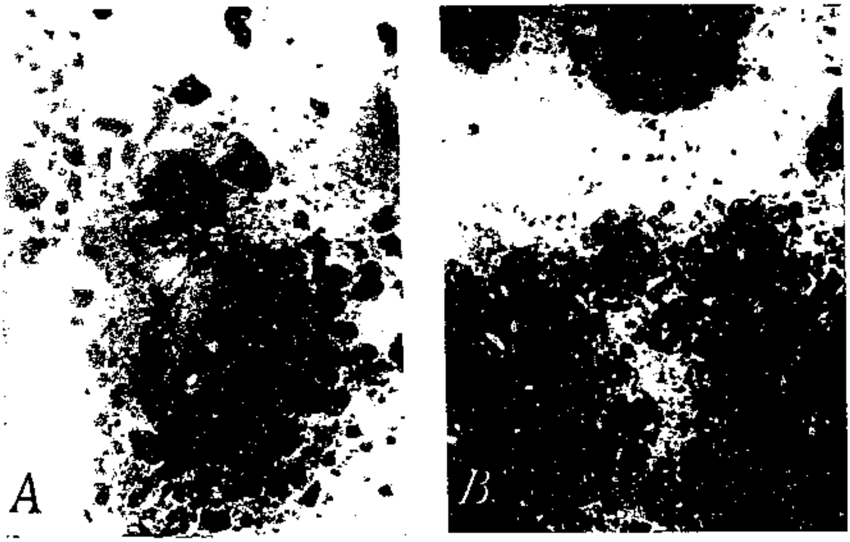

FIGURE 14.—*A*, Chualar gravelly sandy loam sample No. 2. Note the structural similarity to figure 13, *B*. *B*, Catron gravelly loam and clay loam sample No. 2. Note the similar structure to figure 13, *A* with the assorted angular grouping of the granules being even more pronounced. Photomicrographs by H. R. Reynolds, Utah State Agricultural College.

Some of the ratios of iron oxide to calcium oxide given in table 7 bear out this suggestion. If the soils are considered in groups according to their degree of leaching, a variance with erodibility is immediately noted, showing the highest values for the most nonerodible soils. From this table one might infer that the Karro gravelly loam is among the most erodible soils in the United States. Use of the silica sesquioxide ratio as a criterion of erodibility by some investigators (*4*, *30*, *32*, *33*) substantiates such an inference.

SUMMARY AND CONCLUSION

From the data collected in the erosion surveys of the upper Gila watershed, curves have been made by plotting mean percent erosion against slope. From these curves erodibility has been defined and a numerical value, erodibility integral, has been employed to express it.

TABLE 7.—*Fe_2O_3: CaO ratios (molecular ratios) for various soils in United States*[1]

Soil type	Horizon No. 1	2	3	4	5	Average	Soil group
Nipe clay	54.63	58.67				56.65	Laterite.
Aiken silty clay loam	25.83	36.87				31.35	Red-Yellow.
Nacogdoches fine sandy loam	8.10	14.87	21.46	9.26	49.38	20.61	Do.
Kirvin fine sandy loam	7.31	21.77	8.81	21.79	11.83	14.30	Do.
Cecil clay loam	4.55	12.20	15.06			10.61	Do.
Orangeburg fine sandy loam	2.03	3.23	7.76			4.34	Do.
Davidson clay loam	4.93	8.80	10.27	17.33		12.58	Do.
Memphis silty loam	2.09	4.40				3.24	Do.
Iredell fine sandy loam	.98	.99	1.66	.75		1.09	Do.
Muskingum silt loam	2.67	5.40	10.77	10.40	8.96	7.64	Gray-Brown Podzol.
Clinton silt loam	2.04	1.11	1.35	1.38	.89	1.35	Do.
Shelby silt loam	1.69	2.74	1.99	1.36	.02	1.56	Prairie.
Marshall silt loam	1.61	1.68	1.40	1.24		1.48	Do.
Palouse silt loam	1.07	1.23	1.21	1.10	1.06	1.13	Chernozem.
Vernon fine sandy loam No. 1	.67	.65	.03			.45	Do.
Vernon fine sandy loam No. 2	5.88	1.71	3.81	3.25		3.66	Do.
Colby silty clay loam	.29	.10	.09	.08	.11	.13	Do.
Catron loam and clay loam	1.97	1.35				1.66	Southern Brown.
Chuslar sandy loam	.70	.74	.84	.44		.68	Do.
Whitetail loam	2.42	2.46	2.24	.78		1.98	Southern Gray Desert.
Mohave loam	.91	.74	.08	.59		.58	Do.
Karro loam	.06	.05	.04	.03		.04	Do.

[1] The above figures are taken from the work of the authors and the following literature: Middleton et al. (*30, 31, 32*), Cobb (*12*), and Marbut (*28*). Since these ratios are from such a number of sources, variations are to be expected.

An analysis of erodibility-integral values obtained from erosion-survey data for the upper Gila watershed of Arizona and New Mexico indicate the following relations:

1. Soil erodibility varies with the parent rock. In the southern Gray Desert soils, the order from erodible to nonerodible soil-producing parent rock is: (1) Limestone, (2) mixed origin, (3) granite, (4) rhyolite and basalt, and (5) quartzite; in the southern Brown soils, (1) granite, (2) rhyolite, (3) quartzite, limestone, and basalt.
2. Erodibility varies with the size of the rock particles contained in the soil. Rocky soils have been found to be more erodible than gravelly soils within any one soil type.
3. Erodibility varies with the texture of the soil. Erodibility increases as the texture within a series becomes coarser.

Fairly complete analyses of four soils from the upper Gila watershed indicate that:

1. The moisture relations of a soil are intimately associated with erodibility. One moisture relation of an erodible soil cannot be calculated from another.
2. Compactness is a factor in erodibility. Loose topsoils erode easily. Compact or impervious subsoils cause a supersaturation of thin topsoils even in rains of low intensity, resulting in proportionately high surface run-off and accelerated erosion.

3. The dispersion ratio of southern Gray Desert soils and southern Brown soils is very high.

4. Of all the criteria suggested in the past for judging erodibility in the laboratory, only the ratio of colloid to moisture equivalent showed a highly significant correlation with erodibility in this area.

5. A high content of calcium or sodium or a low content of iron or potassium is associated with high erodibility in these soils.

6. Erodibility increases as the ratio of iron to calcium decreases.

7. Every chemical ratio that correlated significantly with erodibility involved at least one or more of the elements, iron, calcium, sodium, and potassium, in its calculation.

LITERATURE CITED

(1) Baldwin, Mark, Kellogg, Charles E., and Thorp, James.
1938. SOIL CLASSIFICATION. U. S. Dept. Agr. Yearbook (Soils and Men) 1938: 979–1001.

(2) Baver, L. D., and Harper, W. G.
1935. THE AGGREGATION OF DESERT SOILS. Amer. Soil Survey Bul. 16: 54.

(3) Bennett, H. H.
1933. THE QUANTITATIVE STUDY OF EROSION TECHNIQUE AND SOME PRELIMINARY RESULTS. Geog. Rev. 23: 423–432, illus.

(4) ———
1934. DYNAMIC ACTION OF RAINS IN RELATION TO EROSION IN THE HUMID REGION. Amer. Geophys. Union Trans., pp. 474–488, illus.

(5) Bouyoucos, George John.
1929. THE ULTIMATE NATURAL STRUCTURE OF SOILS. Soil Sci. 28: 27–37.

(6) ———
1929. A NEW, SIMPLE, AND RAPID METHOD FOR DETERMINING THE MOISTURE EQUIVALENT OF SOILS, AND THE ROLE OF SOIL COLLOIDS ON THIS MOISTURE EQUIVALENT. Soil Sci. 27: 233–241, illus.

(7) ———
1935. SIMPLE AND RAPID METHODS OF ASCERTAINING THE EXISTING STRUCTURAL STABILITY OF SOIL AGGREGATES. Amer. Soc. Agron. Jour. 27: 222–227.

(8) ———
1935. THE CLAY RATIO AS A CRITERION OF THE SUSCEPTIBILITY OF SOILS TO EROSION. Ameri. Soc. Agron. Jour. 27: 738–741.

(9) Brandt, A. E.
1933. A TEST FOR SIGNIFICANCE IN A UNIQUE SAMPLE. (Note) Jour. Amer. Stat. Assoc. 28: 434–437, illus.

(10) Breazeale, J. F.
1926 A STUDY OF THE COLORADO RIVER SILT. Ariz. Agr. Expt. Sta. Tech. Bul. 8: [165]–185.

(11) Briggs, Lyman J., and McLane, J. W.
1911. MOISTURE EQUIVALENT DETERMINATIONS AND THEIR APPLICATION. Amer. Soc. Agron. Proc. (1910) 2: 138–147, illus.

(12) Cobb, W. B.
1928. A COMPARISON OF THE DEVELOPMENT OF SOILS FROM ACIDIC AND BASIC ROCKS. Internatl. Cong. Soil Sci. Proc. (1927) 1 (4): 456–465, illus.

(13) Conner, A. B., Dickson, R. E., and Scoates, D.
1930. FACTORS INFLUENCING RUNOFF AND SOIL EROSION. Tex. Agr. Expt. Sta. Bul. 411, 50 pp., illus.

(14) Dickson, R. E.
1929. RESULTS AND SIGNIFICANCE OF THE SPUR (TEXAS) RUNOFF AND EROSION EXPERIMENTS. Amer. Soc. Agron. Jour. 21: 415–422.

(15) Diseker, Ellis G., and Yoder, Robert E.
1936. SHEET EROSION STUDIES ON CECIL CLAY. Ala. Agr. Expt. Sta. Bul. 245, 52 pp., illus.

(16) Drosdoff, M., and Truog, E.
1935. A METHOD FOR REMOVING AND DETERMINING THE FREE IRON OXIDE IN SOIL COLLOIDS. Amer. Soc. Agron. Jour. 27: 312–317.

(17) Duley, F. L.
1926. THE LOSS OF SOLUBLE SALTS IN RUNOFF WATER. Soil Sci. 21: 401–409.
(18) ——— and Ackerman, F. G.
1934. RUN-OFF AND EROSION FROM PLOTS OF DIFFERENT LENGTHS. Jour. Agr. Res. 48: 505–510, illus.
(19) ——— and Hays, O. E.
1932. THE EFFECT OF THE DEGREE OF SLOPE ON RUNOFF AND SOIL EROSION. Jour. Agr. Res. 45: 349–360, illus.
(20) ——— and Miller, M. F.
1923. EROSION AND SURFACE RUNOFF UNDER DIFFERENT SOIL CONDITIONS. Mo. Agr. Expt. Sta. Res. Bul. 63, 50 pp., illus.
(21) Hendrickson, B. H.
1934. THE CHOKING OF PORE-SPACE IN THE SOIL AND ITS RELATION TO RUNOFF AND EROSION. Amer. Geophys. Union Trans. 15: 500–505.
(22) Keen, Bernard A., and Raczkowski, Henry.
1921. THE RELATION BETWEEN THE CLAY CONTENT AND CERTAIN PHYSICAL PROPERTIES OF A SOIL. Jour. Agr. Sci. [England] 11: 441, 449, illus.
(23) Lowdermilk, W. C.
1930. INFLUENCE OF FOREST LITTER ON RUN-OFF, PERCOLATION, AND EROSION. Jour. Forestry 28: 474–491, illus.
(24) ———.
1934. ACCELERATION OF EROSION ABOVE GEOLOGIC NORMS. Amer. Geophys Union Trans., pp. 505–509, illus.
(25) Lutz, J. Fulton.
1934. THE PHYSICO-CHEMICAL PROPERTIES OF SOILS AFFECTING SOIL EROSION. Mo. Agr. Expt. Sta. Res. Bul. 212, 45 pp., illus.
(26) ———.
1935. THE RELATION OF SOIL EROSION TO CERTAIN INHERENT SOIL PROPERTIES. Soil Sci. 40: 439–457, illus.
(27) ———.
1937. THE RELATION OF FREE IRON IN THE SOIL TO AGGREGATION. Soil Sci. Soc. Amer. Proc. (1936) 1: 43–45, illus.
(28) McGee, W. J.
1911. SOIL EROSION. U. S. Bur. Soils Bul. 71, 60 pp., illus.
(29) Marbut, C. F.
1935. SOILS OF THE UNITED STATES. *In* U. S. Dept. Agr. Atlas of American Agriculture, pt. 3, 98 pp., illus.
(30) Middleton, H. E.
1930. PROPERTIES OF SOILS WHICH INFLUENCE SOIL EROSION. U. S. Dept. Agr. Tech. Bul. 178, 16 pp.
(31) ——— and Byers, H. G.
1934. THE SETTLING VOLUME OF SOILS. Soil Sci. 37: 15–26, illus.
(32) ——— Slater, C. S., and Byers, Horace G.
1932. PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS. U. S. Dept. Agr. Tech. Bul 316, 51 pp.
(33) ——— Slater, C. S., and Byers, H. G.
1934. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS—SECOND REPORT. U. S. Dept. Agr. Tech. Bul. 430, 63 pp., illus.
(34) Miller, M. F.
1929. TEN YEARS OF SOIL EROSION MEASUREMENTS. Amer. Soil Survey Assoc. Bul. 10: 29–34, illus.
(35) ——— and Krusekopf, H. H.
1932. THE INFLUENCE OF SYSTEMS OF CROPPING AND METHODS OF CULTURE ON SURFACE RUNOFF AND SOIL EROSION. Mo. Agr. Expt. Sta. Res. Bul. 177, 32 pp., illus.
(36) Murphy, H. F., and Daniel, H. A.
1935. SOME CHEMICAL AND PHYSICAL PROPERTIES OF NORMAL AND SOLONETZ SOILS AND THEIR RELATION TO EROSION. Soil Sci. 39: 453–461.

(37) Musgrave, G. W.
1934. A QUANTITATIVE STUDY OF CERTAIN FACTORS AFFECTING SOIL AND WATER LOSSES AS THE LOGICAL BASIS FOR DEVELOPING PRACTICAL METHODS OF EROSION CONTROL. Amer. Geophys. Union Trans. 15: 515–521.

(38) ———
1935. SOME RELATIONSHIPS BETWEEN SLOPE-LENGTH, SURFACE RUN-OFF, AND THE SILT-LOAD OF SURFACE RUN-OFF. Amer. Geophys. Union Trans. 16: 472–478, illus.

(39) ———
1935. THE INFILTRATION CAPACITY OF SOILS IN RELATION TO THE CONTROL OF SURFACE RUNOFF AND EROSION. Amer. Soc. Agron. Jour. 27: 336–345, illus.

(40) ——— and Free, G. R.
1936. SOME FACTORS WHICH MODIFY THE RATE AND TOTAL AMOUNT OF INFILTRATION OF FIELD SOILS. Amer. Soc. Agron. Jour. 28: 727–739, illus.

(41) Nichols, M. L., and Sexton, H. D.
1932. A METHOD OF STUDYING SOIL EROSION. Agr. Engin. 13: 101–103, illus.

(42) Peele, T. C.
1937. THE EFFECT OF CALCIUM ON THE ERODIBILITY OF SOILS. Soil Sci. Soc. Amer. Proc. (1936) 1: 47–58, illus.

(43) Puri, A. N.
1937. PHYSICAL CHARACTERISTICS OF SOIL: I. NEW METHODS OF MEASUREMENT. Soil Sci. 44: 481–487.

(44) Renner, F. G.
1936. CONDITIONS INFLUENCING EROSION ON THE BOISE RIVER WATERSHED. U. S. Dept. Agr. Tech. Bul. 528, 32 pp., illus.

(45) Robinson, W. O.
1922. THE ABSORPTION OF WATER BY SOIL COLLOIDS. Jour. Phys. Chem. 26: [647]–653.

(46) Slater, C. S., and Byers, H. G.
1931. A LABORATORY STUDY OF THE FIELD PERCOLATION RATES OF SOILS. U. S. Dept. Agr. Tech. Bul. 232, 24 pp., illus.

(47) ——— and Byers, H. G.
1934. BASE EXCHANGE AND RELATED PROPERTIES OF THE COLLOIDS OF SOILS FROM THE EROSION EXPERIMENT STATIONS. U. S. Dept. Agr. Tech. Bul. 461, 20 pp.

(48) Volk, G. M.
1936. THE DEGREE OF DISPERSION OF SOILS AS A FACTOR IN DETERMINING THEIR STABILITY FOR EARTH WATER RETAINING STRUCTURES. Prog. Rpt. Region 8, S. C. S., U. S. Dept. Agr.

(49) Wallace, H. A., and Snedecor, George W.
1931. CORRELATION AND MACHINE CALCULATION. Iowa State Col. Off. Pub. 30, No. 4, 71 pp.

(50) Weaver, J. E., and Noll, Wm.
1935. MEASUREMENT OF RUN-OFF AND SOIL EROSION BY A SINGLE INVESTIGATOR. Ecology 16: 1–12, illus.

(51) Yoder, Robert E.
1936. A DIRECT METHOD OF AGGREGATE ANALYSIS OF SOILS AND A STUDY OF THE PHYSICAL NATURE OF EROSION LOSSES. Amer. Soc. Agron. Jour. 28: 337–351, illus.

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