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PROPERTIES OF SOILS WHICH INFLUENCE SOIL EROSION

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INTRODUCTION

Soil erosion is not a new problem, the necessity for protection of farm lands from denudation having long been recognized. In 1909 in a report of the National Conservation Commission (*18*)[1] attention was called to the enormous losses resulting from erosion; and in 1911 a bulletin on soil erosion (*15*) discussed the problem and remedial measures which might be employed. These reports apparently roused very little interest. In recent years, however, the work of agricultural experiment stations and of the Federal Government (*8*) has served to focus attention on the great loss resulting from erosion. The Seventieth Congress made a special appropriation for the study of soil erosion and water conservation, with particular reference to the various soil types. Experimental work on erosion will be done at several stations established for this purpose.

Experimental field studies on soil erosion have been in progress for several years at the State agricultural experiment stations at Columbia, Mo., Spur, Tex., and Raleigh, N. C., and at the Forest Service experiment stations at Ephraim, Utah, and San Bernardino, Calif. In this field work it has been recognized that some soil types erode more readily than others. The literature reveals no laboratory studies which show any relation between erosivity and the physical and chemical characteristics of the soil types. The fact that definite information concerning the erosional behavior of soils was not available explains this lack of investigation. Such information became available with the appearance of the results (*4*, *5*, *6*, *7*, *8*) of extensive

[1] Italic numbers in parentheses refer to literature cited, p. 15.

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erosion studies made in the field by H. H. Bennett of this bureau, who observed that certain soil types were easily eroded whereas others were much less susceptible to erosion. With a view to determining the properties of soils which influence soil erosion, samples were collected and work begun.

OUTLINE OF INVESTIGATION

Three groups of soil samples were collected. In one group samples of four soil types were obtained from widely separated regions. Two of these types, the Nipe clay from Cuba and the Aikin silty clay loam from Oregon, were notable because of the resistance they offer to erosion, in spite of heavy rainfall. In contrast with these were the Orangeburg fine sandy loam and the Memphis silt loam from Mississippi. A second group of samples consisted of the Iredell loam, which is erosive, and of the Davidson clay loam, which is nonerosive.[2] These samples were collected near Greensboro, N. C., and under like climatic conditions differ very strikingly in erosional behavior. The samples of these two groups were very carefully examined, especially with respect to the A and B horizons. The properties were contrasted and the effort made to determine which properties accounted for the erosional differences. A third group of samples was later obtained from three erosion experiment stations, and a similar study was made on them.

EXPERIMENTAL WORK

The mechanical analyses were made by a slightly modified form of the international method (*19*). Hydrogen peroxide, hydrochloric acid, and sodium carbonate or hydroxide were used. The quantity of colloid was determined by the water-vapor adsorption method, over 3.3 per cent sulphuric acid (*20*), the moisture equivalent by the method outlined in a previous publication (*16, p. 159*), the maximum water-holding capacity by the method of Hilgard (*13, p. 209*), the lower liquid limit by the method of Atterberg (*3, p. 36*), and the specific gravity by a method essentially the same as that described by Hillebrand (*14, p. 55*).

The slaking value was determined with an apparatus described by Boyd (*9, p. 345*) but by a somewhat different method of procedure. Five grams of air-dry soil was thoroughly mixed with just sufficient water to saturate it at a pressure of 2,000 pounds per square inch and made into a briquette 25 millimeters in diameter. This was immediately placed on a metal ring and submerged in water. The slaking value is the number of seconds necessary for the briquette to disintegrate sufficiently to fall through the ring.

The moisture content, apparent specific gravity, shrinkage, pore space, and volume of voids were calculated by measuring and weighing briquettes made by the method outlined by the writer (*17, p. 502*), in which 20 grams of air-dry soil was mixed with sufficient water to give the greatest density at a pressure of 2,000 pounds per square inch.

The dispersion ratio was determined as follows: A sample of air-dry soil equivalent to 10 grams of oven-dry soil was placed in a tall

[2] "Nonerosive" is used in this bulletin to describe soils notably less susceptible to erosion than normal soils. The terms erosive and nonerosive are used relatively, as are the terms soluble and insoluble. All soils are somewhat susceptible to erosion by run-off water.

cylinder of approximately 1,200 cubic centimeter capacity fitted with a rubber stopper. Sufficient distilled water was added to make the volume a liter. The cylinder was closed with the stopper and was shaken end over end 20 times. The suspension was then allowed to settle until a 25 cubic centimeter sample which was pipetted at a depth of 30 centimeters consisted of particles of a maximum diameter of 0.05 millimeter. A metal tip placed on the end of the pipette with six radial No. 80 drill holes was used; through it liquid was drawn from the side rather than from directly under the pipette. From the dry weight of the pipetted fraction, the total weight of silt and clay in the suspension was calculated. The ratio, expressed in percentage, of the silt and clay so determined to the total silt and clay obtained by mechanical analysis is called the dispersion ratio. The erosion ratio is the quotient obtained by dividing the dispersion ratio by the ratio of colloid to moisture equivalent.

Colloid was extracted (*12, p. 16*), and chemical analyses were made by methods now in use in the Division of Soil Chemistry and Physics of this bureau, but special effort was exerted to make the colloid extraction as complete as possible.

FIRST GROUP

DESCRIPTION OF SAMPLES

The samples used in this experiment were collected by H. H. Bennett, of this bureau. The erosive samples are as follows:

Memphis silt loam from 5 miles east of Vicksburg, Miss. Sample No. 1, A horizon, 0 to 8 inches, brown mellow silt loam; sample No. 2, B horizon, 8 to 28 inches, buff moderately friable silty clay loam; and sample No. 3, C horizon, 120 to 216 inches, yellowish-brown friable silt loam.

Orangeburg fine sandy loam from Jackson County, Miss. Sample No. 4, A horizon, 0 to 16 inches, fine sandy loam, brown to 4 inches and buff below that depth; sample No. 5, B_1 horizon, 16 to 72 inches, red friable sandy clay; sample No. 6, B_2 horizon, 72 to 96 inches, red friable fine sandy loam with some yellowish splotches; and sample No. 7, C horizon, 96 to 136 inches, white and pale-pink coarse sand with some thin seams of red fine sandy loam.

The nonerosive soil types of this group are as follows:

Nipe clay from Fulton mining region, Fulton, Oriente, Cuba. Sample No. 8, 0 to 12 inches, red, highly porous, friable material, somewhat compact in places (plancha layer), with abundance of highly ferruginous small and large nodules (accretions or concretions); and sample No. 9, 12 to 24 inches, red, highly porous, and friable material, with abundance of small and large ferruginous nodules.

Aikin silty clay loam from 5½ miles south of Salem, Oreg. Sample No. 10, 0 to 20 inches, brownish-red silty clay loam to clay; and sample No. 11, 20 to 40 inches, red clay.

RESULTS

The physical determinations which were made on samples of the first group are shown in Table 1 and the chemical analyses in Table 2.

TABLE 1.—*Physical properties of erosive and nonerosive soils*

Character and sample No.		Soil type	Depth	Mechanical analysis: Sand	Mechanical analysis: Silt	Mechanical analysis: Clay	Colloid	Moisture equivalent	Lower liquid limit	Maximum water-holding capacity	Specific gravity	Slaking value
			Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Seconds*
Erosive	1	Memphis silt loam (Miss.).[1]	0–8	11.2	75.4	13.4	14.6	21.5	27.0	48.9	2.65	340
	2	-----do-----------	8–28	6.2	63.0	30.8	32.2	28.6	36.7	57.9	2.73	(2)
	3	-----do-----------	120–216	5.6	80.3	14.2	12.3	21.7	28.3	49.9	2.74	50
	4	Orangeburg fine sandy loam (Miss.).	0–16	64.0	26.1	9.9	11.6	15.0	16.7	36.9	2.64	25
	5	-----do-----------	16–72	56.9	20.1	23.0	23.5	17.3	23.9	41.6	2.69	80
	6	-----do-----------	72–96	77.4	6.4	16.2	16.5	12.5	20.2	38.0	2.69	75
	7	-----do-----------	96–136	97.6	.6	1.8	2.4	2.2	-------	27.1	2.66	1
Nonerosive	8	Nipe clay (Cuba)	0–12	[3]20.4	32.5	47.1	65.1	30.4	40.1	58.7	3.99	(2)
	9	-----do-----------	12–24	[3]23.4	24.1	62.5	63.7	27.2	36.7	51.3	3.92	(2)
	10	Aikin silty clay loam (Oreg.).	0–20	11.7	28.8	59.5	52.5	30.3	36.3	57.5	2.84	(2)
	11	-----do-----------	20–40	10.4	23.7	65.9	59.8	30.8	40.3	57.1	2.87	(2)

Character and sample No.		Soil type	Briquettes at maximum density: Moisture content	Briquettes at maximum density: Apparent specific gravity[1]	Briquettes at maximum density: Shrinkage[1]	Briquettes at maximum density: Pore space[1]	Briquettes at maximum density: Volume of voids[1]	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Ratio of clay to silt
			Per cent		*Per cent*	*Per cent*	*Per cent*				
Erosive	1	Memphis silt loam (Miss.).	16.9	1.64	1.08	38.1	10.5	44.6	0.68	65.2	0.18
	2	-----do-------------	14.7	1.87	3.50	31.5	4.0	26.3	1.13	23.3	.49
	3	-----do-------------	19.5	1.63	.74	40.7	9.0	66.0	.57	115.8	.18
	4	Orangeburg fine sandy loam (Miss.).	9.4	1.87	.75	29.1	11.7	39.2	.77	50.9	.38
	5	-----do-------------	11.2	1.98	1.87	26.3	4.0	16.9	1.36	12.4	1.14
	6	-----do-------------	12.4	1.90	.48	29.4	5.9	29.6	1.32	22.4	2.53
	7	-----do-------------	--------	--------	--------	--------	--------	27.0	1.09	24.8	3.00
Nonerosive	8	Nipe clay (Cuba)--	23.3	1.91	3.97	52.1	7.6	6.1	2.14	2.9	1.45
	9	-----do-------------	22.2	2.03	4.15	51.9	6.9	5.2	2.34	2.2	2.59
	10	Aikin silty clay loam (Oreg.).	19.3	1.77	6.62	37.6	3.6	15.1	1.73	8.7	2.07
	11	-----do-------------	19.9	1.76	6.47	38.6	3.5	13.4	1.94	6.9	2.78

[1] Based on wet volume.
[2] Did not slake in 18 hours.
[3] A considerable part consists of concretions.

TABLE 2.—*Chemical composition*[1] *of erosive and nonerosive soils*[2]

Character and sample No.		Soil type	Depth	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO
			Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Erosive	1	Memphis silt loam-	0–8	80.90	0.92	2.74	7.94	0.11	0.46	0.27
	2	-----do-------------	8–28	73.03	.76	5.15	12.72	.11	.41	.96
	4	Orangeburg fine sandy loam.	0–16	90.63	.63	1.40	3.72	.03	.03	.05
	5	-----do-------------	16–72	83.92	.72	3.09	9.29	.01	Trace.	.05
Nonerosive	8	Nipe clay----------	0–12	7.96	.73	64.00	[3]14.71	1.09	.41	.27
	9	-----do-------------	12–24	7.04	.65	65.37	[3]15.33	.99	.39	.30
	10	Aikin silty clay loam.	0–20	40.57	3.06	17.71	24.11	.30	.24	.46
	11	-----do-------------	20–40	40.54	3.27	17.91	25.18	.23	.17	.43

[1] No sample contained carbonates.
[2] Determinations by G. Edgington.
[3] Sample contains chromium.

TABLE 2.—*Chemical composition of erosive and nonerosive soils*—Continued

Character and sample No.		Soil type	K_2O	Na_2O	P_2O_5	SO_3	N	Ignition loss	H_2O at 110° C.
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Erosive	1	Memphis silt loam	1.84	0.66	0.11	0.11	0.10	4.03	1.27
	2	do	1.95	.71	.20	.06	.04	3.99	3.18
	4	Orangeburg fine sandy loam.	.06	Trace.	.04	.08	.06	2.96	.82
	5	do	.07	.07	.02	.09	.01	3.22	1.14
Nonerosive	8	Nipe clay	Trace.	.03	.04	.24	.08	10.12	3.29
	9	do	Trace.	Trace.	.05	.32	.02	9.20	2.88
	10	Aikin silty clay loam	.55	.18	.43	.14	.17	12.31	4.28
	11	do	.41	.17	.41	.11	.10	11.28	4.47

Data given in Table 1 indicate that the nonerosive soils studied are considerably heavier in texture than the erosive soils. This is unfortunate in that such a wide difference in texture makes comparison difficult. Many of the differences indicated in the various determinations may be explained by this difference in texture without regard to erosional characteristics. The moisture equivalent, lower liquid limit, maximum water-holding capacity, slaking value, and shrinkage follow rather closely the mechanical composition and colloid content. The volume of voids is slightly higher in the erosive than in the nonerosive soils, particularly in the surface soils. The specific gravity of the nonerosive soils is higher than that of the erosive soils, but this is not believed to be significant.

The dispersion ratio seems to have some bearing on the erosional characteristics of the soil without regard to the other properties. For instance, the Nipe clay was regarded as being the least erosive in the group of samples, and it has the lowest dispersion ratio, whereas the Memphis silt loam, which was regarded as being the most easily eroded, has the highest dispersion ratio.

In the Memphis soil the dispersion ratio also indicates the relative degree of erosivity of the different horizons as observed in the field. The A horizon, with a dispersion ratio of 44.6, erodes more rapidly than the B horizon (where it is exposed), which has a dispersion ratio of 26.3. The C horizon, which has a dispersion ratio of 66, erodes more rapidly, once it is exposed, than either the A or the B.

The ratio of the colloid to the moisture equivalent is considerably higher for the nonerosive than for the erosive soils. The higher ratio should indicate a lower water-holding capacity of the soil and, therefore, probably a higher rate of percolation, with a consequent decrease of run-off from one rainfall. It is the water which runs off after the soil is saturated which causes erosion. A soil with a high rate of percolation may not necessarily erode less for a given amount of run-off, but it is believed that conditions which cause rapid percolation tend to make it less erosive. A satisfactory laboratory method of measuring the percolation rate of soils under conditions comparable to those in the field has not been found. A method is now being studied whereby samples may be taken in their natural condition and sent to the laboratory. It is hoped thus to determine a relation between the percolation rate under natural field conditions and artificial conditions in the laboratory. The chief difficulty lies in determining the rate of percolation of the entire profile. A fairly satisfactory determination may be made for a single horizon, but if the horizon examined is underlain by a comparatively impervious stratum the determination will be of little value. Soil samples are ordinarily collected by horizons which in most places, rather than being sharply differentiated, are separated by transitional zones. This arrangement of layers makes it very difficult to repack the material in a condition remotely simulating that in which it occurs originally.

In general, the dispersion ratio decreases as the resistance to erosion increases. The converse is true of the colloid moisture-equivalent ratio. As both ratios are indicative of the erosional characteristics of the soil, it seemed desirable to combine them into one expression. Since the two ratios vary inversely, a combination was accomplished by dividing the dispersion ratio by the colloid moisture-equivalent ratio and designating it as the erosion ratio. The dispersion ratio is a function of the ease of dispersion and of the mechanical composition of the soil, and the colloid moisture-equivalent ratio is a function of the ease of percolation and the absorptive power of the soil. Hence the erosion ratio combines the relations of the soil toward water in such manner that a low value of the ratio is indicative of high resistance to erosion.

The lowest erosion ratio shown by the erosive soils is 12.4 for the Orangeburg subsoil (No. 5), and the highest for the nonerosive soils is 8.7 for the Aikin surface soil (No. 10). The erosion ratio distinguishes the erosive from the nonerosive soils in the same order as the dispersion ratio, but the differentiation is more marked. In the Memphis and Nipe soils previously mentioned, the dispersion ratios are 44.6 and 6.1, and the erosion ratios are 65.2 and 2.9, respectively. The erosion ratios appear to express more satisfactorily the differences between the soils. Neither the dispersion nor the erosion ratios are to be regarded as quantitative expressions of relative erosivity.

The ratio of clay to silt in the soil is taken as an index of the mechanical composition. In soils as heavy as or heavier than a loam (containing more than 50 per cent of silt and clay) in texture this may give some idea of erosiveness. Where the ratio is very low, as in a silt loam soil, very little clay is present to bind the material into aggregates, and the silt particles are free to enter quickly into suspension in the run-off water. This is exemplified in Memphis silt loam, which has a very low ratio of clay to silt and a very high dispersion ratio. This no doubt accounts, at least in part, for the high erosivity of this particular soil. In sandy soils the ratio is not so significant, because the silt and clay together constitute such a small proportion of the total material.

The main variations in the chemical composition of these soils, as indicated in Table 2, may be correlated with the mechanical composition and colloid content. The nonerosive soils are low in sand and high in colloid and are low in SiO_2 and high in Fe_2O_3 and Al_2O_3. This may be indicative of a low silica-sesquioxide ratio,[3] which ratio is believed to have a very important bearing on soil erosion and on other soil characteristics (*2*). Bennett (*4*) has shown that this ratio is indicative of the friability and plasticity of Central American soils and that these properties are closely associated with erosional behavior.

[3] The silica-sesquioxide ratio is the molecular ratio of the silica to the combined alumina and iron oxide present in the colloid.

SECOND GROUP

In the first group of samples the great difference in texture between the erosive and nonerosive soils made it difficult to correlate the results. Furthermore, the samples were derived from very different soil material and were collected in widely separated localities where they had been subject to very different climatic conditions. Therefore it was deemed advisable to collect, from the same locality, two samples as nearly alike in texture as possible, one of which was erosive and the other nonerosive and to make a study of their physical and chemical properties. For this study the Iredell and Davidson soils of North Carolina seemed to furnish admirable examples, as they are derived from the same soil material, occur under the same climatic and topographic conditions, and lie almost immediately adjacent to each other but differ notably in that one is very readily eroded and the other is markedly resistant to erosion.

DESCRIPTION OF SAMPLES

R. C. Jurney, of the Division of Soil Survey of this bureau, collected samples of the Iredell loam (erosive) and of the Davidson clay loam (nonerosive), near Greensboro, N. C. The samples were described as follows:

Iredell loam from 14 miles east of Greensboro, N. C. Sample No. 12, A_1 horizon, 0 to 5 inches, gray loam containing some organic matter; sample No. 13, A_2 horizon, 5 to 10 inches, yellowish-brown loam; sample No. 14, B horizon, 10 to 20 inches, yellowish-brown heavy tenacious impervious plastic clay, breaking into large lumps which on further pressure break into angular particles, and containing few plant roots; and sample No. 15, C horizon, 20 to 27 inches, greenish, yellowish, and brownish decomposed diorite rock. Ironstone concretions occur in the A_2 horizon and in adjoining plowed fields appear on the surface. Horizon B, when exposed to the atmosphere, turns rust brown and cracks when dry. On moderate slopes the B or C horizon is exposed through erosion.

Davidson clay loam from 9 miles north of Greensboro, N. C. Sample No. 16, A horizon, 0 to 9 inches, slightly reddish-brown clay loam; sample No. 17, B_1 horizon, 9 to 36 inches, deep-red heavy brittle clay, breaks into large lumps which finally crumble into smaller angular and subangular particles; sample No. 18, B_2 horizon, 36 to 60 inches, light-red friable crumbly clay; and sample No. 19, C horizon, 60+ inches, ocherous-yellow, black, and reddish-brown decomposed diorite rock. A cut surface of the B_1 horizon shows a lighter-red color than the broken portion, and when well dried the material in road cuts to a depth of about 2 feet shows perpendicular cracks one-eighth inch and less in width. The Davidson soil is much more deeply weathered than the Iredell.

RESULTS

Determinations were made on these samples in the manner described for the first group. The physical determinations are shown in Table 3 and the chemical analyses in Table 4. In addition, samples of colloid were extracted and analyzed, the determinations being shown in Table 5.

TABLE 3.—*Physical properties of an erosive and a nonerosive soil from the same locality*

Character and sample No.		Soil type	Horizon	Depth	Mechanical analysis [1]			Colloid	Moisture equivalent	Lower liquid limit	Maximum water-holding capacity	Specific gravity	Slaking value
					Sand	Silt	Clay						
				Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Seconds*
Erosive	12	Iredell loam	A_1	0–5	36.2	38.4	16.4	24.7	30.5	39.0	67.8	2.74	55
	13	do	A_2	5–10	37.3	45.6	16.4	15.0	18.1	19.5	44.4	2.89	25
	14	do	B	10–20	11.2	23.9	63.1	63.9	45.9	56.1	78.2	2.84	(3)
	15	do	C	20–27	34.9	28.5	35.2	39.0	38.0	34.5	62.0	2.90	------
Nonerosive	16	Davidson clay loam	A	0–9	31.9	39.9	23.8	27.3	25.1	29.1	59.9	2.68	100
	17	do	B_1	9–36	14.0	22.3	60.4	64.8	39.3	61.0	80.9	2.77	(3)
	18	do	B_2	36–60	18.5	30.4	50.3	66.5	43.0	63.1	88.0	2.80	------
	19	do	C	60+	35.4	34.5	29.6	53.8	39.3	52.8	79.0	2.82	------

Character and sample No.		Soil type	Briquettes at maximum density					Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Ratio of clay to silt
			Moisture content	Apparent specific gravity [2]	Shrinkage [2]	Pore space [2]	Volume of voids [2]				
			Per cent		*Per cent*	*Per cent*	*Per cent*				
Erosive	12	Iredell loam	15.5	1.64	6.17	40.2	14.8	19.6	0.81	24.2	0.43
	13	do	11.9	1.95	1.09	32.2	10.5	13.0	.83	15.7	.36
	14	do	17.2	1.83	9.93	35.6	4.1	20.9	1.39	15.0	2.64
	15	do	13.3	2.01	5.57	30.7	3.7	23.5	1.03	22.8	1.24
Nonerosive	16	Davidson clay loam	14.0	1.84	3.60	31.3	5.5	13.3	1.09	12.2	.60
	17	do	19.6	1.69	2.74	39.0	5.8	6.1	1.65	3.7	2.71
	18	do	20.1	1.68	3.00	40.0	6.1	6.6	1.55	4.3	1.65
	19	do	17.6	1.73	2.93	38.7	8.1	10.6	1.37	7.7	.86

[1] Determinations by L. T. Alexander. [2] Based on wet volume. [3] Did not slake in 18 hours.

TABLE 4.—*Chemical composition* [1] *of an erosive and a nonerosive soil from the same locality* [2]

Character and sample No.		Soil type	Horizon	Depth	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO
				Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Erosive	12	Iredell loam	A_1	0–5	56.40	2.41	12.34	11.17	0.27	4.43
	13	do	A_2	5–10	60.56	2.38	12.37	11.83	.22	4.38
	14	do	B	10–20	47.70	1.84	13.82	21.52	.05	2.92
	15	do	C	20–27	47.52	1.82	12.35	20.22	.18	5.77
Nonerosive	16	Davidson clay loam	A	0–9	70.53	1.80	6.10	12.45	.22	.75
	17	do	B_1	9–36	52.70	1.39	10.62	22.87	.07	.51
	18	do	B_2	36–60	50.53	1.47	14.87	23.05	.08	.27
	19	do	C	60+	52.62	1.23	13.37	20.98	.47	.27

Character and sample No.		Soil type	MgO	K_2O	Na_2O	P_2O_5	SO_3	N	Ignition loss	H_2O at 110° C
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Erosive	12	Iredell loam	0.92	0.20	1.48	0.31	0.18	0.27	10.50	2.10
	13	do	.94	.20	1.79	.21	.13	.03	5.03	1.10
	14	do	1.25	.21	1.19	.15	.08	.04	10.00	3.90
	15	do	2.45	.26	2.00	.20	.09	.02	6.96	2.90
Nonerosive	16	Davidson clay loam	.45	.58	0	.10	.12	.11	7.66	1.45
	17	do	.40	.45	0	.12	.12	.02	10.55	1.95
	18	do	.58	.34	0	.20	.12	.01	9.37	3.70
	19	do	1.00	.72	0	.24	.09	.01	9.15	4.25

[1] No sample contained carbonates. [2] Determinations by G. J. Hough.

The results shown in Table 3 indicate that the texture of the two samples was, as a whole, very nearly the same. The Iredell rarely occurs as a clay loam except in eroded phases, and the Davidson rarely occurs as a loam, so the agreement in this respect was considered very satisfactory. The surface horizon of the Iredell contained more organic matter than that of the Davidson, which undoubtedly accounts for the fact that all the determinations involving moisture, except the colloid content, which is higher in proportion to the quantity of clay, are higher for the Iredell A_1 than for the Davidson A. This difference in organic-matter content also constitutes the main difference between the Iredell A_1 and A_2. The slaking value is lower for the Iredell surface horizon than for the Davidson, and the shrinkage is greater. These differences are probably significant. A peculiar circumstance is noted in the volume of voids determinations. The value decreases through the Iredell profile and increases through the Davidson.

The dispersion ratio is notably higher in the Iredell than in corresponding horizons of the Davidson soil, and is higher in the Iredell B than in either the A_1 or A_2. This is the only profile so far examined in which this is the case. The Davidson B horizon has a dispersion ratio very similar to that of the Nipe soil (see Table 1), and the indications are that if it were exposed it would be equally resistant to erosion.

The ratios of colloid to moisture equivalent are all higher for the Davidson soil than for the Iredell in corresponding horizons. The ratio for the Iredell B horizon (1.39) is the highest obtained from several determinations of the moisture equivalent. The material is of such character that it is difficult to make a satisfactory determination of the moisture equivalent.

The erosion ratio differentiates the two soils more completely than the dispersion ratio. The dispersion ratio of the Iredell A_2 horizon is slightly lower than that of the Davidson A. However, the highest erosion ratio of the Davidson is lower than that of any horizon of the Iredell. The relative degree of erosion of these two soils could be determined only by careful measurements under similar conditions. Personal observation indicates that the difference would be greater than is shown by the erosion ratio, as in the cornfield adjoining the area where the sample of Iredell was taken; though the slope was very gentle only a very thin layer of the A_2 horizon was left in the rows, and the B horizon was exposed between the rows. On the other hand, no evidence of erosion was noted in the Davidson soil.

The Davidson A horizon has an erosion ratio higher than the Aikin or the Nipe in the first group. The observations of field men of long experience, with whom the writer has discussed the matter, indicate that it is probably the most erosive of the three nonerosive soils. In fact, there may be some question about classing the A horizon as a nonerosive soil, as defined. However, for the purpose of this phase of the investigation, the marked difference in the resistance of these two soils to erosion is the important consideration. The Davidson B horizon, however, where it has been exposed by the cultivation of steep slopes or because of extraordinary local conditions, is markedly resistant to erosion and unquestionably should be classed as nonerosive.

The ratio of clay to silt is higher in the Davidson than in the Iredell soil. The slightly heavier texture of the Davidson accounts for the small differences noted. In two soils of exactly the same texture this ratio would of necessity be the same and could have no bearing on the erosional characteristics.

The chemical analyses shown in Table 4 indicate that the Davidson soil is slightly higher in silica and alumina and lower in iron, especially in the A and B horizons. However, it is doubtful whether these differences are of significance. The Iredell contains considerably more basic materials which, undoubtedly, have an important bearing on its physical properties, especially its dispersivity and plasticity. The color of the two soils is in marked contrast. The Iredell is yellow, and the Davidson, in spite of its lower iron content, is very red. Undoubtedly the greater part of the iron in the Iredell is present as a part of the complex silicate, whereas in the Davidson it is present as a partly hydrated oxide. This is in accord with the acid dye adsorption figures obtained by J. G. Smith, of this bureau. The Iredell B horizon adsorbed 0.0016 gram of biebrich scarlet per gram of soil, whereas the Davidson B_1 horizon adsorbed 0.0057 gram per gram.

The chemical analyses of the colloid extracted from these soils is shown in Table 5. Only the B horizon was examined. No dispersion agent was used in the Iredell soil, and 63.3 grams of colloid were extracted from 100 grams of soil, the separation being made at 1 micron; 55.7 grams were extracted from 100 grams of the Davidson. Since this colloid would not stay in suspension without some dispersion agent, sufficient ammonia was added to keep it in suspension. This fact is probably as significant with respect to erosion as any of the properties which have been discussed. It accounts for the friability and high percolation rate of the Davidson soil, owing to the flocculation and granulation of the particles. It undoubtedly accounts for the low erosivity and the physical properties, such as the dispersion ratio, of which it is indicative.

TABLE 5.—*Chemical composition of colloids from the Iredell (erosive) and the Davidson (nonerosive) soils* [1]

Sample No.	Soil type from which colloid was extracted	Horizon	Depth	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO
			Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
14C	Iredell loam	B	10–20	40.73	1.91	15.45	26.94	0.014	0.97	0.93
17C	Davidson clay loam	B_1	9–36	36.92	.92	16.03	31.67	.06	.56	.41

Sample No.	Soil type from which colloid was extracted	K_2O	Na_2O	P_2O_5	SO_3	N	Ignition loss	H_2O at 110° C.	$\frac{\text{Mols } SiO_2}{\text{Mols } R_2O_3}$
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
14C	Iredell loam	0.11	0	0.13	0.16	0.15	12.44	7.25	1.88
17C	Davidson clay loam	.37	0	.18	.12	.07	13.14	3.20	1.50

[1] Determinations by G. J. Hough.

The analyses of the two colloids are very similar, the most important difference being shown in the silica-sesquioxide ratio which, however, is not so great as might be expected from such contrasting soils. The water at 110° C. also shows a significant difference. These samples were air-dried and kept together in the same laboratory at all times so the air-dry moisture content would be in the same order as the adsorption of water vapor over 30 per cent sulphuric acid (*2, p. 11*).

Several other determinations, some of which are listed in Table 6, were made on these soils. The heat-of-wetting determinations were made by the method outlined by Anderson (*1, p. 927*), the pH determinations electrometrically, and the modified dispersion ratio by shaking a 10-gram sample of soil in 100 cubic centimeters of water in a reciprocating shaker for seven hours before transferring it to a cylinder and pipetting in the usual manner.

TABLE 6.—*Miscellaneous determinations on the Iredell and Davidson soils*

Sample No.	Soil type	Horizon	Depth	Heat of wetting [1]	pH	Modified dispersion ratio
			Inches	*Cal. per gm.*		
12	Iredell loam	A_1	0–5	4.6	6.6	87.4
13	do	A_2	5–10	2.5	6.9	
14	do	B	10–20	7.4	6.7	96.2
15	do	C	20+	5.4	6.7	
16	Davidson clay loam	A	0–9	2.9	6.4	84.9
17	do	B_1	9–36	3.7	5.2	(2)
18	do	B_2	36–60	4.9	4.5	
19	do	C	60+	3.9	4.4	

1 Determinations by M. S. Anderson.
2 Flocculated. With sufficient NH_4OH to prevent flocculation=96.4.

The heat-of-wetting determinations are approximately twice as high for the respective horizons of the Iredell soil as for the Davidson. Since the two soils have approximately the same colloidal content in their respective horizons, a much higher heat of wetting is indicated, corresponding to the higher silica-sesquioxide ratio, as shown by Anderson and Mattson (*2*) for the Iredell colloid.

The pH determinations indicate that the Iredell soil is more nearly neutral than the Davidson. The acidity of the Davidson, which increases with depth, is probably responsible for the flocculating action of the colloid. The modified dispersion ratio indicates that the Iredell B horizon is nearly completely dispersed by shaking seven hours whereas that of the Davidson is completely flocculated.

THIRD GROUP

Data as to the quantity of run-off and the degree of erosion taking place for periods of three or more years are available for the erosion experiment stations at Columbia, Mo., Spur, Tex., and Raleigh, N. C. These data show rather wide variation when the quantity of rainfall and the slope of the plots are considered. With a view to determining to what extent the character of the soil influenced these results, samples were obtained [4] from the various stations.

DESCRIPTION OF SAMPLES

Cecil fine sandy loam from erosion experiment station, Raleigh, N. C. Sample No. 20, 0 to 6 inches, surface soil; and sample No. 21, 6 to 24 inches, subsoil.

4 The writer wishes to acknowledge the courtesy of R. E. Dickson, of the Texas Agricultural Experiment Station, of H. H. Krusekopf, of the University of Missouri, and of S. H. McCrory, of the Bureau of Public Roads, in providing these samples.

Shelby loam from erosion experiment station, Columbia, Mo. Sample No. 22, 0 to 7 inches, A horizon; sample No. 23, 7 to 24 inches, B horizon; and sample No. 24, 24 to 36 inches, C horizon.

Miles clay loam from erosion experiment station, Spur, Tex. Sample No. 25, 0 to 8 inches, surface soil.

RESULTS

The samples obtained were representative of the erosion station plots. However, only two plot treatments were the same for all three stations—sod plots and bare uncultivated plots. Inasmuch as there was no similarity in the types of grass grown in the sod plots, only the data for bare uncultivated plots [5] (*10, 11*) were examined. Some of the published data have been recalculated. The results obtained are given in Table 7.

TABLE 7.—*Some of the physical properties of soils and erosion data from erosion experiment stations*

Sample No.	Soil type	Duration of experiment	Depth	Mechanical analysis [1] Sand	Mechanical analysis [1] Silt	Mechanical analysis [1] Clay	Colloid	Moisture equivalent	Maximum water-holding capacity
			Inches				*Per cent*	*Per cent*	*Per cent*
20	Cecil fine sandy loam, North Carolina	1924–1927	0–6	58.0	14.4	25.3	21.1	19.2	46.9
21	do	1924–1927	6–24	28.4	12.3	58.6	53.9	32.9	64.4
22	Shelby loam, Missouri	1917–1923	0–7	11.9	61.4	24.3	19.5	23.6	51.6
23	do	1917–1923	7–24	6.1	49.7	42.5	40.2	32.4	64.6
24	do	1917–1923	24–36	14.9	42.3	41.7	37.6	30.4	57.0
25	Miles clay loam, Texas	1926–1928	0–8	30.1	33.1	34.0	31.4	25.2	56.3

Sample No.	Soil type	Slaking value	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Ratio of clay to silt	Bare uncultivated plots: Slope	Average annual rainfall [2]	Average annual run-off	Average annual run-off	Average annual erosion	Erosion per inch of run-off
		Seconds					*Per cent*	*Inches*	*Per cent*	*Inches*	*Tons per acre*	*Tons per acre*
20	Cecil fine sandy loam, North Carolina	60	28.4	1.10	25.8	1.76	9	41.16	32	13.3	21.44	1.6
21	do	------	9.8	1.64	6.0	4.76	------	------	------	------	------	------
22	Shelby loam, Missouri	65	31.0	.83	37.4	.40	3.68	35.87	49	17.6	39.13	2.2
23	do	------	27.6	1.24	22.3	.86	------	------	------	------	------	------
24	do	------	30.3	1.24	24.4	.99	------	------	------	------	------	------
25	Miles clay loam, Texas	25	27.4	1.25	21.9	1.03	2	20.30	38	7.7	21.77	2.8

[1] Determinations by L. T. Alexander.
[2] Average for the duration of the experiment.

The data of Table 7, in the light of the results obtained in the first two groups, would lead one to expect amounts of erosion somewhat at variance with those actually obtained in the field. On the Texas soil (No. 25) the slope, rainfall, and run-off are all lower than at the other stations, but the erosion is the greatest. This soil has the lowest dispersion ratio, the highest ratio of colloid to moisture equivalent, and the lowest erosion ratio of the three surface soils,

[5] BARTEL, F. O. PROGRESS REPORT ON SOIL EROSION AND RUN-OFF EXPERIMENTS AT NORTH CAROLINA EXPERIMENT STATION FARM. U. S. Dept. Agr., Bur. Pub. Roads, Div. Agr. Engin. [Mimeographed.]

which would indicate that it is the least erosive. The differences, however, are not large, and from the laboratory data all these soils would be classed as highly erosive, as they actually are in the field. These soils occur under widely divergent conditions of climate and topography, the experiments did not run concurrently, and additional factors [6] not indicated by the data influenced results.

Under these conditions it would be too much to expect that the laboratory results would indicate accurately the relative erosivity of these soils. Under more nearly similar conditions a closer correlation would undoubtedly appear.

DISCUSSION

The results obtained in the investigation of the three groups of samples do not include all the properties which may have a bearing on the question. A preliminary study made of the angle of repose indicated that it is much greater in nonerosive soil in a saturated condition than in an easily eroded soil. It is possible that the plasticity number would be more significant than the lower liquid limit. The percolation rates, if available, would doubtless be of value.

The quantity of organic matter, the silica-sesquioxide ratio, and the total exchangeable bases all have some bearing on the erosional behavior of soils. A complete picture would, doubtless, require the determination of these quantities. On the other hand, some of the properties actually determined seem to have little bearing on the question at issue. The maximum water-holding capacity, the lower liquid limit, and the properties of briquettes at maximum density show no marked differences with respect to erosive and nonerosive soils. The slaking-value determination may, with some modification, be of distinct value. The results obtained indicate that the slaking value increases with increase in the quantity of colloid, but the indications are that, other things being equal, the slaking value will be higher for a nonerosive soil. This is illustrated by the Iredell (No. 12) and Davidson (No. 16) soils in Table 3.

None of the chemical properties studied have been found useful in differentiating between erosive and nonerosive soils, though undoubtedly the dispersivity of a soil is influenced by the quantity and character of the exchange bases present and the silica-sesquioxide ratio is the determining influence on physical properties.

The nonerosive soils reported in this bulletin have all developed under conditions of high annual rainfall (40 inches or more), which indicates a low silica-sesquioxide ratio. Robinson and Holmes (*21*) found that soil colloids having a ratio less than 1.85 were from localities having 40 or more inches of rainfall annually.

The outstanding characteristics of soils which make possible their differentiation with respect to erosion seem to be the dispersion ratio, the ratio of colloid to moisture equivalent, and the erosion ratio.

The dispersion ratio is probably the most valuable single criterion in distinguishing between erosive and nonerosive soils. It is logical

[6] For example, the Texas experiment was started in 1926, when the rainfall was greater than in any other of the 17 years during which records had been kept at the Spur station. In the annual report of the Spur station for 1926 the condition of the soil at the beginning of the experiment is described as follows: "The soil in the plots at the beginning of this test was in an abnormal condition for the following reasons: Some subsoil was mixed unavoidably with the surface soil when the ditches were dug for the erection of the walls; the soil was packed very hard by men walking across it during the time the plant was under construction; the soil in spots had become puddled."

to assume that soil material which is easily brought into suspension is more readily carried away by run-off water. The highest dispersion ratio obtained for the nonerosive soils was 15.1 (No. 10) and the lowest for the erosive soils was 13.0 (No. 13). It is probable that on the basis of this property alone soils with a dispersion ratio of less than 15 may safely be classed as nonerosive. The method of making the determination may unquestionably be improved. During the course of the investigation several improvements were suggested, but the original method was adhered to in order to keep determinations comparable.

The ratio of colloid to moisture equivalent is also an important criterion of erosion. The nonerosive soils examined have all shown a high ratio (approximately 1.5 or more), and no erosive soil has shown a ratio as high as 1.5. However, the greatest significance of the ratio of colloid to moisture equivalent is in its relation to the erosion ratio.

The erosion ratio is even more significant than the dispersion ratio, because it involves two additional factors which have an important bearing on erosion, the quantity and the character of the colloid. The erosion ratio is an indication of the erosiveness of soils under similar field conditions. It does not necessarily indicate the relative degree of erosion of soils which are subject to different conditions of topography and climate, particularly temperature and quantity and periodicity of rainfall. This, in part, accounts for the lack of correlation between the erosion ratio and the extent of erosion on the experiment-station soils.

In order to illustrate more clearly the variation of the erosion ratio for the soils examined, the erosion ratios in Tables 1, 3, and 7, are shown in descending numerical order in Table 8.

TABLE 8.—*Erosion ratio summarized*

Sample No.	Soil type	Depth	Erosion ratio	Sample No.	Soil type	Depth	Erosion ratio
		Inches				*Inches*	
3	Memphis silt loam	120–216	115.8	13	Iredell loam	5–10	15.7
1	do	0–8	65.2	14	do	10–20	15.0
4	Orangeburg fine sandy loam	0–16	50.9	5	Orangeburg fine sandy loam	16–72	12.4
22	Shelby loam	0–7	37.4	16	Davidson clay loam	0–9	12.2
20	Cecil fine sandy loam	0–6	25.8	10	Aikin silty clay loam	0–20	8.7
7	Orangeburg fine sandy loam	96–136	24.8	19	Davidson clay loam	60+	7.7
24	Shelby loam	24–36	24.4	11	Aikin silty clay loam	20–40	6.9
12	Iredell loam	0–5	24.2	21	Cecil fine sandy loam	6–24	6.0
2	Memphis silt loam	8–28	23.2	18	Davidson clay loam	36–60	4.3
15	Iredell loam	20–27	22.8	17	do	9–36	3.7
6	Orangeburg fine sandy loam	72–96	22.4	8	Nipe clay	0–12	2.9
23	Shelby loam	7–24	22.3	9	do	12–24	2.2
25	Miles clay loam	0–8	21.9				

If the upper limit for nonerosive soils is arbitrarily set at 10, the surface horizon of the Davidson clay loam (No. 16) is the only nonerosive soil which does not come within this limit. If the limit is made higher, the Orangeburg fine sandy loam subsoil (No. 5) will be included. This material is probably relatively resistant to erosion, the difficulty being caused by the ready washing out of the sandy substratum (No. 6), which causes the heavier-textured layers above to cave in. However, until more data are available it seems advisable to set the limit for the erosion ratio at 10 for nonerosive soils.

From these data it is clear that soils may readily be classified as erosive or nonerosive when they differ widely in their erosion ratios as herein defined. However, whether within narrow limits of difference the ratio is sufficiently distinctive to place soils in exact relative order of erosiveness is not wholly certain. The number of samples which have been examined was necessarily limited, owing to the difficulty of obtaining samples whose erosional characteristics were known. As the number of erosion experiments is increased, however, it will be possible to obtain more exact data on the field behavior of soils which are necessary for a proper comparison with the data obtained in the laboratory.

SUMMARY

A study of the physical and chemical properties of three erosive and three nonerosive soil types is presented. The properties having the greatest influence on soil erosion are indicated by the dispersion ratio, the ratio of colloid to moisture equivalent, the erosion ratio, and the silica-sesquioxide ratio. Limiting values of these ratios are tentatively suggested for distinguishing erosive from nonerosive soils.

Determinations made on samples of soil from three erosion experiment stations are compared with the erosion and run-off data.

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