THE EFFECT OF SLOPE AND RATE OF RAINFALL ON RUNOFF AND SOIL EROSION

by

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INTRODUCTION

Soil erosion presents one of the most serious problems in agriculture at the present time. It has been estimated by Bennett (1) that approximately 17.5 million acres of land, formerly fair to good soil, have been abandoned due to soil erosion. This wastage has been due largely to two causes; (1) the breaking out of land that is on steep slopes, and (2) the improper handling of land that is subject to erosion.

It has been long known that the amounts of runoff and erosion increased with the slope and with the rate of rainfall. Very few data, however, have been obtained on the exact relation of these factors to the amounts of runoff and erosion.

The work herein reported was planned with the idea of obtaining more exact measurements on the influence of the degree of slope and the rate of the rainfall on erosion and runoff. Special methods were devised to eliminate so far as possible the variation in soil conditions of the plats included in the study. Field plats were used for the major part of the work and these were supplemented with laboratory experiments.

HISTORICAL

The early work on soil erosion was done mainly by Engineers and Geologists in determining the carrying capacity and the amount of material carried by streams. The formulae derived by Engineers applying to streams and ditch channels where the water has considerable depth were not designed for a thin covering of water which causes the vast amount of soil wastage from fields. Chamberlin and Salisbury (5) state that the transporting power varies as the sixth power of the velocity. That is by doubling the velocity, the carrying power of the water is increased 64 times.

Davis (9), Hitchcock (11) et al. have made estimates on material carried in solution and suspension by various rivers. These data show the vast amount of soil and plant nutrients that are being carried to the sea annually.

Erosion Experiments

Burr (4) determined the safe velocity of water flowing over soils in ditches without causing erosion. Soils were analyzed to determine their clay and sand content. He considered that the larger the proportions of clay to that of sand the greater will be the power of the soil to resist any hydraulic force, be it pressure due to head or depth or erosion due to velocity. His data show that pure sand will stand a velocity of 1.10 feet per second and pure clay will stand a velocity of 7.35 feet per second without eroding. This applies to ditches, but is not what would be expected under field conditions.

Culbertson (8) found that south slopes were from 3 to 4 1/2 degrees steeper than were the opposite north slopes. He found very little difference between the east and the west slopes. The greater erosion of the south slope was accounted for by it being subject to more freezing and thawing than the north slope. As the south slopes become steeper the erosion becomes worse due to the greater slope.

Sampson and Weyl (17) found that one rain of 0.70 effective rainfall inches was far more erosive than 14 rains with an effective rainfall of 4.05 inches. That the percentage of sediment carried in the runoff is proportionately higher as the velocity of the flow increases.

Coffey (6) outlined one of the first experiments to determine the amount of material that is removed from an area by erosion when cropped to various crops. An area of 1/200 of an acre was surrounded by split glazed tile. The runoff was collected from which analyses were made, but no results were recorded.

Vifquain (18) located plats at Columbia, Missouri on Shelby loam soil with a slope of 4.5 degrees. He found that a rain at the rate of 0.47 inches in 36 minutes caused twenty times as much erosion as did a rain at the rate of 0.57 inches in 137 minutes. Next to the condition of the surface in controlling the runoff, is the amount and rapidity of rain. If large or small amounts come suddenly, not giving the soil time to absorb it, much of it runs off and is of little avail. When it comes slowly, most of it is absorbed.

Duley and Miller (10) established plats to determine the effect of crop and rate of rainfall on erosion. The plats were 6 feet wide and 90.75 feet long. Each plat was surrounded by strips of galvanized iron. The slope of the Shelby loam soil used was 3.68 per cent. These plats were located at Columbia, Missouri where the average annual rainfall was 37 inches. The authors make the following statement, "When land is free from vegetation and under a definite system of tillage, or where the land is cultivated and carries a summer intertilled crop like corn, the amount of water absorbed during different years tends toward a constant quantity." A close correlation was found to exist between the amount of erosion taking place and the number of heavy rains falling during a year. Two hundred fifty-six rains caused runoff, but 16 of the most destructive rains during the 6 years carried more than 50 per cent of the loss of soil.

Miller (14) reports on the effect of slope under conditions similar to those used by Duley and Miller. Each plat was planted continuously to corn. Soil was lost from a 3.68 per cent slope at the rate of 26 tons per acre annually. The loss from the 6 per cent slope was 85 tons and from the 8.5 per cent slope the loss was 150 tons. From the 8.5 per cent slope the surface soil was removed at the rate of 1 inch per year. The normal depth of the surface soil is approximately 9 inches so that under such conditions the subsoil would be exposed in less than one decade.

Conner, Dickson and Scoates (7) report the following results from various slopes for a three year period 1926-1928. The average annual rainfall is 22.01 inches.

It will be noticed that there was less runoff from the 3 per cent than from the 2 per cent slope. The authors explain this by saying that due to the filling in of soil to establish the 3 per cent grade the soil was left in a condition to absorb more water than a natural 3 per cent grade would have absorbed. There is an indication here as well as in reports of some other work that the losses of soil bear a more definite relation to the steepness of grade than do the

Slope per cent	Runoff in inches	Runoff per cent	Soil eroded	
			Lbs. per acre	Inches
Level	0.61	3.55	8583	.029
1	3.30	17.21	18624	.064
2	3.63	19.58	25395	.086
3	3.01	16.56	25572	.087

water losses. It was found that the rapidity of rainfall directly influenced the percentage of runoff, but that other factors such as the moisture content of the soil at the time of the rainfall, exerts considerable influence on the losses.

Miller (14) compares the Missouri results on Shelby loam soil and the North Carolina results on Cecil fine sandy loam. The loss of soil at North Carolina with a 9 per cent slope and a rainfall of 41 inches from the cultivated uncropped plat was 21 tons. Under similar conditions at Missouri with a grade of 3.68 per cent and a rainfall of 37 inches, the loss was 26 tons. This emphasizes the influence of kinds of soil and rainfall on soil erosion.

Nichols and Saxton (16) established plats 1/58 acre in area on Cecil clay loam soil. Each plat was surrounded by a concrete wall. Water was applied by means of Skinner catfish nozzles with pressure from water mains. The experiment was planned to determine the effect of slope, direction of rows, and condition of surface soil on soil erosion and runoff. The erosion data found in (15) and the runoff caused by one application of water found in (16) are shown in the table on page 9. The authors state that the rate of rainfall is more important than the amount of rainfall in relation to runoff. The degree of saturation of a soil was found to affect absorption and the erosion. The erosion varied uniformly with the slope up to about 12 per cent grade, above this slope the rate of erosion increased very rapidly and it was concluded that this was the critical slope of this soil.

Lowdermilk (12) in order to determine the influence of forest litter on runoff, percolation and erosion, dug soil up in shallow layers and then repacked them in their original order and approximately to their original volume in rectangular iron tanks. The horizontal dimensions of the tanks were 2 x 5 feet and 2.5 feet deep. The upper end was raised so that a slope of 30 per cent was obtained. Artificial rainfall was produced by using Skinner over-head sprinkling nozzles. Rain gages were placed on the plats to determine the amount of water applied.

The Effect of Slope and Direction of Rows on the Amounts of Soil Eroded and Water Runoff at the Alabama Station. Cecil Clay Loam Soil.

Pounds of soil eroded per acre

Per cent slope	1		5		10		15		20	
	Rows with slope	Rows contour	Rows with slope	Rows contour	Rows with slope	Rows contour	Rows with slope	Rows contour	Rows with slope	Rows contour
(a) Land not plowed	457.62	190.99	1093.72	193.72	1515.54	238.84	6733.22	2393.08	9256.22	5823.2
Land plowed	610.16	623.50	2123.96	1995.2	2315.94	2427.88	9512.16	6294.16	19301.24	19000.8
(b) Run-off	46.88	45.95	83.81	75.0	91.88	84.37	91.13	86.06	93.75	90.0

(a) Data on soil erosion (15)

(b) Data on runoff from one application of water (16)

Middleton (13) analyzed what was considered to be erosive and nonerosive soils to determine the chief differences in their physical properties. He worked out two ratios which hold fairly consistently for the two divisions of soils considered. The ratio expressed in percentage of silt and clay dispersed 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. The dispersion ratio decreases as the resistance to erosion increases. The erosion ratio combines the relation of the soil towards water in such a manner that a low value of the ratio is indicative of high resistance to erosion. He found that the nonerosive soils studied are considerably heavier in texture than the erosive soils.

MATERIAL AND METHODS

Field Tests

The field tests were planned to determine the effect of slope and rate of rainfall on soil erosion and runoff. This experiment was planned to eliminate soil variation as much as possible by placing the plats at different angles on the same hillside. The plats were placed as close together as could be done conveniently. Slopes could thus be obtained varying from level to the maximum slope of the hill. Figure 1(a) shows the arrangement of a field test north of St. George.

The plat was surrounded by strips of 18 gage galvanized iron. This was made so that the iron could be placed in the soil to a depth of 8 inches leaving 2 inches extending above the soil. About three-fourths of an inch of the top edge was turned down to strengthen the frame when it was being settled. The iron across the lower end of the plat was turned down about 2 inches and the narrow apron thus formed turned down into a small metal gutter which was used for carrying the eroded soil and runoff water into a bucket. Each time the plat was set the top of the apron was placed level with the surface of the soil. The frame was so constructed that it could be readily taken apart and moved. The ends of each strip of iron being bent into a hook so that it was easy to set up and to take down. This made it possible to use the one frame on all of the field tests. The frame surrounded an area 34.85 inches by 25 feet which is 1/600 of an acre. A wooden frame was first placed on top of the soil in order to dig around a plat of the proper size. A trench having a perpendicular wall next to the plat was dug to a depth of 6 to 7 inches and then the iron frame was

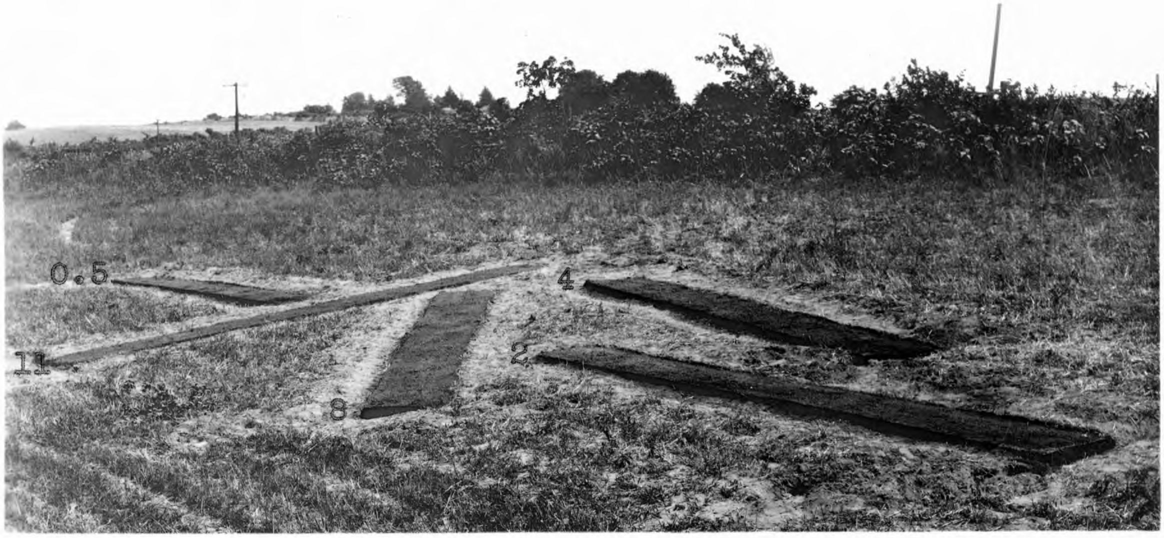

Fig. 1(a). The field plats used in sandy loam test No. 1 showing method used to obtain different slopes on the same hillsides. The figures represent the per cent slope of each plat

Fig. 1(b). Erosion measurements are being made on the plat at the right. This shows water being applied and the measuring of runoff. At the left a new plat with a different slope is being established placed around the plat as shown in figure 1(b). The soil was then replaced on the outside of the iron frame, care being taken that the iron fit in close to the bank. The frame was then settled another inch or two by means of a sledge. This was to prevent water seeping out around the bottom of the frame.

All of the vegetation was then removed from the surface. Many of the larger roots found in the soil were also removed. The soil within the plat was all spaded uniformly to a depth of 4 inches, and the clods pulverized by means of a hoe and rake. The plat was then leveled crosswise. The irregularities in the slope lengthwise of the plat were determined by a straight edge and were eliminated as far as possible. Care was taken that there were no holes or loose places left which would cause irregular settling or increase absorption of water. The slope of the plat was determined by means of a surveyors level. A plat ready to have a test made upon it is shown in figure 1(c).

Barrels were calibrated so that they would hold the amount of water equivalent to 1 surface inch for the plat. Water was applied by means of a sprinkling can. The application of water was carefully timed so that the rate was uniform throughout the entire time of application of water.

Fig. 1(c). A field plat used to determine the effect of slope on amount of soil erosion and runoff

Several mechanical methods of applying water by means of sprinkling nozzles were tried, but it was found that if carefully used, the sprinkling can method was the most satisfactory.

The runoff carrying the eroded soil was collected in buckets and weighed. It was then poured into a barrel and at the end of the run triplicate samples were taken from the entire amount of runoff and placed in moisture cans. A sampling tube was made by fastening a rubber stopper to a wire which was placed inside of a 3 foot soil sampling tube. The solution in the barrel was thoroughly agitated with a hoe and then the sampling tube with end open was pushed down through the solution to the bottom. The bottom of the tube was immediately closed by pulling on the wire. This made it possible to obtain a representative sample of the entire depth of the material in the barrel. The samples were taken to the laboratory where they were weighed, water evaporated on steam bath, heated in an oven at 105° C and reweighed to determine the amount of soil in the sample.

The two soils used for these tests were a silty clay loam on the agronomy farm at Manhattan and a sandy loam at St. George.

Laboratory Tests

These tests were planned to supplement the field results. It was found that the maximum slope obtainable with desirable conditions in the field was about 13 per cent. The laboratory tests were used to determine the results on steeper slopes. A galvanized iron tank 24 inches wide, 28 inches deep and 10 feet long was surrounded by heavy frame work as shown in figure 2(a). This plat was somewhat similar to the one used by Lowdermilk (12) for studying certain questions in connection with forest soils.

One filling was made with silty clay loam soil from the agronomy farm and another with sandy loam soil from north of St. George, Kansas. The surface soil was removed in one layer and the remaining soil in layers varying from 4 to 6 inches. A 2 inch layer of sand was placed in the bottom of the tank in order to provide thorough underdrainage. Each layer was placed in the tank in proper order and packed down to the volume that it occupied under field conditions. The sides of the tank extended 2 inches above the surface of the soil, except at one end where the iron was turned down level with the surface of the soil to permit runoff, as shown in figure 2(b). Near the bottom of this end was a small tube used to drain off the water which had percolated through the soil.

Fig. 2(b). Top view of tank showing method used to collect runoff

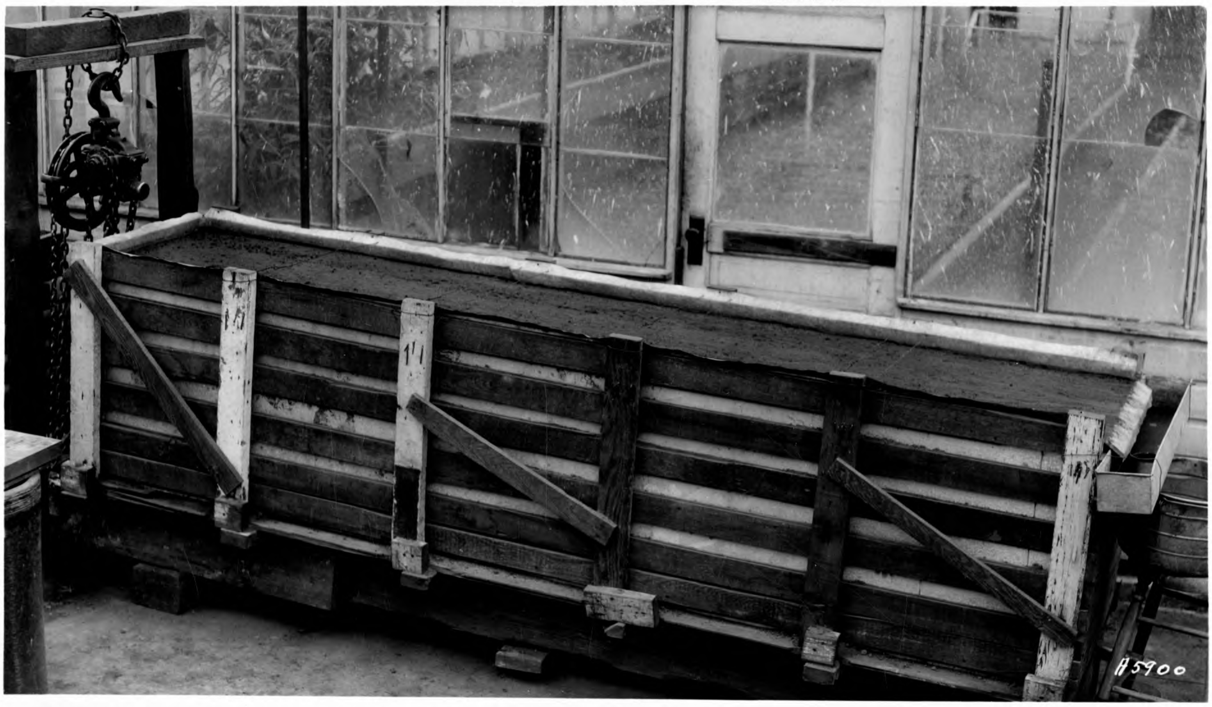

Fig. 2(a). Side view of tank used in erosion experiments. At left of picture is shown the differential hoist used to obtain different slopes

After each set of determinations it was necessary to replace the eroded soil with more surface soil to bring the surface up to the proper level. When complete, the tank equipment with soil and water weighed about 2.5 tons.

Differences in slope were obtained by raising one end of the tank by means of jack screws or a differential hoist. The hoist was easier to operate and caused less distortion of the soil. About 20 per cent slope was as much as it was found possible to give the block of soil without throwing undue strain on the tank and frame work.

The water to be used for a given application was weighed. The water was applied by means of a sprinkling can. The weighing and sampling and determination of amounts of eroded soil were carried out in a manner very similar to that used with the field tests.

EXPERIMENTAL RESULTS

Field Tests, Silty Clay Loam

Runoff. A suitable location was found on the agronomy farm on which to make these tests. This land had grown corn the previous season. The slope of the plats that were established varied from 0.96 to 5.96 per cent which was as steep as could be obtained on this land. The results from these tests are given in Table I. The initial application of water at the rate of 1 inch in 30 minutes was used in order to have the soil of the plat saturated and have runoff started before the 1 inch an hour application was made. This undoubtedly cut down the influence of moisture content of the soil on the runoff from the following applications. The amounts of runoff from these determinations are plotted on curves in figure 3. It will be noticed that there is a marked increase in per cent runoff until a slope of 3 to 4 per cent is reached. After this the curve rises less rapidly but very gradually.

A comparison of the different curves in figure 3 will show that there is a much greater per cent runoff when water is applied at the rate of 2 inches in 60 minutes than at the rate of 1 inch in 60 minutes. This difference seems to be due to absorption. The application at the rate of 1 inch an hour is faster than the soil can absorb the water. At 2 inches in 1 hour the water is absorbed at approximately the same rate so that the excess water is allowed to run off. The initial run of 1 inch in 30 minutes gives less runoff than the 1 inch in 1 hour because a large share of this water is used to soak up the dry soil.

Soil Erosion. An examination of Table I and figure 4 will show that the effect of slope on amount of erosion is nearly opposite to the effect on amount of runoff. The a-

Table I. Soil Erosion and Runoff from Silty Clay Loam Soil.
Agronomy Farm. 1/600 acre plat.

Date	Rate of application of water	Per cent slope	Lbs. water runoff	Per cent runoff	Lbs. soil eroded	Lbs. soil eroded per acre	Lbs. runoff required to remove 1 lb. soil
6/18/31	1" in 30 min.	0.96	1.986	0.53	.0142	9	139
	1" in 1 hour	"	14.875	3.94	.0246	15	604
	1" in 30 min. (1)	"	174.111	46.14	.4889	293	356
(a)	1" in 30 min. (2)	"	189.656	50.26	.4445	267	426
6/18/31	1" in 30 min.	2.12	35.045	9.29	.1544	93	226
	1" in 1 hour	"	86.900	23.03	.2997	180	289
	1" in 30 min. (1)	"	238.966	63.32	.6337	380	377
	1" in 30 min. (2)	"	237.697	62.99	.5026	301	472
6/17/31	1" in 30 min.	3.8	69.564	18.43	.5352	321	129
	1" in 1 hour	"	120.852	32.03	.4472	268	270
	1" in 30 min. (1)	"	248.646	65.89	.9540	572	260
	1" in 30 min. (2)	"	267.006	70.75	.7940	476	336
6/17/31	1" in 30 min.	5.96	77.616	20.57	.4838	290	160
	1" in 1 hour	"	128.794	34.13	.7054	423	182
	1" in 30 min. (1)	"	249.152	66.02	1.2477	748	199
	1" in 30 min. (2)	"	257.735	68.30	1.3647	818	188

(a) Number 2 followed immediately after Number 1, which gave an application of 2 inches in 1 hour

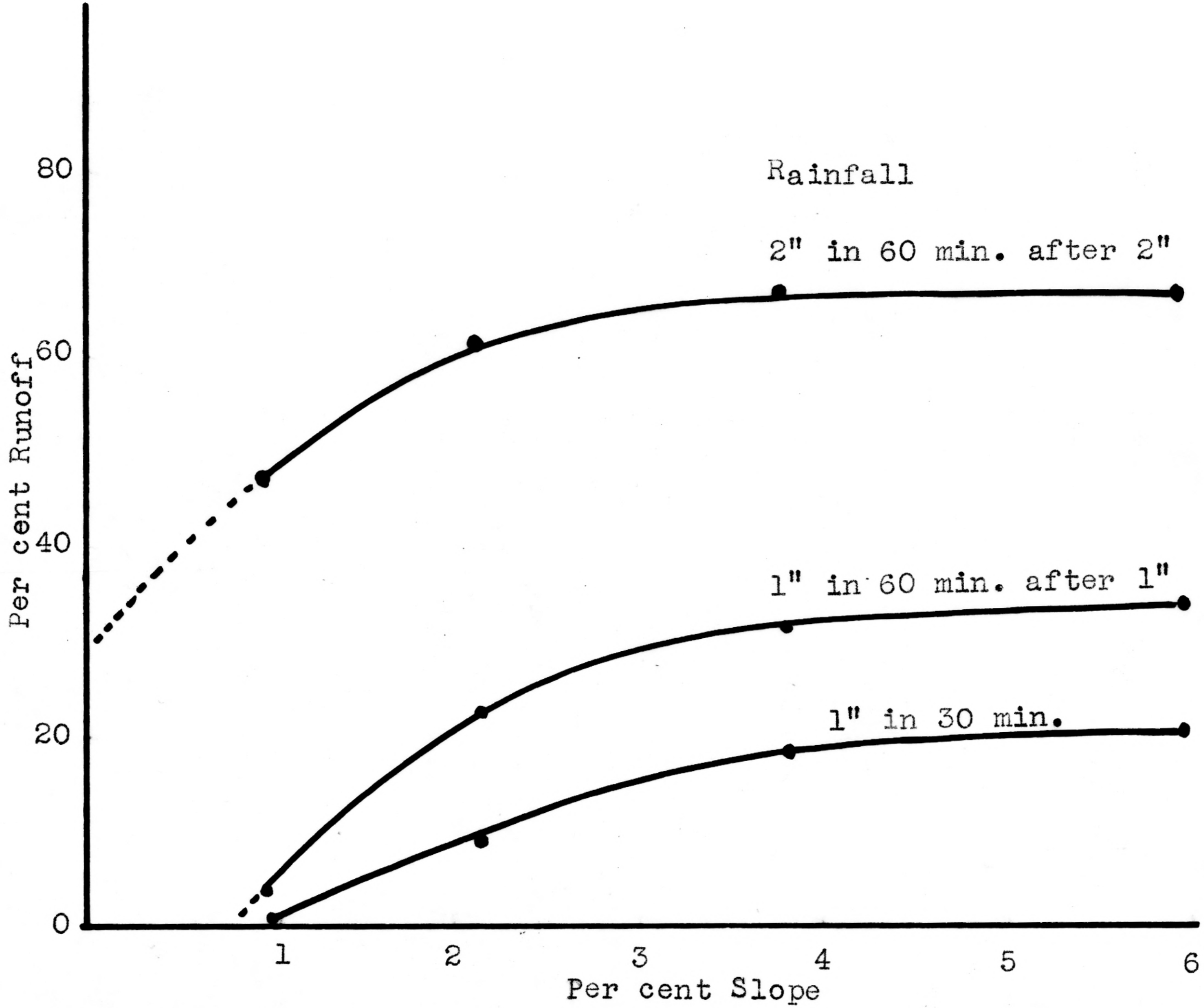

Fig. 3. Runoff from land with different degrees of slope and varying rates of rainfall. Silty clay loam.

mount of soil removed increased very slowly with an increase in slope from 0 to 3 or 4 per cent slopes. Then with increasing slope there was a more rapid rise in amount of soil eroded. This is probably closely correlated with the increase in speed of flow of water down the slope. On the lower slopes the water stands on the plats and runs off only slowly, but with the higher slopes the speed of runoff increases until the water runs off nearly as soon as it is put on the plat. The increased amount of erosion obtained by either an increase in slope or by a greater rate of application of water is due to the increased rate of flow of runoff water resulting in increased carrying power.

There were a few cases where the amount of eroded soil did not fall at the expected place on the curve. It is very difficult to get the surfaces near enough alike to get absolutely consistent results when working with the lesser slopes and light application of water. When the slope is steep or water is applied at the heavier rate more consistent results were obtained. Figure 4 also compares the influence of rate of application of water on amount of erosion. On the 0.96 per cent slope water applied at the rate of 2 inches per hour washed off nearly 38 times as much soil as did the water applied at 1 inch per hour. The heavier application on the 5.96 per cent slope caused 3.5 times as much erosion as did the lighter application.

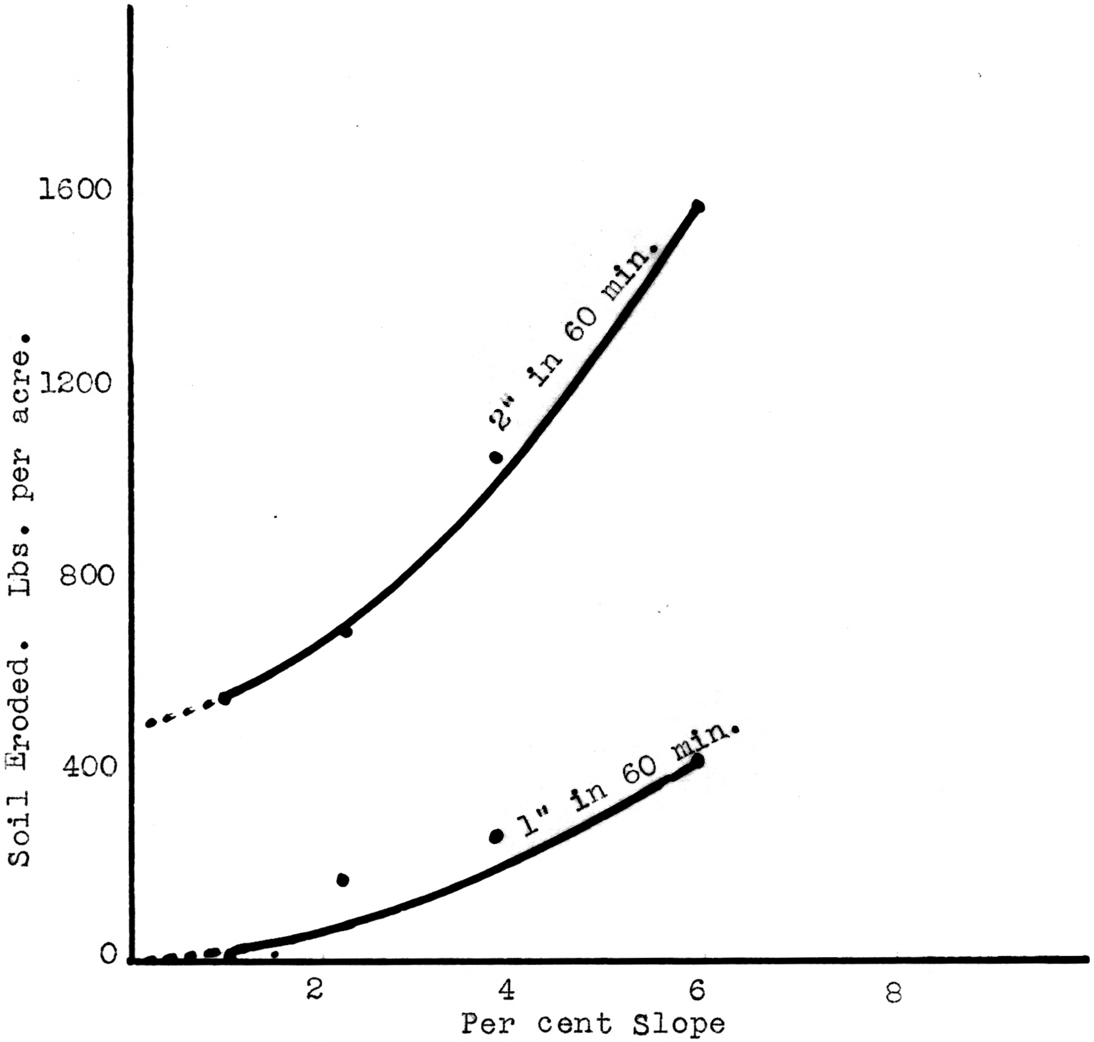

Fig. 4. Soil eroded from different degrees of slope and varying rates of rainfall. Silty clay loam.

Field Tests, Sandy Loam. No. 1

Runoff. For these tests a very sandy soil located north of St. George, Kansas, nine miles east of Manhattan was used. This soil had been cropped to wheat during the season before the tests were made. The maximum slope here was nearly 12 per cent. The tests were made when the soil was very dry and no runoff was obtained on the lower slopes until about 2 inches of water had been applied. The data obtained from these runs are shown in Table II. Two curves, figure 5, were plotted from these results showing the runoff. One was when water was applied equivalent to 1 inch in 30 minutes after 2 inches had been applied. The other curve shows the runoff with a 2 inch application in 30 minutes after 3 inches had been applied. These two curves have the same general trend as shown in the curves for the silty clay loam in figure 4. The curve for the 2 inch application rises more rapidly than the curve for the 1 inch. These data also show that the absorption power of the soil tends to remain constant after the soil is well soaked. In the curve for the application of 2 inches for 30 minutes there was a decrease in per cent runoff for the two higher slopes under the intermediate slopes. No satisfactory explanation can be offered for this unless there was some unnoticed soil variation.

Table II. Soil Erosion and Runoff from Sandy Loam Soil.
July 16 and 17, 1931. St. George, Kansas. 1/600 acre plat.

Rate of application of water	Per cent slope	Lbs. soil eroded	Lbs. soil eroded per acre	Lbs. water runoff	Per cent runoff	Lbs. of runoff required to remove 1 lb. soil
1" in 30 min.	0.6	none	none	none	none	
1" in 1 hour	"	none	none	none	none	
1" in 30 min.	"	.0088	5	.799	0.21	91
2" in 30 min.	"	.2743	164	179.50	23.78	654
1" in 30 min.	2.2	none	none	none	none	
1" in 1 hour	"	none	none	none	none	
1" in 30 min.	"	.0746	8	52.83	14.00	708
2" in 30 min.	"	.4547	273	438.05	58.04	963
1" in 30 min.	4.08				none	
1" in 1 hour	"				none	
1" in 30 min.	"	.2670	160	68.43	18.13	256
2" in 30 min.	"	3.3664	2018	457.54	60.49	136
1" in 30 min.	7.72	.0192	12	1.18	0.31	61
1" in 1 hour	"	.0227	14	2.27	0.60	100
1" in 30 min.	"	.5819	349	56.82	15.06	98
2" in 30 min.	"	7.1769	4303	359.72	47.67	50
1" in 30 min.	11.36	.2943	176	2.80	0.74	10
1" in 1 hour	"	.3702	222	8.12	2.15	22
1" in 30 min.	"	3.9212	2291	77.68	20.59	20
2" in 30 min.	"	28.881	17316	355.82	47.14	12

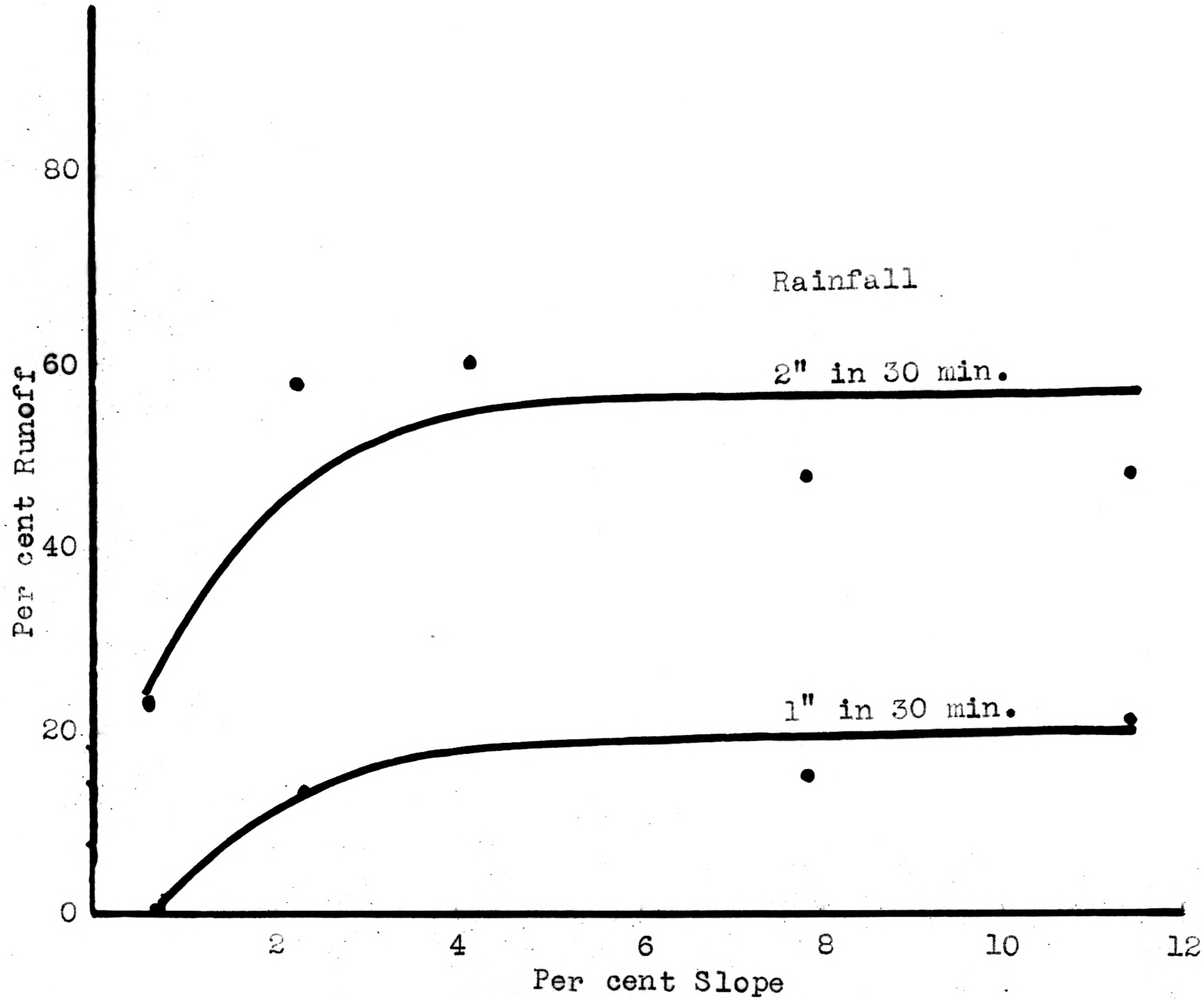

Fig. 5. Runoff from land with different degrees of slope and different rates of rainfall. Sandy loam.

Soil Erosion. The data on amount of soil eroded from these plats are recorded in Table II. Figures 6 and 7 show the amounts eroded from the various slopes from an application of water at the rate of 2 inches in 30 minutes after 3 inches and 1 inch in 30 minutes after 2 inches. The curve for the heavier application rises more rapidly and much more soil is eroded. These curves show the same general trend as has been shown for the soil eroded from the silty clay loam.

The sandy loam soil erodes less on the lower slopes. This gives a curve that is nearly flat up to 3 to 4 per cent then a more rapid rise up to 7 to 8 per cent when the curve rises very rapidly. These results show that an application of water at the rate of 2 inches in 30 minutes caused seven times as much erosion on this soil on the steeper slopes and about 30 times as much on the gentle slopes as a 1 inch application in 30 minutes. The difference is due partly to the fact that the sand grains are difficult to move, but when the water is running off at a more rapid rate as is the case with the heavier application on the lower slopes or of either application on the steeper slopes, the water is able to carry and roll the sand grains along with it.

Field Tests, Sandy Loam. No. 2

Runoff. Another test was made on a very sandy soil

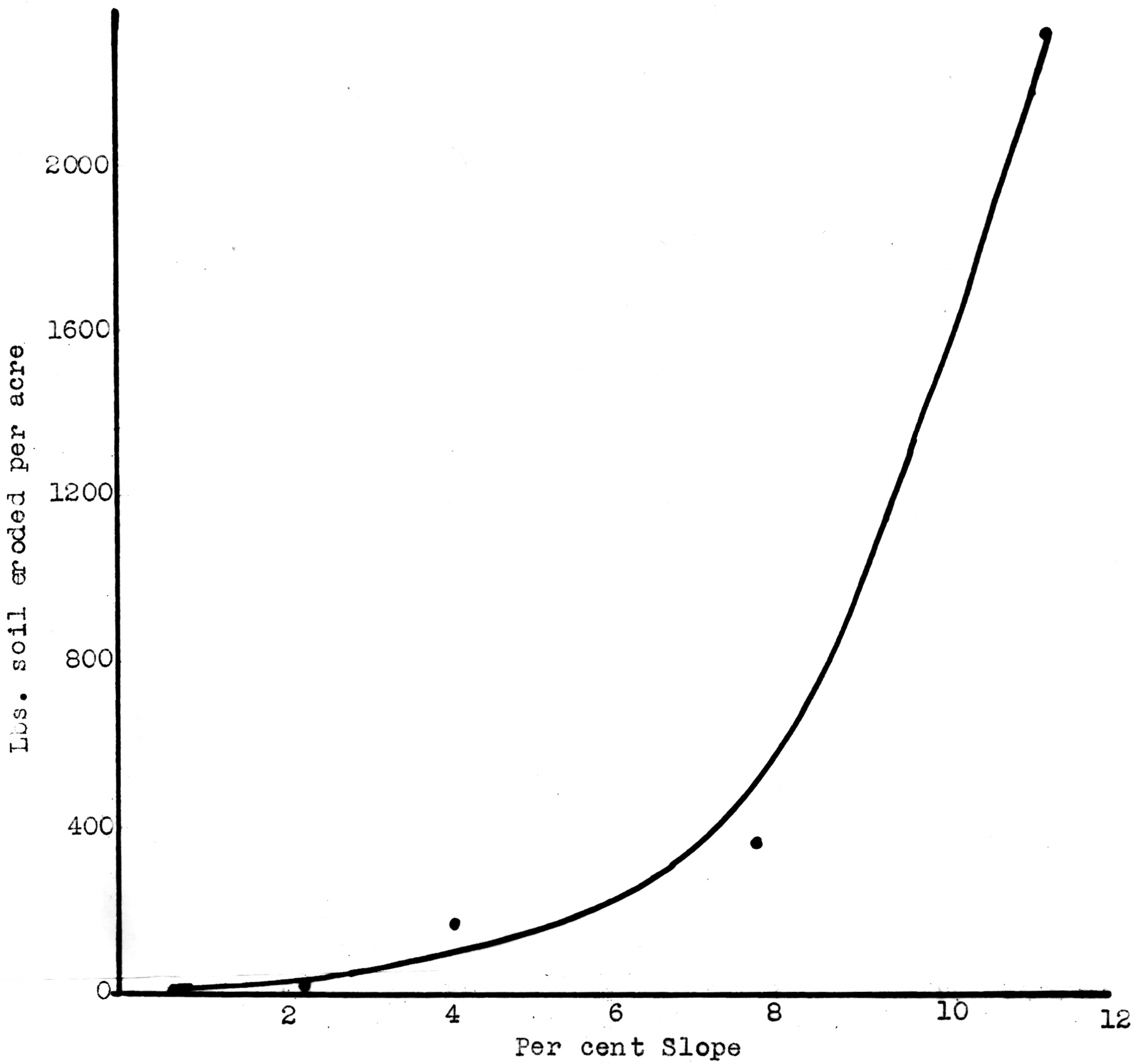

Fig. 6. Effect of degree of slope on amount of soil eroded. Sandy loam. Water applied at rate of 1 inch in 30 minutes.

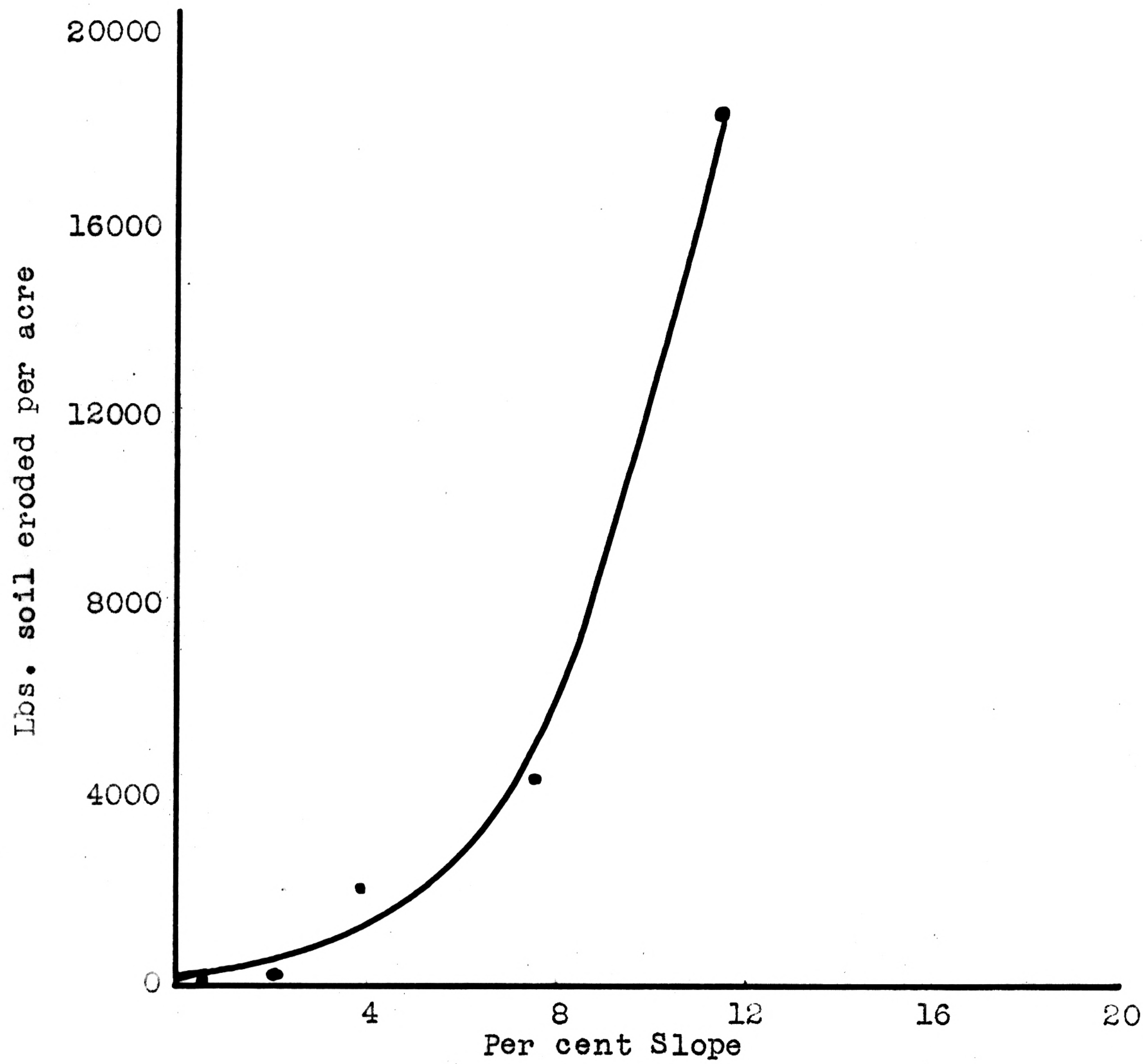

Fig. 7. Effect of degree of slope on amount of soil eroded. Sandy loam. 2 inches in 30 minutes.

west of St. George. The field had grown wheat earlier the present season. On this hillside it was possible to get a maximum slope of 13.2 per cent. Data obtained from these tests are given in Table III. The runoff data from these plats do not follow the same general trend that was found to be true from data gathered from other tests. The per cent runoff for the 0.76 per cent slope is nearly as much as for the 13.2 per cent slope and exceeds the amounts of runoff from the 2.72 and from the 8.68 per cent slopes. On a more careful examination of the subsurface soil with a soil auger, it was found that gophers had dug holes through this area. The ununiform absorption of water probably can be attributed to these holes.

Soil Erosion. The amounts of soil eroded from the various slopes are shown in Table III. The amounts of soil eroded give the same general trend of the curve as was shown in figures 6 and 7. Figure 8 shows the relation between slope and amount of soil eroded when water is applied at the rate of 1 inch per hour. Figure 9 shows the relation between slope and the amount of soil eroded when water is applied at the rate of 2 inches per hour. Doubling the rate of application increased the erosion about 9 times on the 13.2 per cent slope and about 46 times on the 2.72 per cent slope.

Table III. Soil Erosion and Runoff from Sandy Loam Soil. No. 2. August 14 and 15, 1931. St. George, Kansas. 1/600 acre plat

Rate of application of water	Per cent slope	Lbs. soil eroded	Lbs. soil eroded per acre	Lbs. water runoff	Per cent runoff	Lbs. runoff required to remove 1 lb. soil
1" in 1 hour	.76	.0849	51	43.82	11.59	516
1" in 30 min. (1)	"	.2108	126	172.3	45.60	817
1" in 30 min. (2)	"	.1875	112	155.01	41.00	827
1" in 1 hour	2.72	.0134	8	7.59	2.01	566
1" in 30 min. (1)	"	.2549	153	154.5	40.90	606
1" in 30 min. (2)	"	.3916	235	183.7	48.60	469
1" in 1 hour	8.68	0.2323	139	11.56	3.06	50
1" in 30 min. (1)	"	2.157	1293	129.14	34.19	60
1" in 30 min. (2)	"	2.574	1543	136.13	36.04	53
1" in 1 hour	13.2	1.973	1183	42.43	11.23	22
1" in 30 min. (1)	"	9.484	5686	165.82	43.90	17
1" in 30 min. (2)	"	7.938	4759	164.36	43.90	21

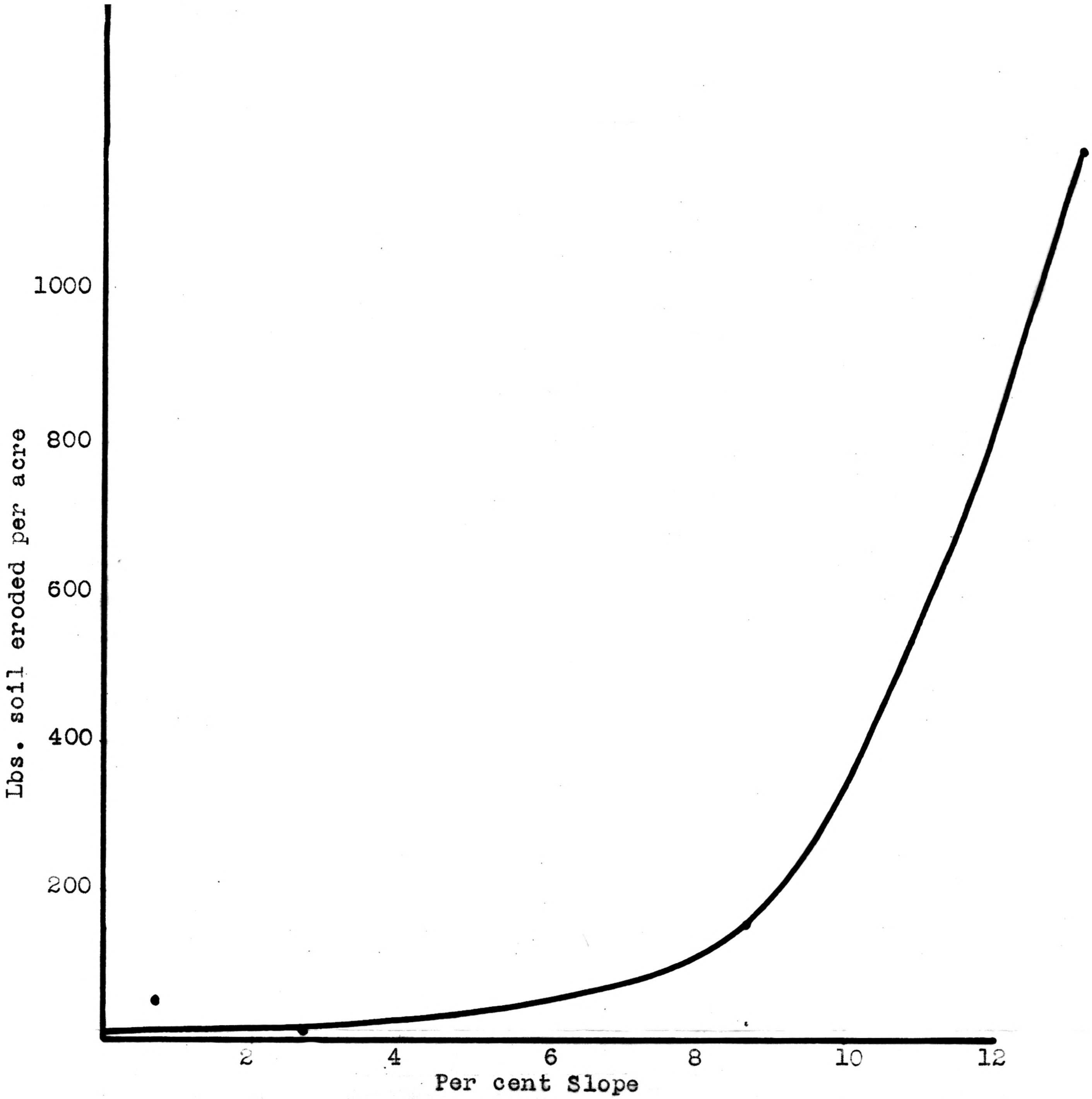

Fig. 8. Effect of degree of slope on amount of soil eroded. Sandy loam. Water applied at rate of 1 inch in 1 hour.

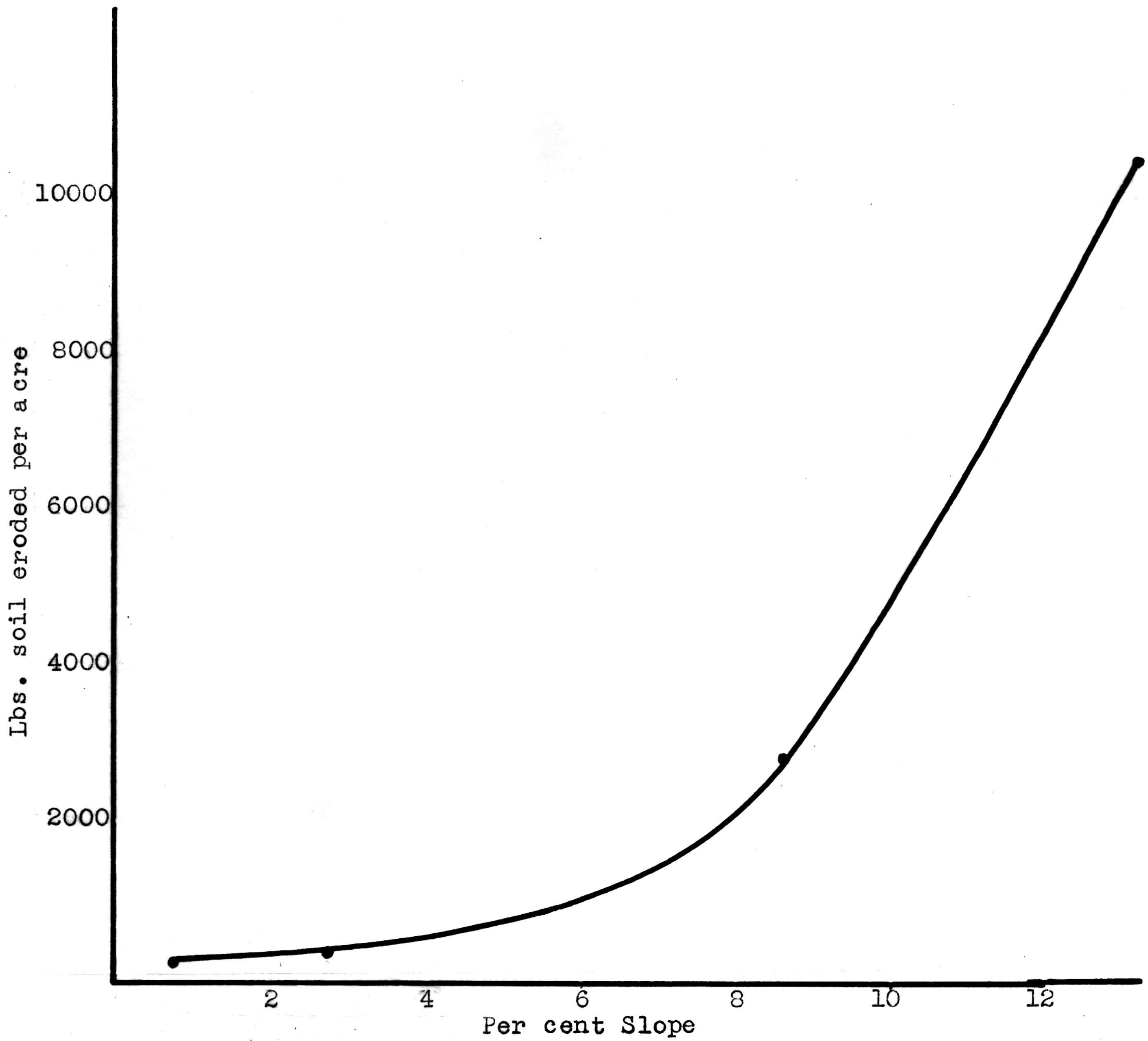

Fig. 9. Effect of degree of slope on amount of soil eroded. Sandy loam. Water applied at rate of 2 inches per hour.

It seems to be very difficult to get runoff data that will check consistently for the various slopes. The amount of erosion seems to be less affected by other factors so that it is easier to obtain consistent erosion data. In the above tests the amounts eroded fell in line in good order except the 0.76 per cent slope with a rainfall of 1 inch in 1 hour. This amount was too high in comparison with the other data. Conner et al. (7) have experienced the same difficulty with the amounts of runoff obtained from their plats on various slopes.

Tank Tests, Silty Clay Loam

Runoff. Water applied at rate of 1 inch per hour. In the fall of 1930 the tank was filled with silty clay loam soil from the agronomy farm from an area near where the field tests were made. The surface 8 inches of soil was removed in one layer. The next 4 inches was removed in one layer, and the last foot in two 6 inch layers. When the soil had been settled down to approximately the same volume occupied in the field, the plat was thoroughly soaked. The soil was thoroughly soaked before each determination was made so that a uniform soil moisture content could be maintained. The amounts of runoff and erosion were first determined for the zero slope or level land. The slope was then increased and the water and soil loss determined on each increase in slope. Table IV gives amounts of runoff obtained from four determinations. The slope was varied from 0 to 20 per cent. The average per cent runoff has been plotted on curve (a) in figure 10. The general trend of the curve is the same as that shown in figure 3 for the field determinations on silty clay loam soil. It will be noticed that even with a level slope the per cent of runoff is 33 per cent. The curve rises rapidly from 0 to 3 or 4 per cent slope and then with increase in slope the rise is much more gradual.

Soil Erosion. The amounts of soil eroded from the various slopes with water applied at the rate of 1 inch per hour are shown in Table V. The average pounds of soil lost per acre from the various slopes are shown in figure 11. This curve is very similar to the curves shown in figure 4 for the soil eroded for the field plat. The main difference between the two being the extent of the curve. In the field test it was possible only to make determinations on the lesser per cent slopes.

Tank Tests, Sandy Loam

Runoff. In the fall of 1931 the tank was filled with soil taken from an area close to where the field test was made north of St. George. The filling was done in a manner very similar to the way the tank was filled with silty clay

Table IV. Effect of Slope of Tank on Runoff Water from Silty Clay Loam Soil. Pounds Water (a).

Per cent slope	Jan. 25, 1931	Jan. 31, 1931	Feb. 21, 1931	Feb. 28, 1931	Average	Average per cent runoff
0	38.1	----	20.4	47.2	35.2	33.85
1	57.8	52.2	45.8	70.5	56.5	54.33
2	61.8	65.9	59.5	76.8	66.0	63.47
4	72.0 (b)	70.5	62.8	81.2	71.6	68.86
6	80.8	62.3	72.7	----	71.9	69.15
8	83.3	70.7	74.7	----	76.2	73.28
10	82.3	72.6	76.3	81.5	78.2	75.21
15				86.8	86.8	83.48
20				89.9	89.9	86.45

(a) Rainfall at rate of 1 inch per hour. Size of tank 2 x 10 feet.
(b) 4.16% slope on January 25, 1931.

Table V. Effect of Slope of Tank on Soil Eroded from Surface of Silty Clay Loam. Pounds Soil.

Per cent slope	Jan. 24, 1931	Jan. 31, 1931	Feb. 21, 1931	Feb. 28, 1931	Average	Lbs. per acre	Lbs. runoff required to remove 1 lb. soil
0	0.037	-----	0.087	0.038	.054	118	651
1	0.090	0.429	0.287	0.265	.267	582	211
2	0.103	0.275	0.185	0.160	.180	392	367
4	0.238 (a)	0.166	0.171	0.559	.283	616	253
6	0.587	0.260	0.722	-----	.523	1139	137
8	1.269	1.002	1.259	-----	1.176	2561	65
10	1.289	3.064	1.751	2.502	2.1515	4685	36
15				3.591	3.591	7821	24
20				5.566	5.566	12123	16

(a) 4.16% slope.

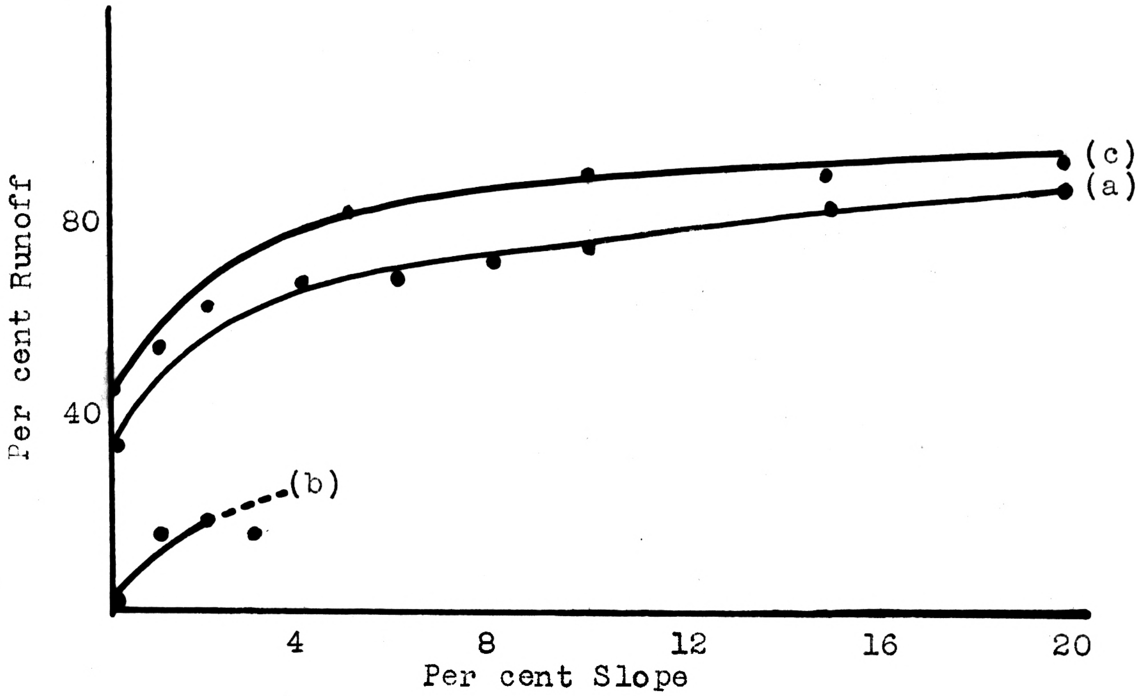

Fig. 10. Relation between degree of slope and per cent runoff. Tank plat. Silty clay loam. (a) Texas runoff (b) Alabama runoff (c).

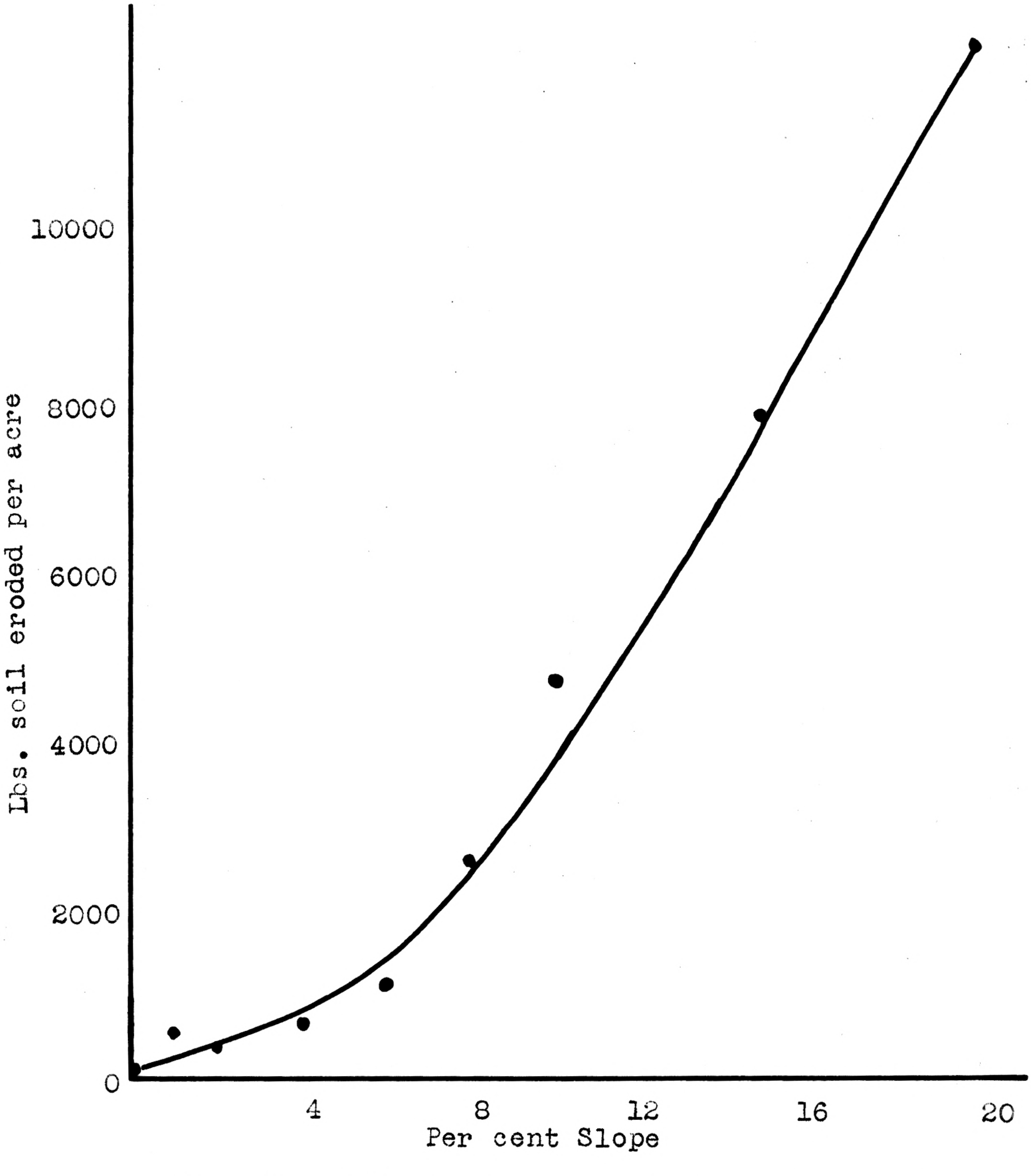

Fig. 11. Effect of degree of slope on amount of soil eroded. Tank plat. 1 inch in 60 minutes.

loam soil. The soil was soaked thoroughly with water before any determinations were made so as to insure uniformity of moisture content throughout. On September 19 a test was made with water applied at the rate of 1 inch per hour. The results are given in Table VI. A curve made from these data are shown in figure 12(a). The per cent runoff from these slopes gives a curve which has the same general trend that was observed from the other determinations.

Soil Erosion. The first determination conducted with this tank filled with sandy loam soil failed to give concordant results. There was more soil eroded from the 0.5 per cent slope than there was from either the 2 or the 4 per cent slopes, and more from the 2 than from the 4 per cent slope. It was found upon examination of the plat after the determination had been made that the surface of the soil was nearly 1 1/2 inches below the proper level. Part of this was due to erosion but most of it was due to the settling of the soil. This occured during and after the 0.5 per cent slope was run so that it did not have so much influence on this slope. Then on the 2 and the 4 per cent slopes the soil had settled enough so that the top of the tank at the lower end acted as a soil saving dam. This factor materially influenced the results on the lower slopes, but had less influence on the steeper slopes.

Soil was added until the surface was raised to the

Table VI. Effect of Slope of Tank on Soil Eroded and Runoff from Surface of Sandy Loam Soil. Pounds. September 19, 1931.

Per cent slope	Pounds soil	Pounds soil per acre	Pounds water	Per cent runoff	Lbs. runoff required to remove 1 lb. soil
0.5	.1765	384	48.3	46.5	273
2.0	.1231	268	58.97	56.7	479
4.0	.0948	207	64	61.5	685
8.0	.1515	330	63.48	61.1	419
16.0	.8082	1760	73.09	70.2	90

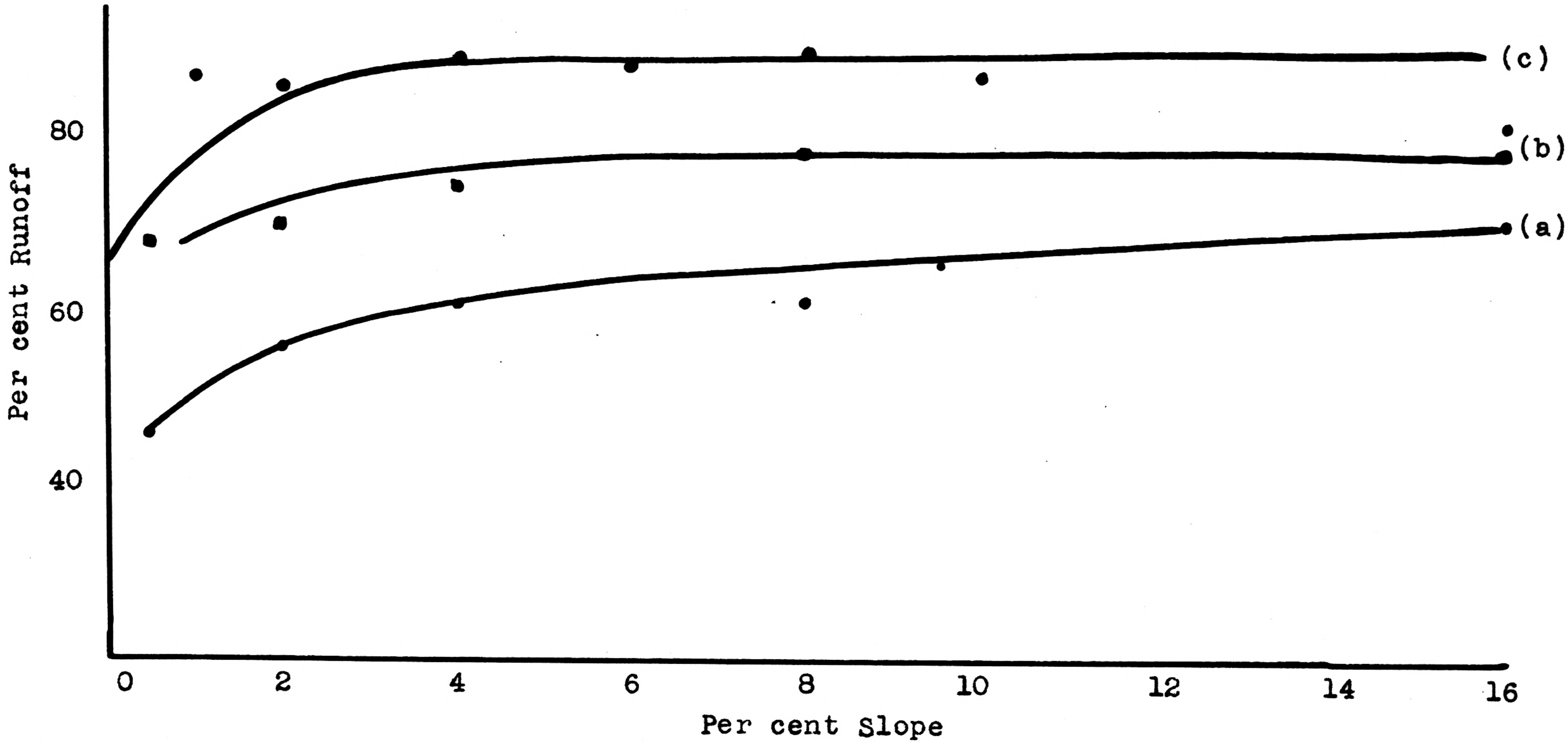

Fig. 12. Relation between degree of slope and per cent runoff. Tank plat. Sandy loam. One inch water applied per hour.

proper height. The plat was then given a thorough soaking. On November 2 another determination was made with water applied at the rate of 1 inch per hour. These results are shown in Table VII. These too show a slight discrepancy between the first two slopes, but otherwise are approximately as would be expected from previous results.

Another determination was made on December 7, 1931. Data obtained from this determination are shown in Table VIII. A variation in slope was used so that by combining the results shown in Tables VII and VIII it was possible to plot more points on the curve.

Runoff. The runoff data for November 2 are shown in figure 12 curve (b). This curve is flatter on the lower slopes than one would expect. Curve (c) shows the data from the determination of December 7. The smooth curves follow the same general trend as given for the field determinations for sandy loam in figure 5. The per cent runoff for the 16 per cent slope in Table VIII was less than one would expect from the results obtained for the other slopes on December 7, 1931. This slope was run the following day and it is possible that the soil was not saturated with water before starting so that more was absorbed during the time of measurement. In order to get concordant results it has been found necessary to make all measurements from the tank in one continuous operation.

Table VII. Effect of Slope of Tank on Soil Eroded and Runoff from Surface of Sandy Loam Soil. Pounds. November 2, 1931

Water applied - 1 inch in 1 hour

Per cent slope	Pounds lost			Per cent runoff	Lbs. water required to remove 1 lb. soil
	Soil eroded		Runoff water		
	Plat	Per acre			
0.5	.0897	195	71.09	68.36	793
2.0	.05194	113	73.62	70.80	1417
4.0	.08796	192	78.74	75.73	895
8.0	.4559	993	81.53	78.41	179
16.0	11.559	25176	81.74	78.61	7

Table VIII. Effect of Slope of Tank on Soil Eroded and Runoff from Surface of Sandy Loam Soil. Pounds. December 7, 1931

Water applied - 1 inch in 1 hour

Per cent slope	Pounds lost			Per cent runoff	Lbs. water required to remove 1 lb. soil
	Soil eroded		Runoff water		
	Plat	Per acre			
0	.0358	78	63.44	61.02	1772
1	.0651	142	90.53	87.07	1390
2	.1167	254	90.08	86.64	772
4	.1446	315	92.76	89.2	641
6	.2861	623	92.01	88.49	322
8	.6752	1471	93.5	89.9	138
10	2.98	6490	90.7	87.23	30
16(b)	7.86	17119	84.9	81.6	11

(b) Test made December 8, 1931

Soil Erosion. The amounts of soil eroded from these two determinations are given in Tables VII and VIII. These data are represented graphically in figure 13. When this curve is compared with figure 6 it will be seen that the two curves show the same general trend.

Rate of Rainfall

Runoff. In order to study further the influence of rate of application of water on amount of soil eroded and runoff another test was made on the tank plat filled with sandy loam soil. The water was applied at the rate of 1 inch in 30 minutes. By examining the half hour parts of the 2 inch an hour applications of the field tests it was noticed that there was no consistent variation between the first and second half hour. From this observation it was thought a half hour application at 1 inch rate would be as good as an hour at 2 inch rate. A determination was made on November 7 and the results obtained are shown in Table IX. The per cents runoff from these tests are higher than from those for 1 inch in 1 hour showing that the soil tends to absorb the water at the same rate independent of the rate of application of water.

Soil Erosion. The amounts of soil eroded per acre are recorded in Table IX. These have been plotted on a curve in figure 14. Compare this with figure 6 which is the field

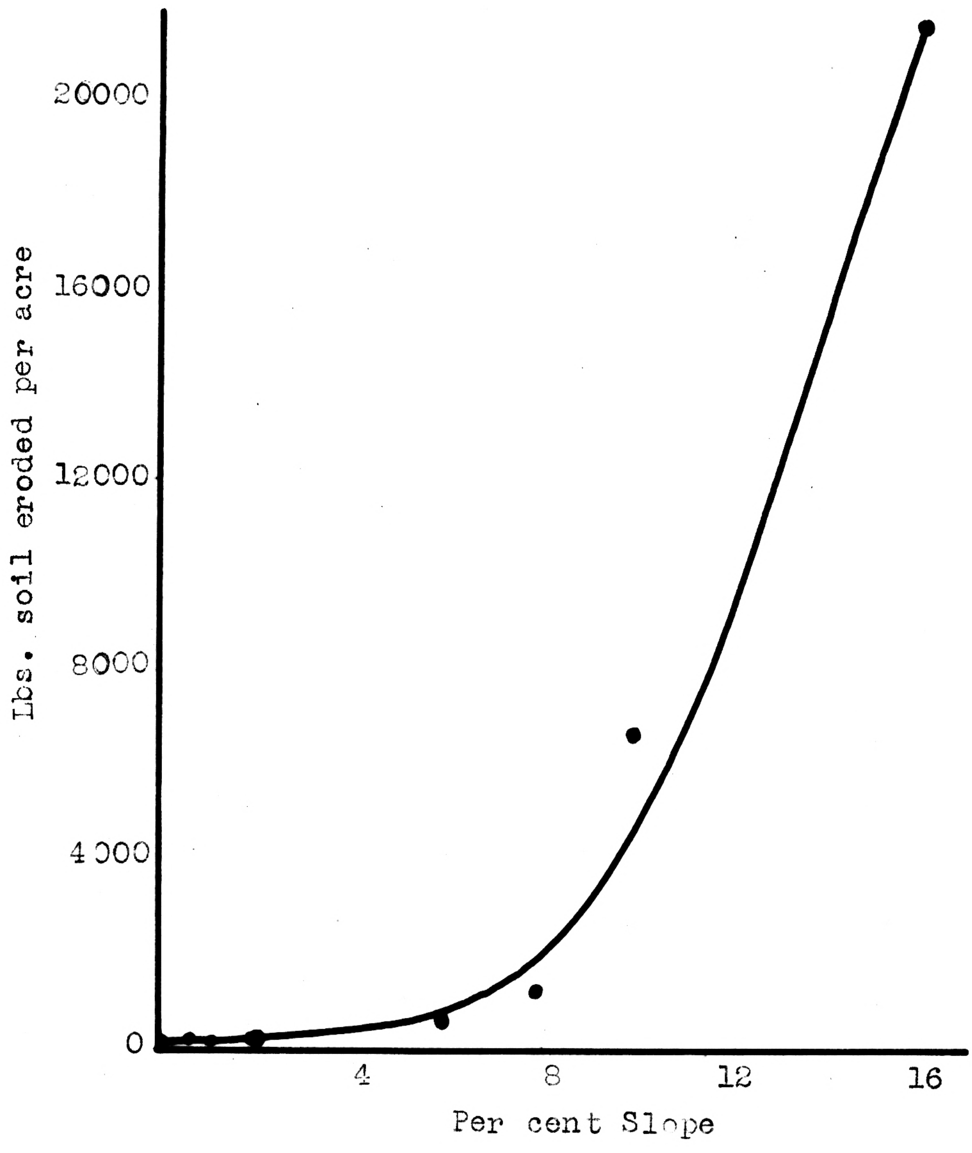

Fig. 13. Effect of degree of slope on amount of soil eroded. Tank plat. Sandy loam. 1 inch in 60 minutes.

Table IX. Effect of Slope of Tank on Soil Eroded and Runoff from Surface of Sandy Loam Soil. Pounds. November 7, 1931

Water applied - 1 inch in 30 min.

Per cent slope	Pounds lost: Soil eroded: Plat	Pounds lost: Soil eroded: Per acre	Pounds lost: Runoff water	Per cent runoff	Lbs. water required to remove 1 lb. soil
0.5	.1643	357.8	86.11	82.81	524.1
2.0	.2138	465.7	93.08	89.52	435.3
4.0	.3551	773.4	93.78	90.19	264.1
8.0	2.573	5604.0	95.59	91.93	37.2
16.0	26.44	57586.3	95.54	91.88	3.6

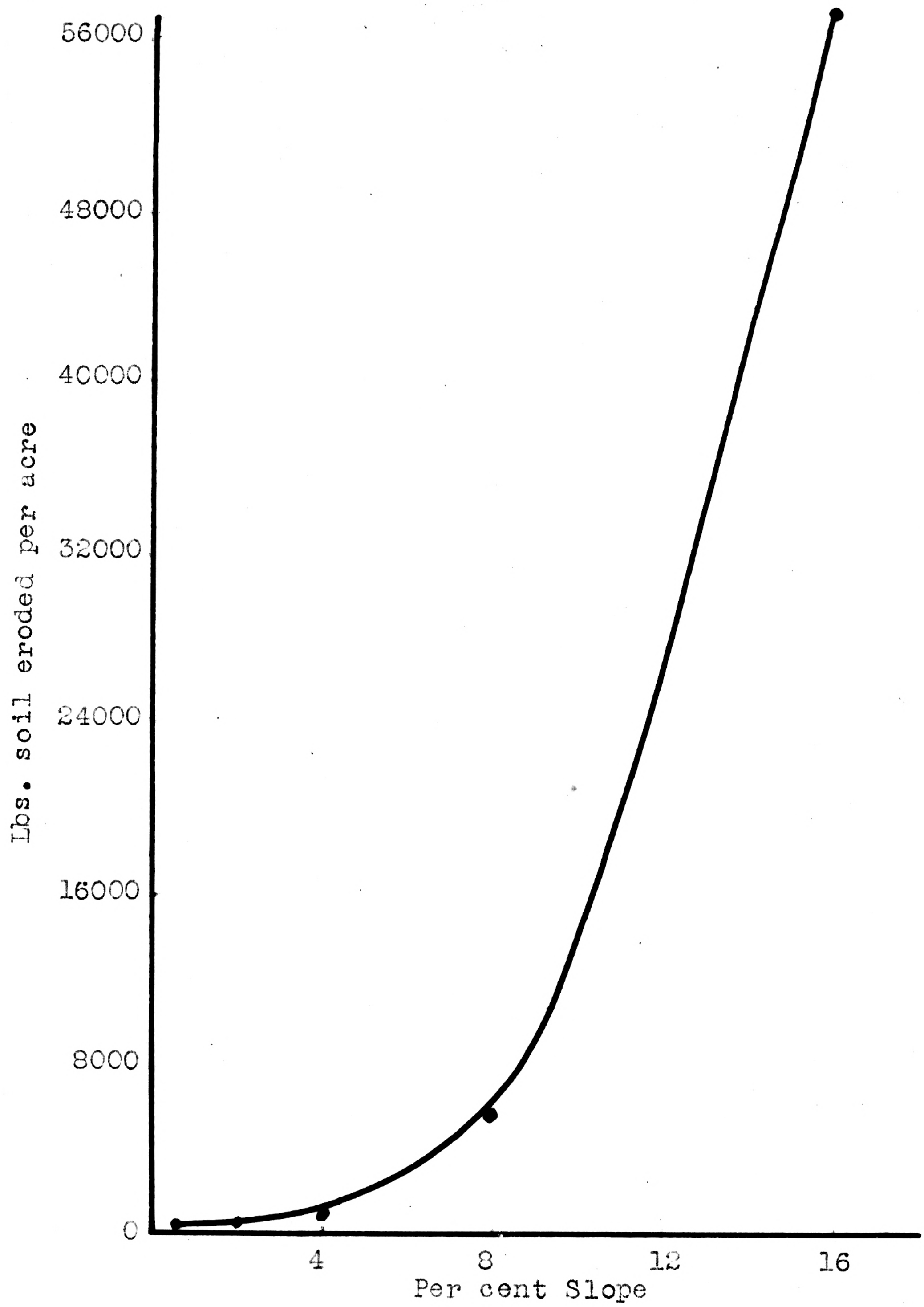

Fig. 14. Effect of degree of slope on amount of soil eroded. Tank plat. Sandy loam. 1 inch in 30 minutes.

determination at 1 inch in 30 minutes. These two curves are quite similar in trend. Compare this curve with the curve for a rate of application of 1 inch per hour, figure 13. The curve for the 1 inch in 30 minutes is plotted on twice the scale used for 1 inch in 1 hour. For the slope of 8 per cent the heavier application of water eroded 4.5 times as much as did the lighter, and on the 16 per cent slope 2.7 times as much.

Soil Erosiveness

By comparing the amounts of erosion in Table V with Tables VII and VIII, it will be seen that there are some striking differences in the amount of erosion from silty clay loam and sandy loam soils. The data found in these tables have been plotted on curves in figure 15. The amount of soil eroded as the slope is increased up to 8 per cent is greater for the silty clay loam. On these lower slopes the curve for the sandy loam soil is quite flat up to 8 per cent. Between 8 and 9 per cent slopes under the conditions of the tank plat the sandy loam soil became more erosive than the silty clay loam soil. On a 4 per cent slope the silty clay loam soil eroded 2.8 times as much as did the sandy loam soil, but on a 16 per cent slope the sandy loam soil eroded 2.3 times as much as did the silty clay loam soil. That is the erosiveness of the two soils was completely reversed

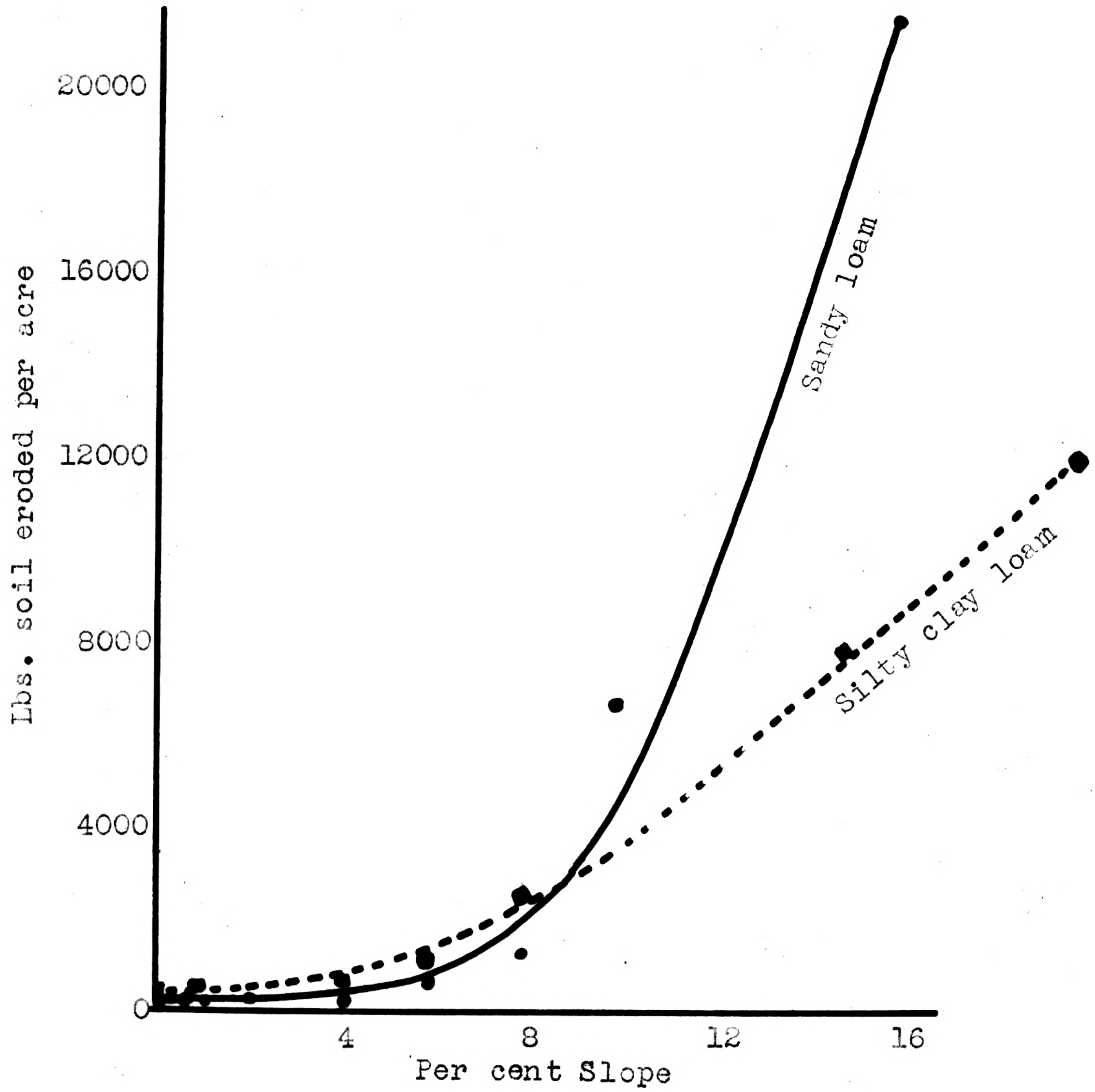

Fig. 15. Comparison of erosiveness of two soils.

with an increase of slope from 0 to 16 per cent. Silty clay soil particles are easier for the water to carry than are the more heavy sandy loam particles. On the lower slopes the water is not traveling fast enough to carry any but the smaller sandy loam soil particles, but it can carry considerable silty clay soil. On the slopes above 9 per cent the water carries more silty clay soil, but it is able to move a greater quantity of sandy soil. Most of the silty clay soil is carried in suspension. The sandy soil is carried in suspension and also rolls down the surface of the soil with the water. Middleton (13) classified soils as erosive and nonerosive and determined certain physical constants which were characteristic of these divisions.

Tests were conducted to determine these factors on these two soils. A metal tip with six radial holes was fitted to a pippette to obtain samples for dispersion determinations. The Bouyoucos (2) hydrometer method for determining colloids, clay, silt and sand content was used. The Briggs and McLane (3) method for determining the moisture equivalent was used. The data from these determinations are shown in Table X.

Middleton sets the lower limit at 10 for the erosion ratio for more erosive soils. The surface soil for the silty clay loam soil has an erosion ratio of 5.8 which would

Table X. Physical Properties of the Silty Clay Loam Soil and the Sandy Loam Soil

Soil	Depth	Per cent sand	Per cent conventional silt	Per cent conventional clay	Per cent colloidal content	Moisture equivalent	Dispersion ratio	Ratio of colloid to M. equivalent	Erosion ratio
Silty clay loam	0-12"	23	44	33	39	29.61	7.65	1.317	5.808
" " "	12"-24"	22	40	38	46	31.1	5.58	1.479	3.772
" " "	24"-36"	24	42	34	42	29.01	7.73	1.447	5.342
Sandy loam	0-12"	76	18	6	8	7.29	16.25	1.097	14.813
" "	12"-24"	74	14	12	15	12.25	11.57	1.224	9.452
" "	24"-36"	71.5	16.5	12	13	12.34	11.82	1.053	11.225

make it a nonerosive soil. The surface soil for the sandy loam soil had an erosion ratio of 14.8 which would make it an erosive soil. This division holds all right for these soils on steep slopes, which were the conditions under which Middleton made his divisions, but it does not hold for the lesser slopes with the two particular soils on which the present experiment was conducted. It would seem from the present data that one could not divide soils into erosive and nonerosive soils by their physical properties, but would have to take into consideration the slope, and possibly other factors such as rate of rainfall, etc.

Pounds of Runoff to Remove One Pound Soil

The pounds of runoff required to remove 1 pound of soil is found in the last column of each table containing soil erosion determinations. It will be noticed that the amount of runoff required to remove 1 pound of soil is greater for the lower slope than it is for the steeper slopes. Tables VIII and IX present data which show the influence of rate of application of water on pounds of water required to remove 1 pound of soil. With an application of 1 inch per hour on a 0.5 per cent slope, 1.5 times as much runoff was required to remove 1 pound of soil as with 1 inch in 30 minutes. On the 8 per cent slope the lighter application required nearly 5 times as much runoff to carry a pound of

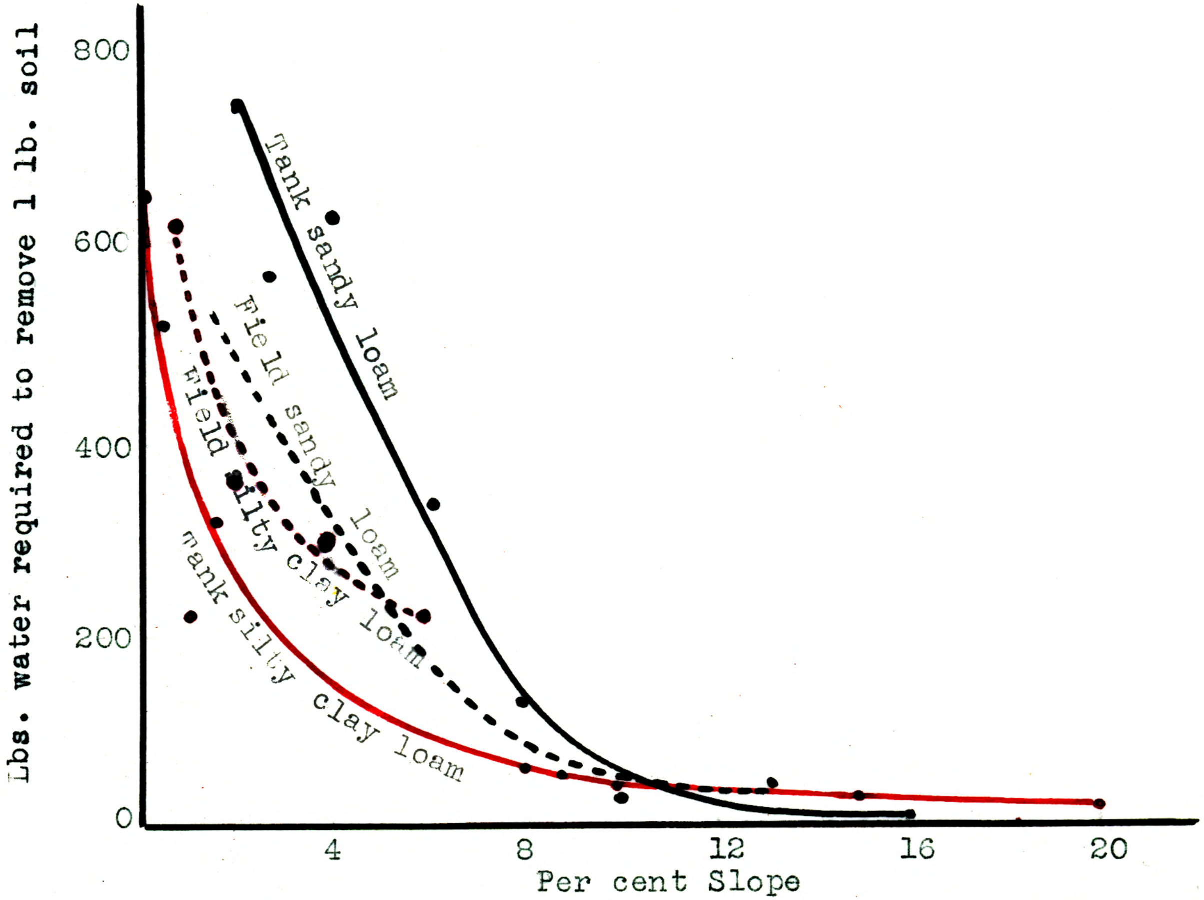

Fig. 16. The effect of slope on pounds of runoff required to remove 1 pound of soil.

soil as did the heavier application.

Figure 16 shows curves made from data on amounts of runoff required to remove 1 pound of soil with water applied at the rate of 1 inch per hour. Curves are shown for the test west of St. George, silty clay loam field test on the agronomy farm and the tank tests on both soils. These curves show a marked decrease in amounts of runoff required until 8 to 10 per cent slope is reached when the curves flatten out.

A Comparison of the Above Data with that of Other Experiments

The amounts of soil eroded from different slopes at Missouri, Texas, Alabama and from these field tests are shown in figures 17 and 18. These curves compare the results obtained from small plats with artificial application of water with larger plats with natural rainfall. The curves showing the results from the Missouri station reported by Miller (14) is nearly a straight line. This follows the general trend of the curve for the silty clay loam soil used in these tests for the same degree slope. When differences in location and methods used are considered, this probably could be considered a good agreement. Since in the Missouri tests only 3 points on the curve are represented it is impossible to show the trend for a wide range of slope since

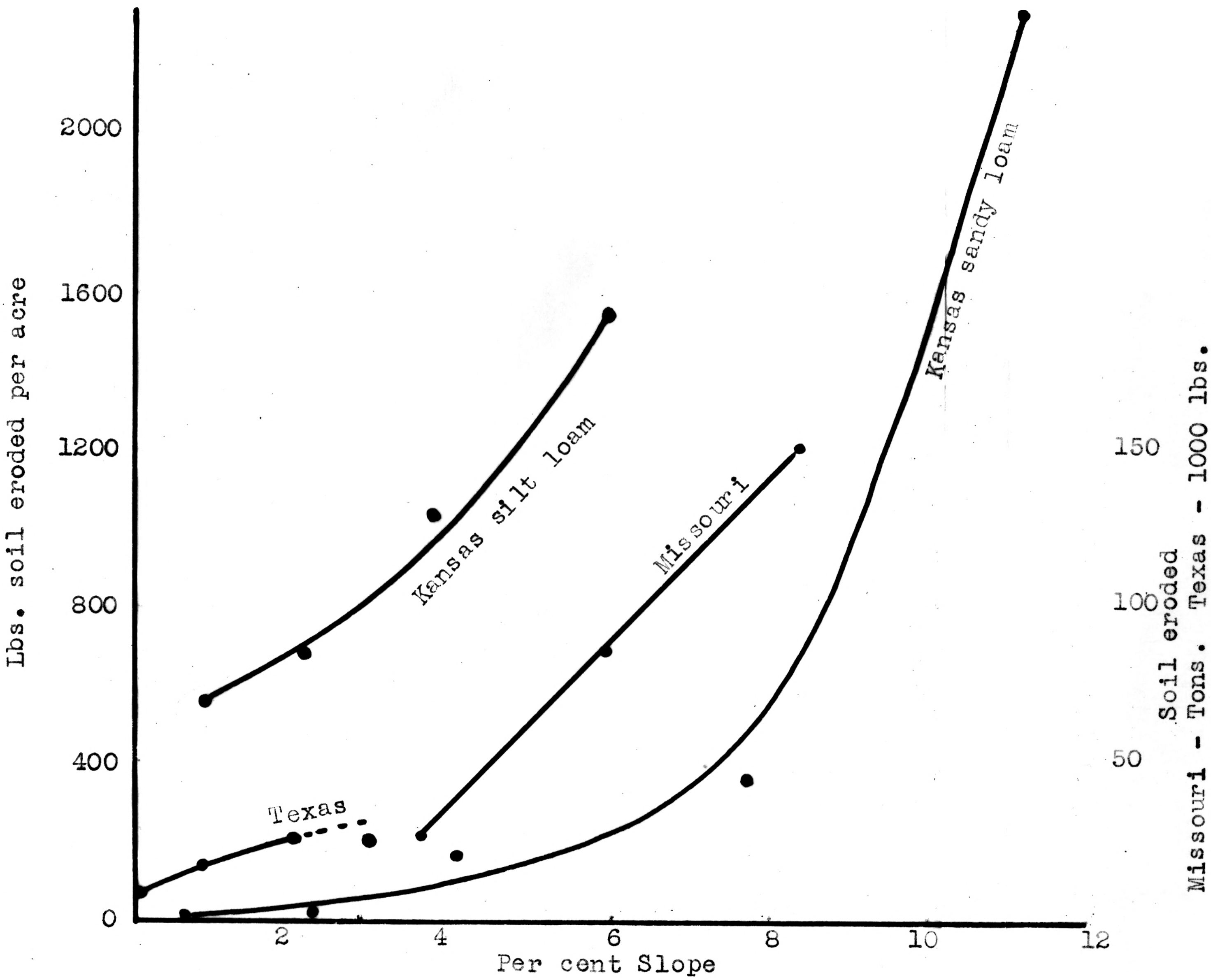

Fig. 17. Effect of degree of slope on amount of soil eroded. Comparison of results from different stations.

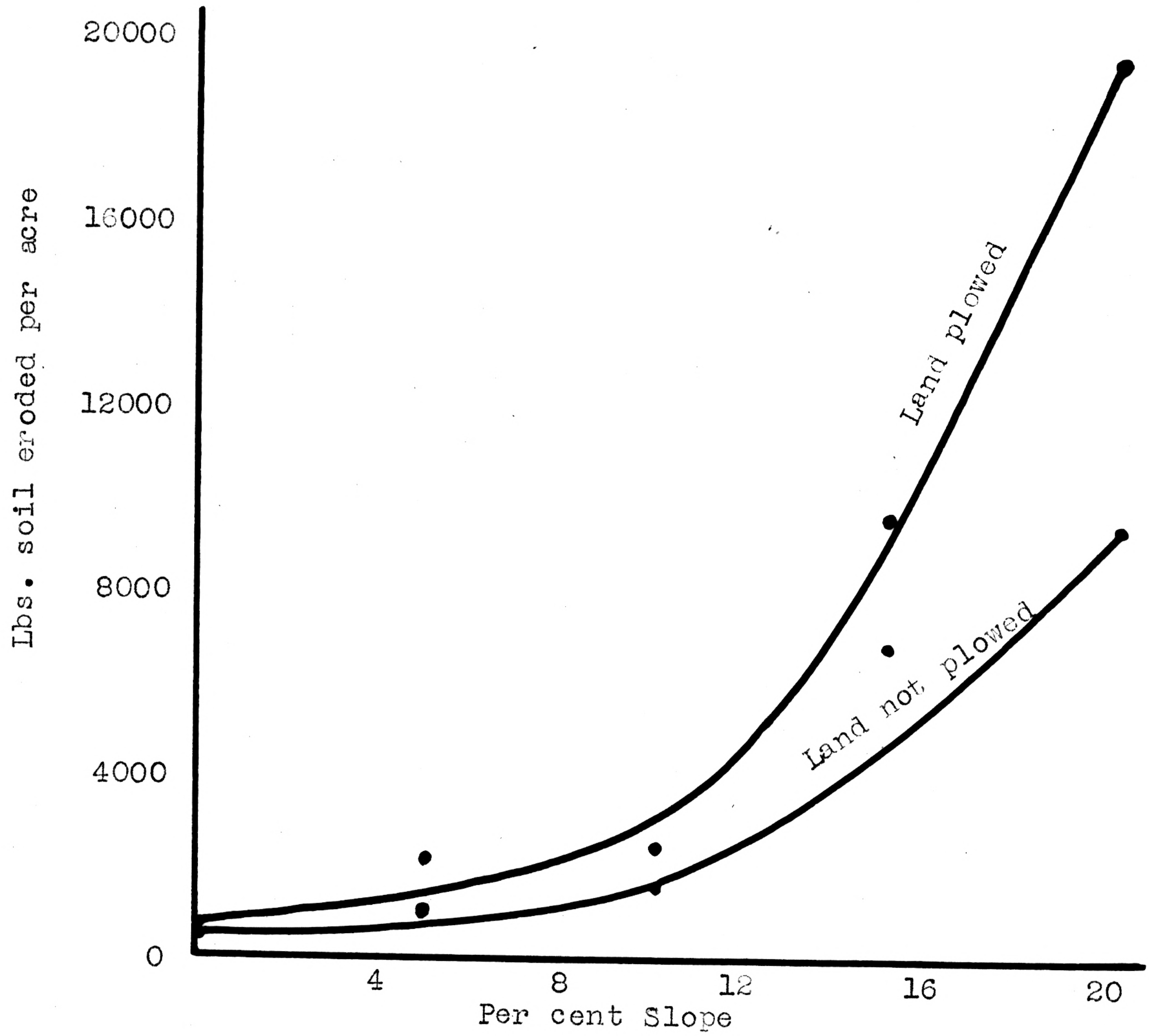

Fig. 18. Effect of slope on pounds of soil eroded from Cecil clay loam. Alabama results. Rows with slope.

it has been found in the present work with small plats that the greatest increase in erosion is to be found at about the point of the lowest slope used in the Missouri tests. A similar comparison was made with the results obtained by Connor, Dickson and Scoates (7) at the Spur, Texas station. Their results were obtained on slopes varying from 0 to 3 per cent. This was below the point of greatest increase found in the tests herein reported. The chief difference in the results is the fact that in Texas they obtained a large increase in erosion with the 1 per cent slope as compared with the zero slope. The increase from 1 to 3 per cent slope was much less marked. Another difference in method is that the different slopes were produced by artificially adjusting some of the slopes for the entire length of the plat, whereas in the present work the natural slope was used for the length of the plat and the only adjustment of the surface was in leveling across the plat. The curves for the Alabama results (15) are similar to the curves for the results reported in this paper. The curve for their plowed plats is very similar to the curve obtained from the results with the sandy loam soil at St. George. Nichols and Saxton found that the erosion varied uniformly with the slope up to 12 per cent grade, above this slope the rate of erosion increased very rapidly and it was concluded that 12 per cent was the critical slope of this soil. From the results obtained on the Kansas soils it is not possible to fix a definite per cent as the critical slope. It was found that there was a gradual increase in amount of soil eroded with an increase in slope on the lower slope up to a 3 or 4 per cent slope. Then on up to 8 or 10 per cent slope the increase was more rapid, and above 10 per cent slope the increase was very rapid.

The amounts of runoff obtained in the Texas experiment is represented by figure 10, curve (b). This shows a curve very similar to that obtained with the tank except that in their results the 3 per cent slope has given less runoff than the 2 per cent slope. This, the authors state, is probably due to the building up of the soil to obtain the 3 per cent grade.

The amounts of runoff obtained from one rain in the Alabama experiment is represented in figure 10, curve (c). This curve covers as wide a range as the tank plat, but does not have as many points on the curve. This curve follows very closely the trend shown for the tank plat in curve (a).

It would seem from the few comparisons, at least the methods herein reported gives results comparable with larger plats conducted under natural rainfall conditions, and they have the distinct advantage of affording opportunity for a large number of repetitions of comparable conditions as well as the possibility of studying a great number of different conditions bearing on a given erosion problem; and in addition to this, may be used for a wide variety of problems. Permanent plats placed at different angles on a hillside could be used to excellent advantage for determining the effect of slope under normal rainfall conditions extending over a long period of time.

SUMMARY AND CONCLUSIONS

Experiments were made to determine the influence of slope and rate of artificial application of water on the amount of runoff and soil eroded. Water was applied by means of a sprinkling can.

Field plats with an area of 1/600 of an acre were used. A variation in slope was obtained by setting the plats at various angles on the hillside. This made it possible to obtain a difference in slope from level to the maximum slope of the hillside. The plats were placed closely together so as to eliminate great variations in soil profile. It was necessary to level the plats crosswise in order to have slope only in one direction.

A laboratory test plat was made by surrounding a galvanized iron tank by heavy frame work. This was filled with soil which was removed from the field in shallow layers.

The layers were placed in the tank in the same order as they existed in the field and settled to their approximate volume. A variation in slope was obtained by raising one end of the tank. This plat has an area of 1/2178 of an acre.

The results from the laboratory test check very closely with those obtained from the field plats. The tank has the advantages of having exactly the same soil profile for all the slopes, a greater variation in slope can be obtained than was possible under field conditions, and was convenient to use for a winter test plat when the other plats were frozen.

The runoff was found to increase rapidly as the slope increased up to 3 or 4 per cent. The increase in runoff after 3 or 4 per cent slope was very slight for each increase in per cent slope.

The soil eroded increased nearly opposite to the increase in runoff. The soil eroded increased very gradually up to 3 or 4 per cent slope, then there was a more rapid rise up to 7 or 8 per cent after which there was a still greater increase of soil eroded for each per cent increase in slope.

It was found that by increasing the rate of application of water from 1 inch per hour to 2 inches per hour, the amount of erosion was increased 30 to 40 times on the lower slope and six to nine times on the steeper slopes. The increase in loss on sandy loam field tests was from 5 pounds to 164 pounds per acre on the 0.6 per cent slope and from 2297 to 17316 pounds per acre on the 11.36 per cent slope.

The soil tended to absorb the same amount of water independent of the rate of application when the rate of application was greater than 1 inch per hour. The lighter rate was in excess of what the soil could absorb so that there was very little increase in rate of absorption due to the heavier application.

A comparison was made of the erosiveness of the silty clay loam soil and the sandy loam soil. It was found that the silty clay loam soil was more erosive on the lower slopes than was the sandy loam soil until a slope of 9 per cent was obtained when the sandy loam became the more erosive. At 4 per cent slope the silty clay loam eroded 2.8 times as much as did the sandy loam. At 16 per cent the sandy loam soil eroded 2.3 times as much as did the silty clay loam soil. Determinations were made to find the erosion ratio as defined by Middleton (13). The erosion ratio would place the silty clay loam as a nonerosive soil and the sandy loam as an erosive soil. The above data support this division for slope above 9 per cent, but do not for those less than 9 per cent.

The pounds of water required to remove 1 pound of soil decreased very rapidly as the slope increased from 0 to 10 per cent. Above 10 per cent the decrease was gradual and only slight.

A comparison was made between the data presented and that obtained at the Texas, Missouri and Alabama stations. The curves made from these data all have about the same general trend. There was some difference found between the curves, but this probably can be attributed to differences in soils used, in methods of application of water and in methods of handling the plats, such as surface condition, etc. It would seem that these data coincide close enough with the data presented to justify the use of small plats and methods used for the determination of the effect of various factors on the amounts of runoff and soil eroded under a great variety of conditions.

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