UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

RESEARCH BULLETIN 63

Erosion and Surface Runoff Under Different Soil Conditions

(Publication authorized November 21, 1923)

COLUMBIA, MISSOURI

DECEMBER, 1923

UNIVERSITY OF MISSOURI

COLLEGE OF AGRICULTURE

Agricultural Experiment Station

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Erosion and Surface Runoff Under Different Soil Conditions

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Abstract.—Seven plots, each one-eightieth of an acre in area, were laid out on a phase of the Shelby loam soil. The slope of the land averaged 3.68 feet per hundred. At the lower ends of the plots were concrete tanks for collecting the runoff and eroded soil, which were determined after each rain. The results of these experiments showed that grass or clover land absorbed much more water than cultivated land. Deep plowing (8 inches) was only slightly more effective than shallow plowing (4 inches) in preventing runoff and erosion. The surface inches of rainfall absorbed by uncropped land, or land in a cultivated crop like corn, was practically constant from year to year even with considerable variation in the annual precipitation. The character of the rainfall largely determined the amount of soil erosion. A heavy dashing rain was observed to remove more soil within a few hours than was lost during a whole year when the rainfall was well distributed. The loss of important nutrient elements from the soil through erosion may often be more serious than the loss through the removal of crops. The use of a cropping system that includes sod crops a considerable portion of the time is the most practical means of reducing erosion on rolling lands.

Surface erosion is one of the most important causes of soil deterioration, throughout the humid regions of the United States. While erosion is constantly taking place from uncultivated lands, it is from lands under the plow that it reaches its maximum. It is common knowledge that the greatest destruction from erosion has taken place in the southern states. This has been due to the generally rolling topography, the heavy rainfall, the lack of winter freezing and the excessive growing of cultivated crops—mainly cotton. In the corn belt states the conditions have been somewhat less favorable for erosion, yet the amount of soil removed from these fertile uplands has been very great. Naturally, some soil removal through erosion is inevitable in any system of agriculture. It is, however, the excessive losses of soil which should give concern. The question then arises as to what may be considered excessive losses and normal losses. It was with the idea of determining definitely the losses to be expected from soil erosion under carefully controlled and widely varying conditions, that these experiments were undertaken.

Considerable work has been done by geologists and engineers in the matter of measuring in a gross way, the water-soluble material and sediment carried by streams. Such investigations have dealt with most of the important rivers of the world. In only a few cases have investigations been made as to the losses of surface soil from definite areas of agricultural land. However, the determinations of runoff and suspended matter, as well as of soluble materials, are of so much importance in connection with this particular field study that it seems advisable to include some of them in a review of the literature.

HISTORICAL

Hitchcock[7] stated in 1855 that the Merrimac River sends forward, annually, about 839,171 tons of sediment to its delta. The Ganges carries about 355,361,464 tons of mud each year. The Mississippi carries about 28,188,383,892 cu. ft. or one cubic mile in a little over five years. Since the whole delta contains 2720 cubic miles it would require at this rate about 14,000 years to form it.

Norton[12] states that with an annual rainfall of about 50 inches approximately 50 per cent is discharged through rivers. He states further that the Ohio River discharges 30 per cent of the rainfall of its basin, while the Missouri carries away but 15 per cent. A number of streams of the semi-arid lands of the West do not discharge more than 5 per cent of the rainfall. Desert streams may lose all of their water before they reach the sea.

Babb[2] reports determinations made on the Potomac River which show that the average annual discharge of this stream, from a drainage area of 11,043 square miles is 20,160 second-feet, varying from 2,000 second-feet in time of low water, to 470,000 second-feet during the great flood of 1889. The total amount of sediment transported annually averaged 353 pounds per second for a period of 6 years (1886-1891). The total loss was lowest in 1887 with 2,372,800 tons, and greatest in 1889 with 10,142,600 tons. The average daily amount varied from 1 to 21,900 pounds per second. The average amount of sediment was to the weight of water discharged as 1 to 3575. Assuming 1 cubic

River	Drainage area, sq. mi.	Mean annual discharge, second-feet	Sediment			Years to erode top 7 inches*
			Total annual, tons	Ratio wt. soil. to wt. water. Soil=1	Surface inches eroded annually	
Potomac	11,043	20,160	5,557,250	3,575	0.00433	1,616
Mississippi	1,214,000	610,000	406,250,000	1,500	0.00288	2,430
Rio Grande	30,000	1,700	3,830,000	291	0.00110	6,363
Uruguay	150,000	150,000	14,782,500	10,000	0.00085	8,235
Rhone	34,800	65,850	36,000,000	1,775	0.01071	653
Po	27,100	62,200	67,000,000	900	†0.02612	268
Danube	320,300	315,200	108,000,000	2,880	0.00354	1,977
Nile	1,100,000	113,000	54,000,000	2,050	0.00042	16,666
Irrawaddy	125,000	475,000	291,430,000	1,610	0.02005	349

*Calculated by writer. †Corrected by writer.

foot of soil to weigh 100 pounds, this average amount of sediment would cover the entire drainage area to a depth of 0.0043 inches. At this rate it would take the river 2,770 years to erode 1 foot from the drainage area.

The results of this investigation are tabulated on page 6 along with data compiled from various sources giving the drainage and erosion of several of the important rivers of the world.

Davis[4] reports estimates by the Geological Survey that the amounts of sediment carried by several American rivers are as follows:

	Tons a year
Hudson	240,000
Susquehanna	240,000
Roanoke	3,000,000
Alabama	3,039,000
Savannah	1,000,000
Tennessee	11,000,000
Missouri	176,000,000

McHargue and Peter[9] determined the amount of mineral matter in solution found in the drainage water of various rivers in Kentucky flowing through different geological areas. They found that the drainage from limestone areas had the most mineral matter and that from sandstone areas the least, but the potassium was higher from the sandstone areas than from limestone regions.

These authors also give results of determinations on the soluble materials found in the water of the Mississippi River. The samples were taken at Baton Rouge, La. The parts per million as well as total tons lost per year are as follows:

Element	P. P. M. Lost in solution	Tons lost per year
P	0.07	62,188
N	0.80	630,720
K	2.09	1,626,312
Ca	28.29	22,446,379
Mg	6.62	5,179,788
S	8.52	6,732,936
Total	66.39	36,678,323

Torrance[17] reports estimates showing that the Little Buak River carried material in suspension to the extent of 4,000 parts per 100,000 and the Thebus River 2,355 parts per 100,000. He gives the results by Juritz of the analyses of silts from various rivers in South Africa which show a lime content of 0.584 per cent, potash 0.153 per cent and phosphoric oxide 0.106 per cent. He further showed that land covered with ½ inch of silt deposited by the Orange River would be enriched to the extent of 3,314 pounds of lime, 1,086 pounds of potash and 507 pounds of phosphoric acid per acre.

Norton[13], measured the drainage water from Richard Creek, which drains a territory of 84,954 acres in Madison and Washington Counties, Arkansas. This region is described as being a purely agricultural one, but no statement is made as to the amount of cultivated soil.

Determinations of the stream flow were made by the use of a current meter every two weeks during the year 1906. A sample of water for analysis was taken at the time of these determinations. The total rainfall averaged 202,520 cu. ft. per acre. The runoff as measured in the stream averaged 59,471 cu. ft. per acre. If the difference in these two figures is taken as the evaporation it would amount to 143,049 cu. ft. per acre. Or in other words 70.6 per cent of the rainfall evaporated and only 29.4 per cent was included in the runoff. During the growing season more than 90 per cent of the rainfall evaporated. The mean temperature for the year was 57.9 degrees which will largely account for the high amount of evaporation.

The composition of the soil of this region and the composition of the eroded material was determined by analyses. There was found to be considerable difference in the composition of the eroded material as compared with the original soil. From the analytical data the conclusion is drawn that there is a tendency for the soil to accumulate silica, iron, manganese and phosphorus, but a tendency to lose aluminum calcium, sulphur, potassium, nitrogen and sodium.

The author concludes from this work that the loss due to erosion and drainage is not serious since it would require on the average 300 years to remove one inch of soil. The annual loss of fertility elements he calculates to be but 89 cents an acre a year.

Forbes[6] determined the silt and salt content of water from different rivers in Arizona. The increase in percentage of silt during flood time was much greater than the increase in flow of water, due to the variation in carrying power with changes in velocity. The percentage of silt varied greatly in different streams.

A summary of the silt and salts in the Salt River waters removed from Aug. 1, 1899 to Aug. 4, 1900 showed that the water taken out by canals during the period was 307,388 acre-feet. The total silt removed was 675,948 tons and the total salts removed was 414,716 tons. During only 7 of 42 approximate weekly periods throughout the year was the weight of silt greater than the weight of salts in solution. The total amount of sediment was sufficient to make a layer approximately 0.000603- inch deep over the entire drainage area. This would mean that the surface 7 inches would be removed in about 11,608 years.

Chemical analyses of the drainage water and sediment showed that considerable quantities of plant food material is lost during the course of a year, but if this is calculated on the acre basis the loss is insignificant, amounting to only a few pounds an acre.

The maximum and minimum percentages of sediment were found to vary widely with three different rivers studied. The maximum percentage of sediment in Salt River at flood stage was 0.951, in the Gila 9.046, and in the Colorado 2.072. The minimum percentage at low water was 0.0036 in Salt River, 0.0082 in the Gila, and 0.0326 in the Colorado River.

Low waters in all cases contain higher than the average proportions of salts, partly because of concentration by evaporation, and partly because of the predominance of seepage waters during the summer. The amounts of sediment in low waters is very small.

Ashe[1] states that the floods of the many rivers in the South are greater than formerly due to a greater runoff with the same amount of rainfall. This is doubtless due to better facilities for runoff and the land is in poorer condition for absorption.

Clarke[3] has collected from various sources the analyses of a number of rivers in different parts of the world. He has also calculated a "denudation factor" which represents the number of metric tons annually removed in solution from each square mile of a drainage basin. These analyses show some striking differences between humid and arid regions. The St. Lawrence represents a humid area entirely and hence it has a high denudation factor of 105. The Mississippi carries some water from humid and some from arid and semi-arid regions and its load is somewhat lowered, being 98. The Colorado and Rio Grande flow through arid regions in large part and therefore carry much less material to the sea, because much of their drainage area contributes practically nothing to the salinity of their waters. Their denudation factors were 46.2 and 22.7 respectively. The St. Lawrence carries a high proportion of carbonate, while the Colorado and Rio Grande have more sulfates and chlorides.

Sampson and Weyl[15] report the results of experiments in the Manti National Forest, Utah, in which two selected irregular 10-acre areas designated as A and B were used to determine runoff and erosion from grazing lands. In order to measure accurately the runoff and sediment, a settling tank of adequate size, provided with weir and water register was installed at the lowest drainage point on each area. A summary of the data obtained may be seen in the following table:

Runoff and Erosion From Rainstorms.

Year	Area	Total number of storm days	Total rainfall	Effective storm days*	Effective rainfall, inches*	Runoff cu. ft.	Sediment cu. ft.	Sediment per cent
1915	A	26	5.79	1	0.70	3,018.96	716.92	23.70
1915	B	26	6.48	1	1.43	335.15	94.29	28.13
1916	A	36	7.70	14	4.05	2,266.68	197.49	8.70
1916	B	36	8.13	8	3.23	835.55	59.81	7.20

*Effective here refers to storms that produced runoff.

It should be noted from the above table that the one rain which produced runoff in 1915 was far more erosive than the total for the 14 rains on A or the 8 rains on B in 1916. That the percentage of sediment carried in the runoff is proportionately higher as the velocity of the flow increases is shown by the figures in the last column.

During the season of 1915 both the areas were ungrazed and the erosion was much more severe on A, since A was somewhat steeper and not so well covered with grass. In 1916 area B was grazed while A was ungrazed, and the erosion was relatively much more severe on area B. The ratios of precipitation, runoff, and erosion on area B as compared with area A were changed from 2:1, 1:12, and 1:8 in 1915, to 1:1, 1:1, and 1:2 in 1916, respectively, as a result of grazing area B and not grazing area A. It has been observed by many other foresters and herdsmen that overgrazing is one of the greatest causes of erosion on range lands.

Smith[16] calls attention to the fact that since the white man has taken possession of the American continent he has greatly increased the acreage of the three great cultivated crops, corn, cotton and tobacco. These are grown in regions of heavy summer rainfall and are the cause of serious soil erosion over great areas in the most fertile parts of North America.

Rodhouse[11] measured the runoff from the small Grindstone Creek about one mile from where the experiments reported in the present bulletin were made. He found for the year 1910 with 42.22 inches of rainfall there was a runoff of 15.74 inches or 37.3 per cent. During the first six months of the very dry year 1911 with 13.05 inches of rainfall there was 3.33 inches of runoff or 25.5 per cent.

Rodhouse also made measurements on Current River in the southern part of Missouri which showed that with an average rainfall (1913-1920) of 42.24 inches there was an average runoff of approximately 12.76 inches or 30.2 per cent. During the year 1917 the rainfall was 41.07 inches while in 1918 it was 41.26 inches. The runoff in 1918 was 43.14 per cent greater than in 1917. This seemed to be due to the fact that more rain fell during the warmer months, April to August, 1917 when evaporation was highest.

Duce[5] observed the effect of grazing upon erosion in Colorado. He states that cattle influence erosion in two ways; first, by the wearing of trails; and second, by the destruction of vegetation. The rapidity of runoff and the rate of erosion is increased by destroying vegetation, while the wearing of trails forms channels which result in gullying.

Lynde[8] determined the runoff from Third Creek near Statesville, North Carolina. These measurements covered the period 1914 to 1918 including also a part of 1913. The results show that the five-year average rainfall was 50.52 inches and the runoff 21.14 or 41.8 per cent. Except for 1914 when it dropped to 16.73 inches the actual inches of runoff each year was very near the average for the five-year period. The per cent runoff, however, varied from 33 in 1914 to 52 in 1918.

Morin[10] reported studies covering a ten-year period 1909-1918 in which he determined the relation between the rainfall and the runoff in the upper Cher River basin in France. It was found that this relation, called the coefficient of annual runoff, varied from 0.64 in 1910 to 0.30 in 1914. The average being 0.42. The average annual rainfall was 903 mm. It was concluded that this coefficient depended principally upon the rainfall. The total amount of water evaporated was smallest during very wet or very dry years. On the average 54.7 per cent of the rainfall was evaporated and 45.3 per cent was found in the runoff. The amount of runoff varied considerably, depending upon the time of year when the heaviest rains fell.

Mosier and Gustafson[11] state that in 62 Illinois counties that have been surveyed, the percentage of hilly and broken land is 15.2 per cent of the total area. Besides this there is a large area of undulating to rolling land, both timber and prairie, that has not been badly damaged as yet, but which with continued cropping and consequent loss of organic matter is becoming more subject to injurious surface erosion.

The work of the Illinois State Geological Survey shows that the runoff for the Spoon River basin is 21.5 per cent of the total rainfall; for the Embarrass River basin 25 per cent; and for the Kaskaskia, when the rainfall was 42.8 inches as a three-year average, 37.9 per cent.

In 1908 the runoff was 50.23 per cent when the rainfall was below the average. This was due to the fact that more than half the rainfall occurred during February, April and May.

PLAN OF THE EXPERIMENTS

The experiments described in this bulletin were planned with the idea of determining accurately the amount of runoff and soil erosion taking place on a given soil under different systems of cropping and of tillage. The soil type on which the experiment was carried out was the Shelby loam, although this particular piece of land was somewhat more deficient in organic matter than is typical of this type. Seven elongated plots, separated by partition strips, were laid out running up and down the slope and ending in concrete tanks at the lower ends. These tanks were built in the ground so that their tops were on a level with the lower ends of the plots thus admitting the runoff water and the eroded soil. Figure 1 shows the general layout of the plots as well as the treatment given each.

The plots were first divided by using 1 by 8-inch boards, but these did not prove very satisfactory, and they were replaced the second year by 10-inch strips of galvanized iron. These were attached to iron stakes, every 3 feet set in concrete. The land originally sloped toward the tanks (east) with a fall of about 3.68 feet per hundred, and toward the south at about 3.75 feet per hundred. When the plots were laid out a 3-inch drop was made from one plot to the next beginning at No. 7. The surface of each was then leveled from north to south so that the plots had a slope in only one direction, toward the east. This plan was considered advantageous in order to prevent the water from following along what would have been the lower side of each plot and cutting a gully. The final slope toward the east was 4.16 feet per hundred for the lower part and 2.71 feet per hundred for the 30 feet at the west ends of the plots, or an average of 3.68 feet per hundred.

The tanks for collecting the runoff and eroded soil had flat bottoms and were provided with an outlet tube as shown at (a) in Figure 1. This tube extended up into the tank to a height of approximately 1½ inches. It was provided with a screw cap to prevent leakage. Following rains the eroded soil was allowed to settle about one day after which the cap was removed by means of a long stem wrench and the water drained away, leaving the soil in the bottom of the tank. There was some loss of the colloidal particles which remained in suspension, but tests showed that this amount was very small during the greater part of the year. The largest loss was in the early spring, immediately after the ground thawed and when the amount of colloidal material

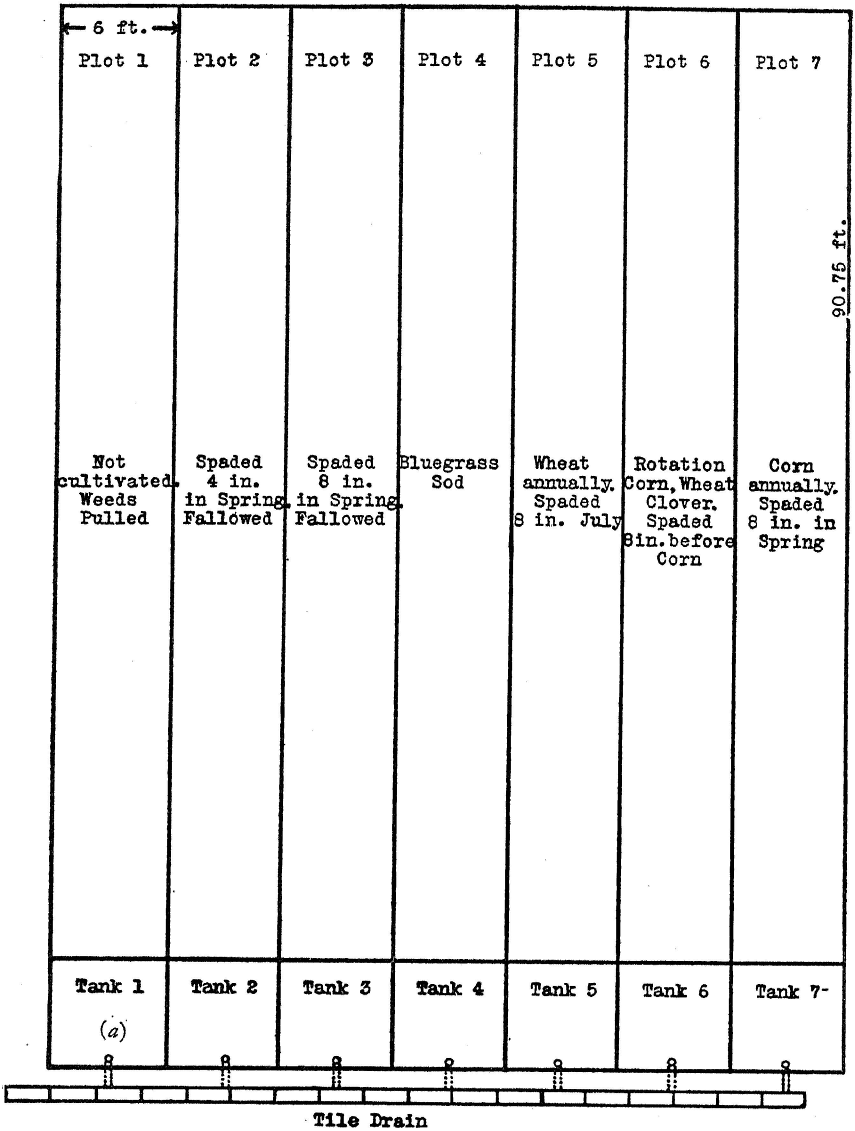


Fig. 1.—Diagram showing arrangement of plots and treatments as well as the location of tanks for catching runoff. The drain pipes are shown at a.

remaining in suspension is greatest. During the spring and after heavy rains the water was left in the tanks for a longer period so that the settling would be more complete. In the summer and winter the settling was rapid and when the runoff was small the water drained from the tanks was practically clear. Various attempts were made to flocculate the material, but none of these proved very practical, especially where samples of the soil were desired for analysis. The loss was determined at various times and it was found to be small enough to be considered within the limits of error. During small rains when the water in the tank did not come above the top of the outlet tube all the water was sampled and no error was caused by the loss of suspended material.

The eroded soil and water left in the tank, after draining down to the outlet tube, was removed and placed in large galvanized iron cans. After still further settling, more water could usually be poured off. The remainder of the material was weighed and samples taken in pint moisture cans. These were taken to the laboratory and the moisture content determined by evaporating to dryness.

There was some difficulty encountered in getting representative samples. The most satisfactory method was by taking a small cup and dipping into the mixture of soil and water as it was rapidly stirred with a hoe. The stirring was so done as to give the mixture a rotary motion. This brought the heavy sand grains to the top along with the finer soil particles.

TREATMENT OF PLOTS

The treatments chosen for the various plots were expected to give a wide variation in the amounts of runoff an erosion, and to represent most of the conditions to be found in the field. After the plots were brought to the proper levels, the permanent plan to be followed was put into operation at once. The plan of treatment for the different plots was as follows:

Plot 1. Bare soil.—This plot was left without cultivation during the course of the experiment. The weeds were kept down by clipping or pulling, so that the ground was disturbed very little. After the second year most of the weeds had been killed and they gave little further trouble. Occasionally it was found necessary to do a small amount of leveling in order to prevent the formation of a gutter down the middle of the plot.

Plot 2. Spaded four inches deep and cultivated.—This plot was spaded each year in early spring to a depth of 4 inches. An ordinary garden spading fork was used with a cross-bar that kept it from going deeper than the desired depth. The plot was hoed after rains in order to keep the surface in the best condition for absorbing the rainfall, and to prevent the growth of weeds. It was leveled at each hoeing and there was little difficulty caused by gutters washing out in the middle of it.

Plot 3. Spaded eight inches deep and cultivated.—This plot was spaded 8 inches deep in the spring and cultivated in the same manner and at the same time as Plot 2, the only difference being in the depth of spring spading.

Plot 4. Continuous sod.—This plot was seeded down to grass in the spring of 1917, and kept in sod continuously during the experiment. The sod was principally blue grass, but some difficulty was found in keeping down red sorrel and crab grass.

Plot 5. Continuous small grain.—This plot was kept in small grain. It was sown to oats in the spring of 1917 in order to get a small grain on the land at once but it was kept in wheat each year afterward. The land was spaded during the latter part of July each year to a depth of 8 inches. It was then cultivated sufficiently to keep down weeds until about October first when it was seeded to wheat. The wheat rows were run up and down the slope rather than across the slope. This has doubtless given somewhat greater erosion than if the rows had run with the contour. It was feared, however, that the saving of soil by small grain would be exaggerated if the rows were planted across the slope, especially since it is not always possible to do this in practice.

Plot 6. Rotation.—This plot was kept in a three-year rotation of corn, wheat and clover. It had exactly two rounds of the rotation during the progress of the experiments. The ground was spaded 8 inches deep before planting corn. It was then hoed up before wheat in a way to approximate the disking it would receive under field conditions. The clover was seeded on the wheat in the spring, and allowed to stand over the following year.

Plot 7. Continuous corn.—This plot was spaded 8 inches deep each spring and planted to corn about the first week in May. The hills were placed 3 feet apart each way. The surface of the soil was kept as level as possible during cultivations. During October the corn was cut and removed from the plot. The land was therefore quite bare during the winter.

RESULTS OF EXPERIMENTS

RUNOFF

The amount of water lost from each plot was obtained by measuring the depth of water in the tanks after each rain and then calculating to cubic feet and surface inches. The amounts of runoff for each plot during the different years are shown in Table 1.

It may be seen from the results recorded in Table 1 and Fig. 2 that there was a great variation in the amount of runoff from a given plot during the different years of the experiment. There was a still greater

TABLE 1.—AMOUNTS OF WATER LOST BY RUNOFF FROM EACH PLOT DURING THE DIFFERENT YEARS OF THE EXPERIMENTS.

Year of experiment.	Plot 1 Not cultivated	Plot 2 Spaded 4 in.	Plot 3 Spaded 8 in.	Plot 4 Sod.	Plot 5 Wheat annually	Plot 6 Rotation	Plot 7 Corn annually
	cu. ft.*	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
First	355	182	211	79	175	151	125
Second	779	544	512	262	324	395	456
Third	1,053	692	598	201	511	250	638
Fourth	539	227	162	23	195	124	170
Fifth	1,416	1,129	1,042	467	1,012	439	1,033
Sixth	632	277	242	93	240	19	249
Average	796	508	461	187	409	230	445

*Fractions of a cubic foot omitted.

variation between the amounts of runoff from different plots during the same year. For example, during the sixth year of the experiment the runoff on Plot 1 was 33.2 times as much as on Plot 6 which was in clover. The greatest difference between the various years on Plot 1 is shown by the runoff the fifth year which is four times what it was the first year.

The effect of grass in saving water or causing a soil to absorb more water is well shown in Plot 4. The total loss from this plot has been less than half as much as the loss from Plots 2, 3, 5, or 7 and less than one-fourth as much as the loss from Plot 1 which had no crop and was uncultivated.

Table 2 brings out the differences in these soil treatments. The percentage of the total rainfall lost during the six years is shown in the lower horizontal column. It will be seen that on the uncultivated plot 48.92 per cent or nearly half of the rainfall has been lost by runoff. The effect of plowing is illustrated by Plots 2 and 3. Plot 2 plowed 4 inches deep, lost 31.26 per cent of the rainfall by runoff, or in other words the 4-inch plowing saved 17.7 per cent of the rainfall as compared with unstirred soil. The 8-inch plowing was only slightly more effective in absorbing water than 4-inch plowing. Land kept in bluegrass sod was by far the most effective in the prevention of runoff. The average loss here was only 11.55 per cent and during the fourth year it dropped as low as 1.7 per cent. During the fifth year which was one of heavy rainfall the loss on this plot went up to 20.44 per cent. The amount and character of the rainfall is responsible for these wide variations between different years. During a season when the rainfall is not excessive and is well distributed, grass land will take in nearly all the rainfall. It is only after prolonged wet periods, particularly in the spring and fall, that the sod land loses much water by runoff. At

TABLE 2.—PERCENTAGE OF RAINFALL LOST BY RUNOFF FROM EACH PLOT DURING THE DIFFERENT YEARS OF THE EXPERIMENT.

Year of experiment.	Plot 1 Not cultivated	Plot 2 Plowed 4 in.	Plot 3 Plowed 8 in.	Plot 4 Sod.	Plot 5 Wheat annually.	Plot 6 Rotation	Plot 7 Corn annually.
First	32.28	16.60	19.25	7.25	15.92	13.72	11.37
Second	46.49	32.46	30.56	15.67	19.37	23.58	27.24
Third	55.20	36.26	31.36	10.56	26.79	13.12	33.44
Fourth	39.61	16.70	11.90	1.70	14.33	9.15	12.53
Fifth	62.03	49.43	45.65	20.44	44.32	19.25	45.25
Sixth	44.28	19.41	16.97	6.56	16.85	1.34	17.46
Percentage of total rainfall lost by runoff during six years	48.92	31.26	28.36	11.55	25.19	14.14	27.38

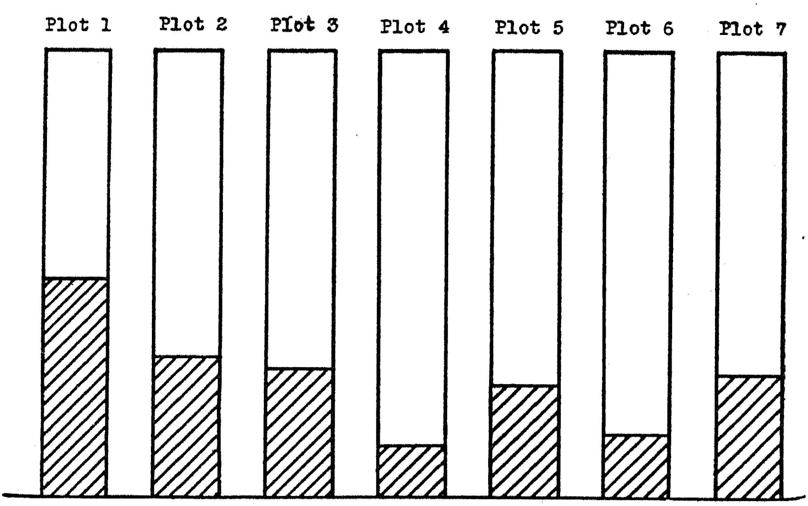


Fig. 2.—The columns represent the average rainfall during the time of this experiment. The shaded portion represents the average percentage of runoff from each plot. The blank part of the column represents the average percentage of rainfall absorbed by each plot.

these times the evaporation and transpiration are low. There are probably three principal reasons why sod land absorbs such a high percentage of the rainfall.

1. The entire surface is covered with a growing crop which is continually removing large quantities of water from the soil and subsoil. This keeps the moisture content far below that of uncropped land at nearly all seasons of the year.

2. The roots extend down into the subsoil and since these are not disturbed, some vertical passages for water become established which allow rather rapid percolation.

3. The stubble and other organic materials lying on top of the ground not only absorb considerable water but very greatly restrict the flow down the slope, thus giving more time for it to be absorbed.

The effect of sod in controlling runoff is still further shown in the case of red clover on Plot 6 during the third and sixth years. During the third year the clover sod lost 13.12 per cent as compared with 10.56 per cent from the grass sod. However, the loss from wheat land during the same year on Plot 5 was slightly more than twice the loss from clover sod, and the loss from corn land on Plot 7 was over two and one-half times as great. Another effect of the clover can be seen during the fifth year. Plot 6 was in wheat followed by clover, while Plot 5 was in wheat followed by wheat. This proved to be a year of very high rainfall, with 15.47 inches of rain during August and September. At this time Plot 5 had been spaded and worked down for wheat. It lost 216.6 cubic feet of water during September, while the loss from Plot 6 was only 75.2 cubic feet. The following spring 18.41 inches of rain fell during March and April. This was before the wheat had made enough growth to draw much water from the soil and the plants did not occupy the surface of the ground sufficiently to prevent rapid runoff, consequently the loss was nearly twice as high as from the land having young clover.

The sixth year of the experiment affords the best illustration of the effect of red clover upon the absorptive capacity of the soil. All during this year Plot 6 was covered with a dense growth of red clover. The runoff totaled but 1.34 per cent of the rainfall. Only seven rains during the entire year gave any runoff at all from this plot. The red clover sod was more effective than the grass sod on Plot 4 which allowed 6.56 per cent of runoff during the sixth year. This difference in favor of clover sod was probably due to the large plant growth which used up much of the soil water between rains and also to the deep root system of the clover plants which probably tended to allow the water to go down into the subsoil. There was also considerable organic matter on the surface, which absorbed water and retarded its flow down the slope.

Absorption.—In Table 3 and Figs. 3 to 9 is brought out the very interesting fact that the total inches of rainfall absorbed by uncropped land, whether cultivated or not does not vary greatly for a given condition from year to year. This is shown by the results given for Plots 1, 2 and 3. The average surface inches of water absorbed by the uncultivated land was 18.31. The greatest deviation from this figure was during the first year, when the total rainfall was only 24.25 inches and the amount absorbed 16.42 inches. This amount was only 1.89 inches

TABLE 3.—INCHES OF WATER ABSORBED DURING DIFFERENT YEARS.

Year of experiment.	Plot 1 Not cultivated	Plot 2 Spaded 4 in.	Plot 3 Spaded 8 in.	Plot 4 Sod	Plot 5 Wheat annually	Plot 6 Corn, wheat, clover.	Plot 7 Corn annually
First	16.42	20.22	19.58	22.49	20.39	20.92	21.49
Second	19.78	24.97	25.67	31.17	29.81	28.25	26.90
Third	18.85	26.82	28.88	37.63	30.80	36.55	28.00
Fourth	18.14	25.01	26.46	29.52	25.73	27.28	26.27
Fifth	19.15	25.51	27.41	40.13	28.08	40.73	27.62
Sixth	17.54	25.36	26.13	29.41	26.17	31.05	25.98
Average	18.31	24.65	25.69	31.73	26.83	30.80	26.04

Diagrams follow showing the relation between total rainfall and absorption for each plot. The columns from left to right represent the successive years of the experiment and the shaded part the portion of each year's rainfall absorbed.

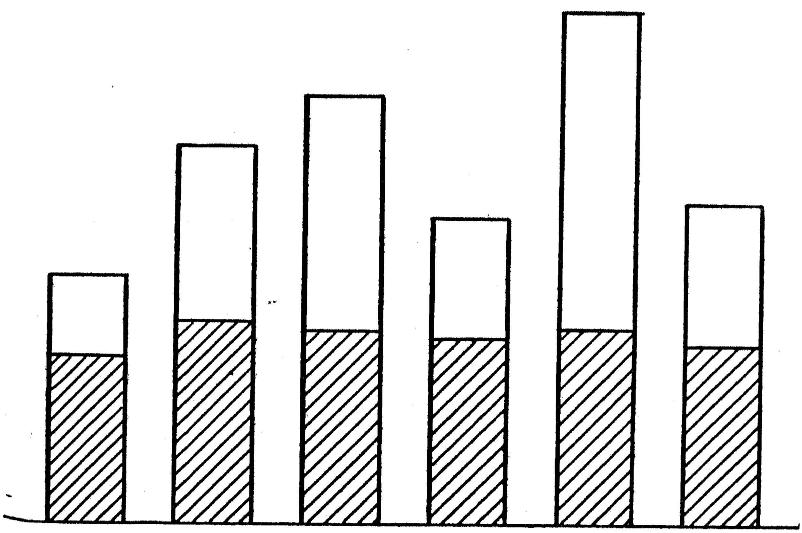


Fig. 3.—Absorption and runoff on Plot 1. The height of the columns in Figs. 3 to 9 represents the annual rainfall for the six years of this experiment. The successive years are arranged in order from left to right. The shaded parts of the columns represent the surface inches of absorption. The remaining portions of the columns represent the surface inches of runoff.

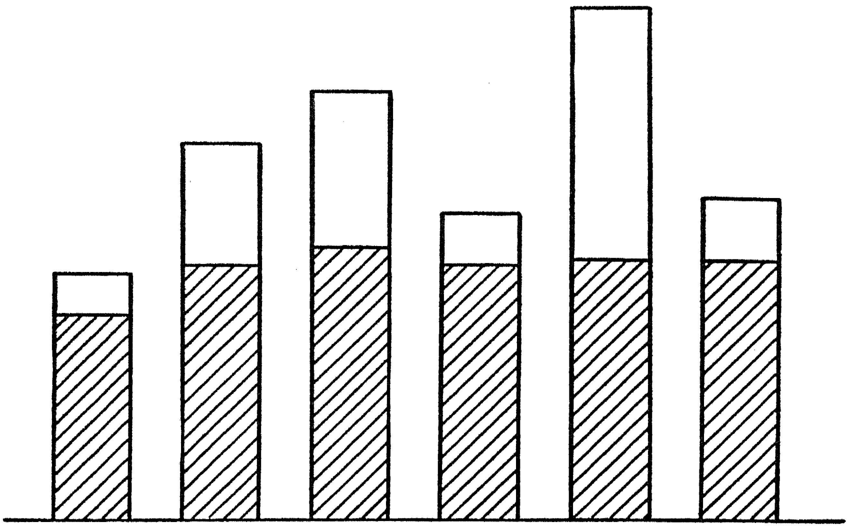


Fig. 4.—Absorption and runoff on Plot 2 which was spaded 4 inches deep in the spring and then fallowed after rains.

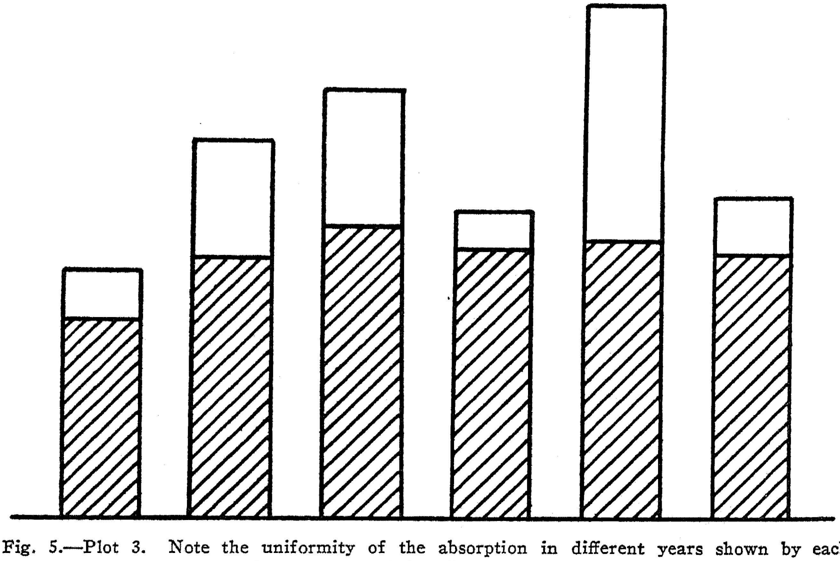


Fig. 5.—Plot 3. Note the uniformity of the absorption in different years shown by each plot represented in Figs. 3, 4 and 5.

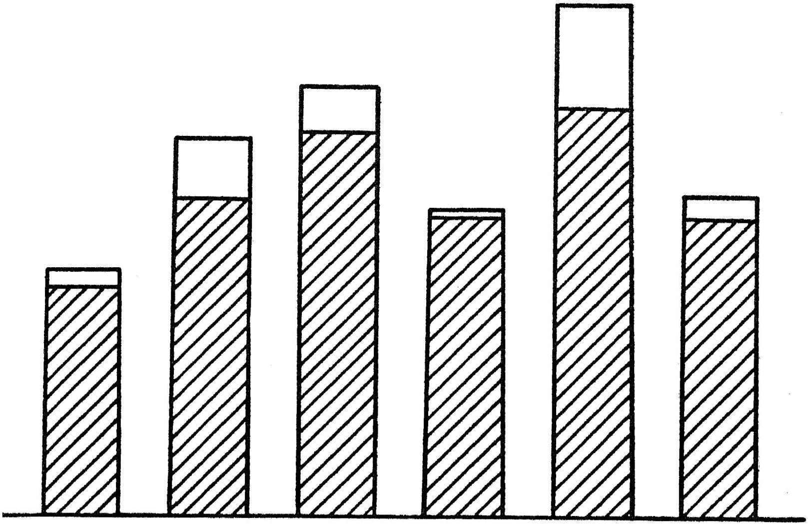


Fig. 6.—Plot 4. The absorption by grass land was much more variable from year to year than that of the uncropped plots.

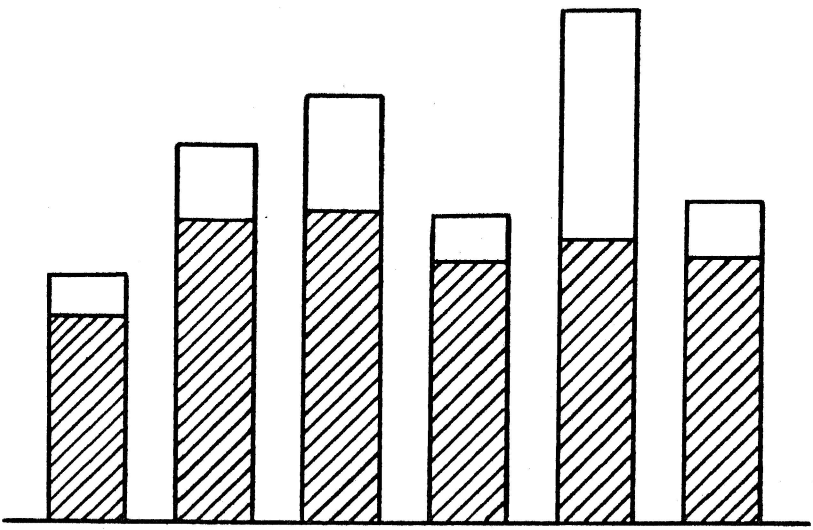


Fig. 7.—Plot 5. The variation in absorption by wheat land was much less than in the case of sod land, but somewhat more variable than that of the uncropped soil.

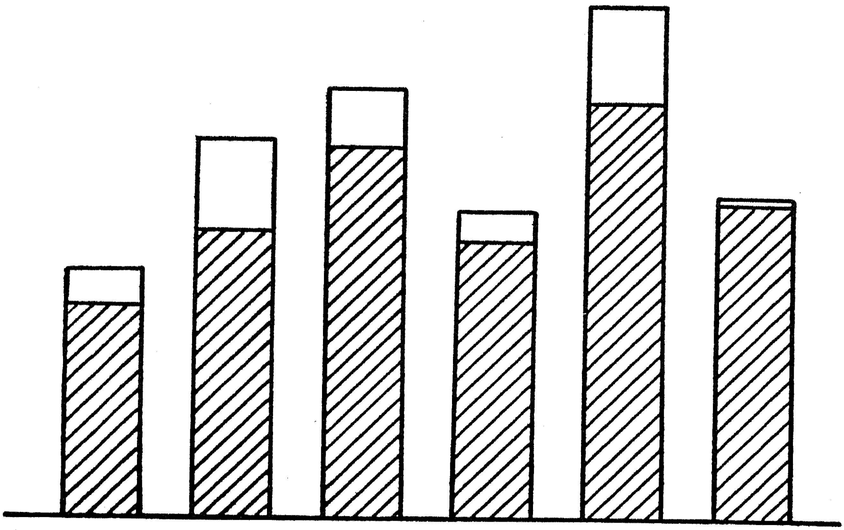


Fig. 8.—Plot 6. This plot was in rotation and showed a wide variation in the amount of absorption due to the fact that the clover took up much more of the rainfall than the other crops.

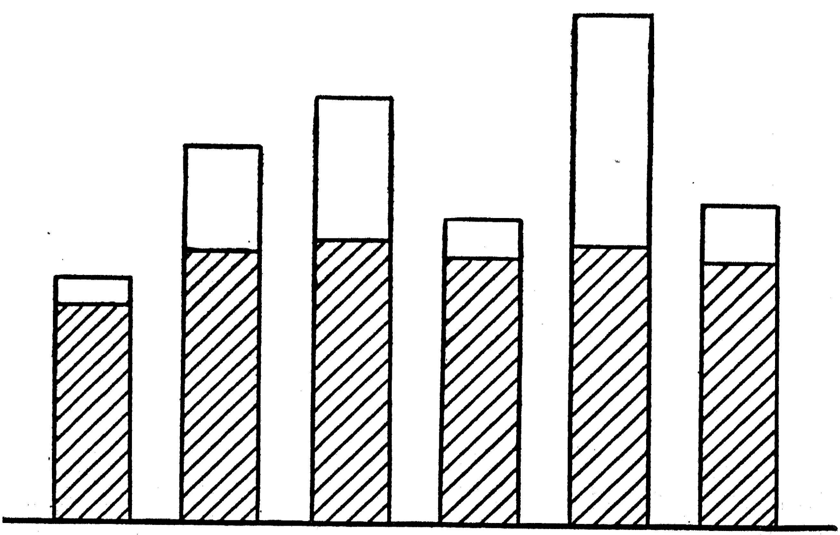


Fig. 9.—Plot 7. Corn annually showed a very uniform absorption of rainfall throughout the entire period of the experiment.

less than the average and only 3.36 less than the greatest amount of absorption which occurred during the second year of the experiment when the rainfall was 36.97 inches. It would seem that the distribution of rainfall has more effect upon the absorption than does the total amount. The absorption on Plot 1 was greater the second year than it was during the third or fifth years when the total rainfall was much greater.

Plots 2 and 3 show a similar regularity in the amount of water absorbed during the different years. Except for the first year when the rainfall was unusually light there is a remarkably close agreement between the absorption during different years. Practically as good agreement is to be found in the case of land kept in corn continually. In fact, excluding the first year, the variation between the highest and lowest amounts absorbed by Plot 7 is only 2.02 inches. This variation is relatively small when it is remembered that the annual rainfall during these same years ranged from 30.03 to 50.44 inches.

From these results it would seem safe to conclude that, under the conditions of these experiments, where 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.

With land carrying a long season crop, like wheat, or a sod crop, the variation was somewhat greater than on uncropped land or corn land, although in the case of continuous wheat on Plot 5 the variation was not great.

On Plot 4 which was in continuous sod, the absorption of rainfall varied from 22.49 inches the first year to 40.13 inches the fifth year. Probably the most satisfactory explanation for this variation in the case of sod land is that when the rainfall in this region is light, the soil and subsoil becomes very dry, due to the removal of water through transpiration. That is, the plants would have the ability to remove much larger quantities if it were present in the soil. This is what happens during seasons of heavy rainfall. There is a more rapid growth of grass, more water is removed, and consequently proportionately more absorbed with additional precipitation.

In the case of the rotated land, Plot 6, the amount of water absorbed varied with the crop grown, but checked very closely with the same crops grown on the other plots. For example, during the fourth year when Plots 6 and 7 were in corn, Plot 6 absorbed only 1.01 inches more water than Plot 7. This difference can probably be explained by the fact that the corn on Plot 6 followed clover sod and gave a more vigorous growth of plants which removed more soil water through transpiration.

Lynde[8] found that the surface runoff from Third Creek was more uniform than the absorption. This is probably due to the fact that much of the drainage area was in grass or timber.

During the sixth year Plot 6 was in sod and the amount absorbed was similar to Plot 4. The cause for the slight variation has been previously explained. There is an apparent lack of agreement during the fifth year between Plots 5 and 6 which were both in wheat, but it must be remembered that Plot 6 carried a good growth of stubble clover which makes it more like Plot 4, with which it agrees remarkably well. A study of Figs. 3 to 9 will bring out the relations between the different soil treatments. The amount absorbed from year to year in the uncropped plots and the corn plot is practically constant for each, regardless of the total amount of rainfall.

Rainfall.—Table 4 shows that the rainfall has varied from 24.25 inches the first year of the experiment to 50.44 inches during the fifth year. The average annual rainfall during the six years has been 35.87 inches. Whenever the rainfall has fallen far below the average, as during the first and fourth years, the per cent of runoff has dropped down very materially. This is more noticeable on the plots in grass or small grain than on the uncropped plots. That is, they used up the moisture about as fast as it came and kept the soil in the best possible condition for absorption. The distribution of rainfall has much to do with the runoff. The fourth year was not only one of low rainfall, but the rains were numerous and well distributed. The heaviest rainfall for any 24 hours during the year was 1.56 inches, April 16, 1921. The fifth year was one of very high rainfall and had nine rains between 1 and 2 inches, two rains between 2 and 3 inches and one rain over 3 inches.

TABLE 4.—PRECIPITATION DURING EACH YEAR OF THE EXPERIMENTS.

Year of experiment	Dates*	Annual precipitation	Deviation from 6-yr. average	Deviation from 34-yr. average
First	May 1, 1917 to April 30, 1918	24.25	-11.62	-13.35
Second	May 1, 1918 to April 30, 1919	36.97	+1.10	-0.63
Third	May 1, 1919 to April 30, 1920	42.07	+6.20	+4.47
Fourth	May 1, 1920 to April 30, 1921	30.03	-5.84	-7.57
Fifth	May 1, 1921 to April 30, 1922	50.44	+14.57	+12.84
Sixth	May 1, 1922 to April 30, 1923	31.47	-4.40	-6.13
Average	May 1, 1917 to April 30, 1923	35.87	±7.29	-1.73

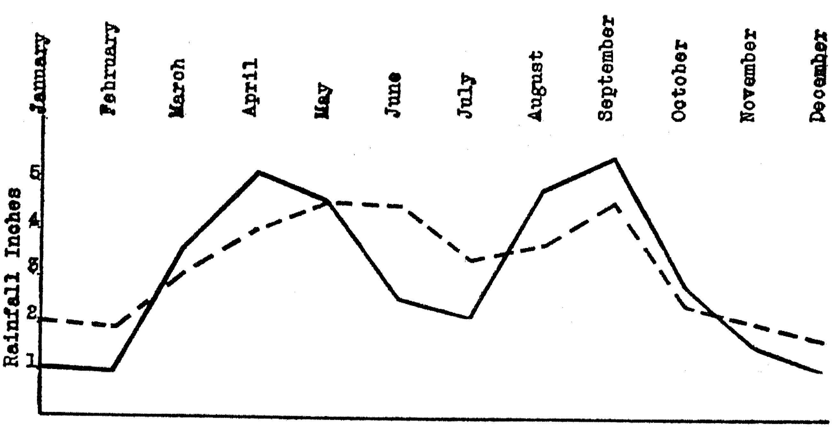
*These experiments were started May 1, 1917 and consequently each year was assumed from May 1 of one year until April 30 of the following calendar year.

The average rainfall for each month during the six years has varied considerably from the 34-year average obtained by the U. S.

Weather Observatory, at Columbia, about three-fourths of a mile from the location of these experiments. A study of Table 5 will show that during the past six years there have been two very pronounced periods of maximum rainfall, one in the spring and one in the fall. The summers and winters have been below normal in their rainfall. The 34-year average, therefore, does not show such a pronounced maximum during the spring and fall. The total annual rainfall has bee 35.87 inches as an average for the past six years and 37.60 inches as a 34-year average. The large amount of runoff during the time of this experiment cannot therefore be attributed to an abnormally high rainfall because the average has been 1.73 inches below the average for 34 years. If

TABLE 5.—PRECIPITATION FOR EACH MONTH DURING THE SIX YEARS OF THE EXPERIMENTS.

Month	1st Year	2d Year	3d Year	4th Year	5th Year	6th Year
Jan.	1.00	.07	0.71	1.61	1.42	1.38
Feb.	1.30	1.73	0.41	.44	1.02	.99
Mar.	0.74	1.17	4.16	3.20	8.68	3.62
Apr.	4.97	2.83	4.06	5.25	9.73	4.10
May	4.55	4.09	6.56	4.17	3.85	4.32
June	2.60	3.25	4.10	1.20	3.05	1.17
July	0.88	0.73	2.30	2.69	2.11	4.03
Aug.	5.17	6.96	5.30	3.31	5.44	2.90
Sept.	2.18	9.51	3.46	4.02	10.03	3.85
Oct.	0.65	1.88	7.91	2.61	2.31	1.57
Nov.	0.02	2.45	2.53	.64	1.43	2.34
Dec.	0.19	2.30	0.57	.89	1.37	1.19



——— Average rainfall 6 years, May 1,1917-1923

— — — Average rainfall 34 years, 1889-1923. (U.S.Weather Bureau)

Fig. 10.—Comparison of the average monthly rainfall for the six years of this experiment with the average monthly rainfall recorded by the U. S. Weather Bureau observatory located at Columbia, Mo.

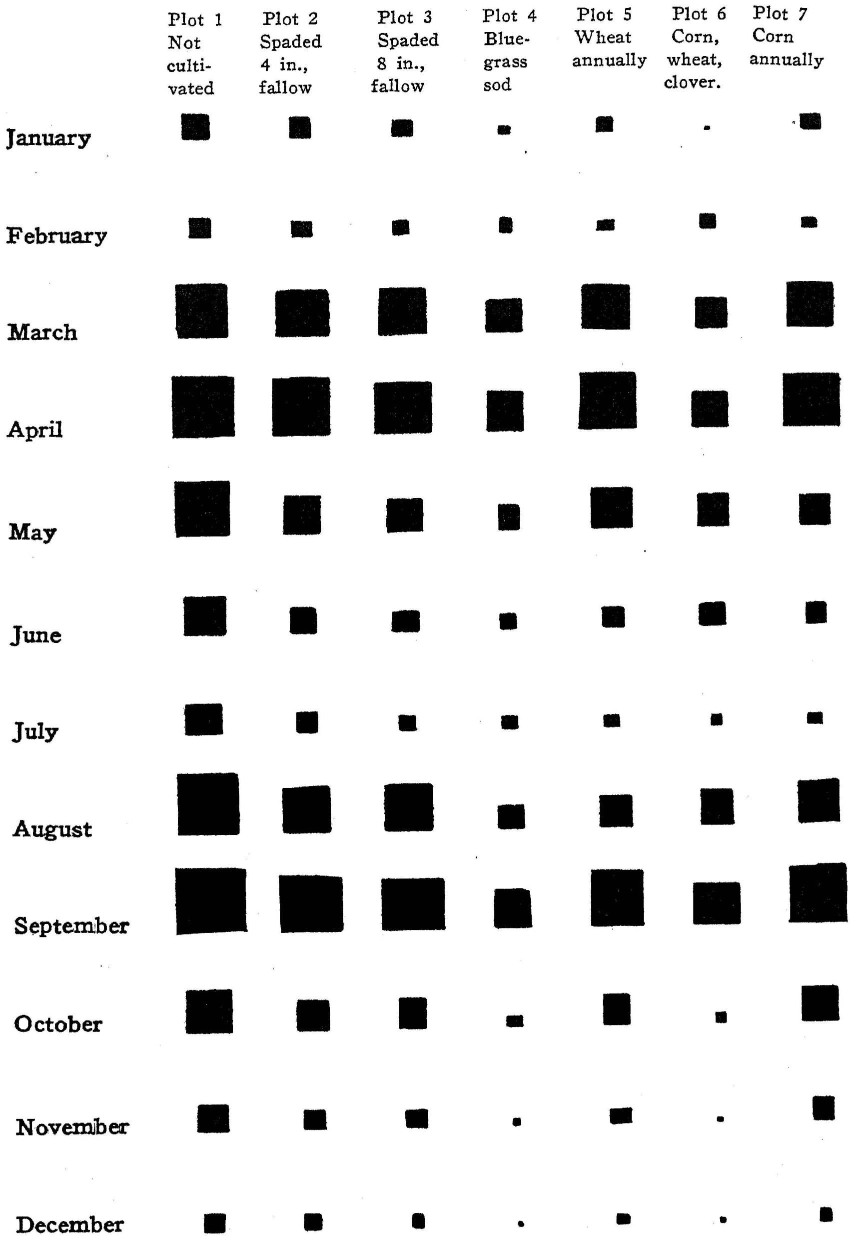


Fig. 11.—The black areas represent the average amount of runoff from each plot during different months of the year.

the runoff can for any reason be considered high, the reason must be found in the seasonal distribution of rainfall rather than in the total amount. That there may be some reason to think this has been the case may be seen from Fig. 10, which shows that the spring and fall maxima have been a little more pronounced during the six years of these experiments than the average of the 34-year period.

Runoff during different months of the year.—A study of Fig. 11 will reveal the fact that the runoff from the various plots shows two very distinct periods of maximum loss, one during March and April and to a certain extent in May, and the other during August and September. The winter rainfall and runoff from November to February has been very light. June, July and October fall into a group giving

TABLE 6.—DISTRIBUTION OF RAINFALL DURING THE SIX YEARS OF THE EXPERIMENTS.

Year of experiment	Total rainfall, inches	Number of rains causing runoff	Number of rains giving no runoff	Number of 1 to 2 inch rains in 24 hrs.	Number of rains over 2 inches in 24 hrs.
1	24.25	30*	52	2	None
2	36.97	38	47	6	2
3	42.07	46	60	14	None
4	30.03	47	57	5	None
5	50.44	56	51	9	3
6	31.47	39	57	5	2

*In some cases the rains of two or more days have been nearly continuous and have therefore been reported as a single rain in reporting the amount of runoff, but the actual records show the rains for each 24 hours.

an intermediate amount of runoff. The amount of the runoff from the different plots was much less variable than was the erosion, as will be shown later in Fig. 12. Plot 4 (sod) and Plot 6 (rotation) showed considerably less runoff than the other plots. The greatest runoff occurred on the uncropped areas, Plots 1, 2, and 3. However, during the spring and fall months, when the crops on plots 5 and 7 did not protect the soil, the runoff was often equal to or in excess of the runoff from Plots 2 and 3 which were cultivated after each rain.

SOIL EROSION

The amount of soil lost by erosion from the different plots in these experiments varied even more than did the runoff. There are many factors which affect the amount of erosion. Doubtless the one of most importance is the condition of the surface or surface cover. The character of the rainfall is probably next in importance, and this factor would include the time between rains as well as the rate at which the rain falls. The weather conditions between rains also affect the rate of evaporation and therefore the rate of runoff and erosion. In regions where the soil remains frozen much of the time, winter erosion becomes negligible. The steepness of slope is a very important factor in determining the amount of runoff as well as erosion, but in this work different slopes have not been compared. There may be considerable wind erosion also, but this too, has not been considered in this work.

The amount of erosion with different amounts of rainfall varied widely, but a summary of the amount lost during different years shows about the variation to be expected with varying amounts of annual rainfall. It should be remembered that these experiments were begun on May 1, 1917 and each year was considered as extending from May first of one year to April 30 of the next.

Table 7 shows the amount of erosion from the different plots for each year of the experiments. It will be seen from these results that the erosion during the first year was very low due to an unusually low rainfall. The erosion from Plot 1 was relatively heavy as compared with Plots 2 and 3 during years of light rainfall. This is shown by the

TABLE 7.—POUNDS SOIL ERODED FROM EACH 1/80-ACRE PLOT DURING EACH YEAR OF EXPERIMENT AND TOTAL FOR SIX YEARS (1917-1923).

Year of experiment	Rainfall, inches	Plot 1 Not cultivated	Plot 2 Plowed 4 in.	Plot 3 Plowed 8 in.	Plot 4 Sod	Plot 5 Wheat annually	Plot 6 Rotation Corn, wheat, clover	Plot 7 Corn annually
First	24.25	222.17	203.24	242.61	7.21	28.65	150.94	105.61
Second	36.97	673.94	1,777.11	2,051.43	24.46	153.23	67,93	752.53
Third	42.07	992.94	1,025.56	694.94	5.26	120.66	28.90	743.24
Fourth	30.03	619.86	579.66	320.26	1.18	164.75	77.70	155.22
Fifth	50.44	1,714.30	1,998.48	1,621.14	2.80	362.02	16.62	652.21
Sixth	31.47	972.16	599.64	424.73	1.29	169.00	1.18	253.75
Total	215.23	5,195.37	6,183.69	5,355.11	42.20	998.31	343.27	2,662.56

results of the first, fourth and sixth years. This result was due to the fact that during years of light rainfall the plowed land absorbed a larger proportion of the water and the runoff was less frequent than in the case of the bare, uncultivated plot, where there was some runoff and consequently some erosion, even with relatively light showers.

The heavy losses from Plots 2 and 3 during the second year were due to heavy rains during August and September 1918 when the total rainfall from August 10 to September 4 was 14.96 inches. One rain on September 2, amounted to 6.42 inches. During the fifth year also, between March 10 and April 17, 1922, the total rainfall was 17.18 inches. One rain of 4.32 inches on March 13 and 14 caused a loss of 533.2 pounds of soil from Plot 2 when the total for the year was 1998.4 pounds.

Thus more than one-fourth of the year's erosion with a rainfall of 50.44 inches occurred during this single rain.

Plot 4 eroded most rapidly during the first and second years, before the sod was well established. Sod was, on the whole, by far the most effective treatment in the control of erosion. During the sixth year the clover sod on Plot 6 was slightly more effective than the bluegrass sod in the absorption of water as well as in the control of erosion.

Plot 5 showed less variation from year to year in the amount of soil lost by erosion than any of the other plots, although during the fifth year when the rainfall was far above normal, the amount of erosion was much above the average for this plot and during the first year when the rainfall was much below normal the erosion was considerably below the average. The large loss during the fifth year was due to the heavy rains in the fall before the wheat was seeded and again in the early spring before the plants were large enough to give much protection to the land.

Plot 6 which has a three-year crop rotation of corn, wheat, clover has furnished striking evidence of the benefit to be derived from a crop rotation which includes sod crops. During the first year when the plot was in corn the erosion was somewhat higher than on Plot 7 which was also in corn. During the second and fifth years, however, when the plot was in wheat, the erosion was far below that of Plot 5 which was also in wheat. The reason for this is because Plot 6 had clover seeded with the wheat in the spring and this stubble and clover protected the soil from washing during the heavy fall rains of August and September, while the land on Plot 5 had been plowed for wheat again and was therefore in condition to lose much soil by erosion. During the third year there was only a small loss from Plot 6 which was in clover, but it was considerably higher than that from Plot 4 which was in bluegrass sod. This difference is due in part at least to the fact that the stand of clover was not perfect over the entire plot. The effect of a perfect stand with a rank growth of clover is strikingly shown in the sixth year when the erosion as well as the runoff from Plot 6 was less than from the bluegrass sod and far below the loss from any of the other plots. During the fourth year the loss from Plot 6 was low as compared with Plot 7 which was also in corn. This difference is due to the fact that wheat followed the corn on Plot 6 and prevented excessive erosion from this plot during March and April when the loss from the corn land was high.

Plot 7 was kept in corn each year and the annual loss of soil has been high as compared with the rotated land, small grain or sod. However, when Plot 7 is compared with Plot 3, which was spaded to the same depth and at the same time in the spring, it will be seen that the corn had a very marked effect in reducing the amount of erosion over uncropped land. The total loss from Plot 7 was only about one-half that from Plot 3. The corn crop uses considerable water during the growing season and this seems to put the soil in better condition for absorption. Furthermore, the corn plants have a tendency to obstruct the flow of water down the slope, which gives it more time to be taken up by the soil. This factor is important during the winter when some organic matter is caught by the corn stalks or stubble and this helps in the prevention of winter and early spring erosion. Finally, the fibrous roots which develop near the surface, assist in holding the soil and preventing its removal.

Table 8 gives a summary of the amount of soil eroded from each plot when calculated on the basis of tons an acre. This brings out very strikingly the differences between the plots having different treatments. The plot spaded 4 inches deep in the spring has lost soil at the rate of 247 tons an acre during the six-year period, while the land spaded 8 inches deep has lost 214 tons. This difference is relatively small when compared with the other plots, indicating that the beneficial effect of deep plowing in the prevention of erosion is probably much less than is usually assumed. It is true that the deep plowing does take in slightly more water and runoff occurs less frequently than on the shallow spaded land, but when the soil is once thoroughly saturated with water a very heavy rain may cause more erosion on the deep spaded land due to the greater depth of the loosened layer of soil. This fact has been demonstrated several times during the course of the experiments.

When we consider that the loss from each of the uncropped plots has been over 200 tons of soil an acre and that the loss from the sod land has been only 1.7 tons an acre during the six years, the value of a crop on the land is at once apparent. The relative values of different sorts of crops is shown by the results of Plots 5, 6 and 7.

In the second column of Table 8 is shown the amount which the surface has been lowered during six years. It is a very significant loss when we consider that 1.73 inches of soil has been removed from the plowed land or that 0.745 inch has been lost from the land kept in corn. The rate of this destruction is strikingly brought out in the third column of this table which shows the length of time that it would require to lose the surface 7 inches of soil or the usual plowed layer under these various systems of handling. Land spaded 4 inches deep and uncropped has lost soil at such a rate that the surface 7-inch layer would be lost in

TABLE 8.—SUMMARY OF SOIL ERODED DURING SIX YEARS AND TIME THAT WOULD BE REQUIRED TO ERODE THE SURFACE 7 INCHES OF SOIL.

Plot	Treatment	Tons Soil eroded per acre	Surface inches eroded	Years to erode 7 inches
1	Uncultivated	207.8	1.454	29
2	Spaded 4 in.	247.3	1.731	24
3	Spaded 8 in.	214.2	1.499	28
4	Sod	1.7	0.011	3,547
5	Wheat continually	39.9	0.279	150
6	Rotation, corn, wheat, clover	13.7	0.096	437
7	Corn Continually	106.5	0.745	56

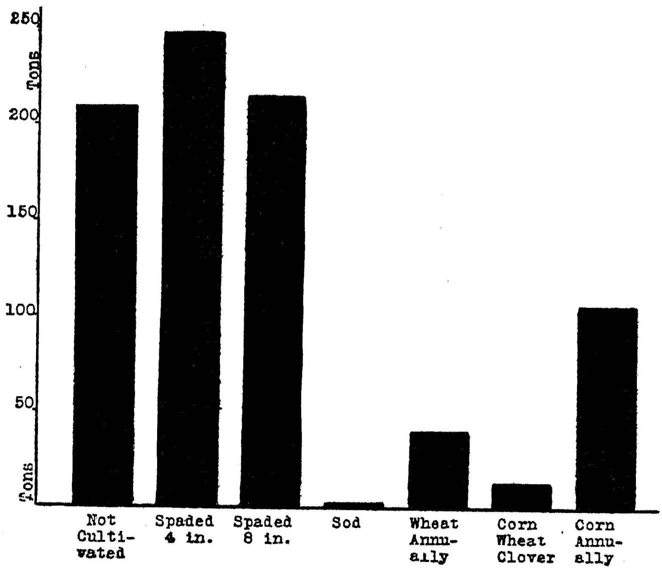


Fig. 12.—Relative total amounts of soil eroded during six years from plots having different treatments. Tons per acre.

approximately 24 years, and that of the other uncropped soils in only a little longer period. The land in a cultivated crop of corn would lose the surface 7 inches in 56 years. These results are in striking contrast with land more thoroughly protected. Wheat annually would require 150 years, a three-year rotation 437 years to lose the surface 7 inches of soil, while 3,547 years would be required for the same amount of erosion from sod land. In considering these losses it must be remembered that they apply to a slope averaging but 3.68 feet in a hundred.

While this may be somewhere near an average of the corn belt lands as a whole, there is a great deal of cultivated land having a much greater slope and consequently much greater erosion.

Monthly erosion.—The amount of erosion varied greatly during the different months of the year. These facts are brought out in Table 9 and Fig. 13. There were clearly two periods of maximum erosion,

TABLE 9.—TOTAL POUNDS OF SOIL ERODED PER MONTH DURING SIX YEARS.

Month	Av. Rain-fall inches	Plot 1 Not cul-tivated	Plot 2 Plowed 4 in.	Plot 3 Plowed 8 in.	Plot 4 Sod	Plot 5 Wheat annually	Plot 6 Rotation corn, wheat, clover	Plot 7 Corn annually
Jan.	1.03	25.36	32.37	40.28	0.58	8.62	0.44	9.76
Feb.	0.98	13.16	15.99	12.27	2.01	3.67	2.59	7.34
Mar.	3.59	567.86	833.32	558.93	2.95	202.40	12.24	415.06
Apr.	5.16	1,062.72	995.14	1,041.17	3.25	217.89	52.03	559.53
May	4.59	489.24	190.51	219.13	4.96	34.80	70.20	203.70
June	2.56	300.36	318.07	159.75	2.57	6.22	21.82	172.61
July	2.12	472.10	247.40	79.81	.89	19.68	8.06	37.24
Aug.	4.85	1,075.35	1,647.01	1,768.19	19.08	134.83	117.06	498.84
Sept.	5.51	908.70	1,663.79	1,289.67	5.50	293.12	58.08	553.64
Oct.	2.82	224.45	176.97	134.01	0.36	60.98	0.56	163.50
Nov.	1.57	50.54	59.46	49.96	0.05	14.73	0.11	38.50
Dec.	1.09	5.57	3.71	1.94	0.00	0.78	0.08	2.02
Total		5,195.41	6,183.74	5,355.11	42.20	997.72	343.27	2,661.74

one during March and April and the other during August and September. Table 10 will show that on Plots 2, 3, 4 and 6 more than 50 per cent of the erosion took place during August and September. The erosion on Plot 1 which was uncultivated was more uniformly distributed

TABLE 10.—PERCENTAGE OF EROSION TAKING PLACE DURING EACH MONTH OF THE YEAR.

Month	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7
Jan.	0.48	0.52	0.75	1.37	0.86	0.12	0.36
Feb.	0.25	0.25	0.22	4.76	0.36	0.75	0.27
Mar.	10.93	13.47	10.43	6.99	20.28	3.56	15.59
Apr.	20.45	16.09	19.44	7.70	21.83	15.15	21.01
May	9.41	3.08	4.09	11.75	3.48	20.45	7.65
June	5.78	5.14	2.98	6.09	0.62	6.36	6.10
July	9.08	4.00	1.49	2.10	1.97	2.34	1.39
Aug.	20.69	26.63	33.01	45.20	13.51	34.10	18.73
Sept.	17.49	26.90	24.08	13.03	29.37	16.90	20.79
Oct.	4.32	2.86	2.50	0.85	6.11	0.16	6.14
Nov.	0.97	0.96	0.93	0.011	1.47	0.03	1.44
Dec.	0.107	0.051	0.03	0.00	0.07	0.002	0.75

throughout the year than on any other plot. This was due to the fact that runoff was more frequent on this plot and since the surface was bare, conditions were always more or less favorable for erosion.

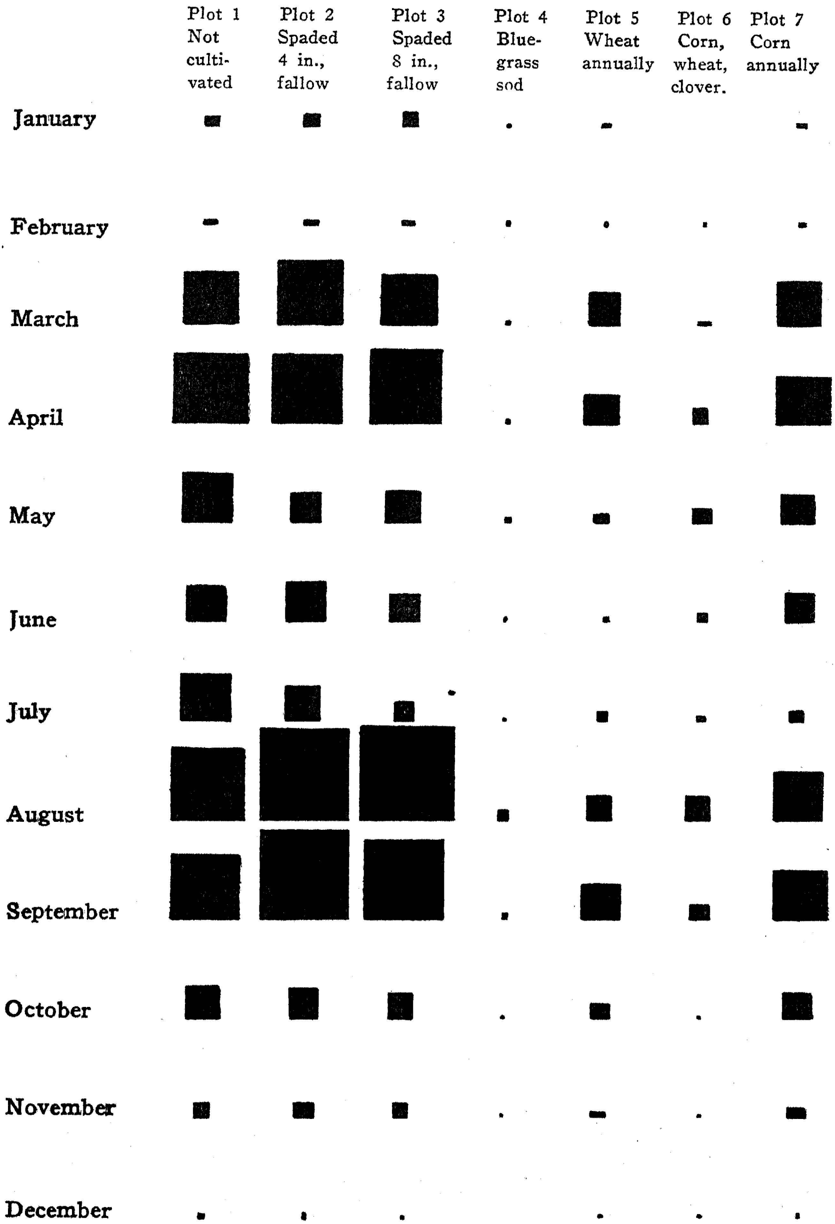


Fig. 13.—The black areas represent the average amount of soil eroded from each plot during different months of the year.

The amount of winter erosion has been very small and apparently is not a serious factor in this region. This is due largely to the light winter precipitation because the ground is unfrozen a large share of the time during the winter at Columbia and it would erode if the rainfall were heavy. The midsummer erosion is low, first because of the rather light rainfall and second because of the high temperatures which increase evaporation and thus enable the land to absorb a high-per cent of the water. On the cropped plots, the water used by the crops is also a factor.

Table 11 shows the average monthly temperatures during the six years of the experiments. It may be seen from this that the temperatures have been slightly above normal for the period of these experiments. This rather high average temperature has been especially marked during the winter months. During four of the six years the average temperatures of December and January have been above normal and the February temperature has been above normal in five of the six years. These high winter temperatures, when the ground has been unfrozen much of the time, might indicate that the erosion could be expected to be above normal. However, a study of Fig. 10 will show that the winter precipitation has also fallen below normal during the course of these experiments. This fact may entirely overbalance the factor of high temperature in causing winter erosion.

TABLE 11.—AVERAGE MONTHLY TEMPERATURE DURING THE SIX YEARS OF THE EXPERIMENT 1917-1923*

Month	1st Year	2d Year	3d Year	4th Year	5th Year	6th Year	6-yr. Av. 1917-23	Normal	6-yr. deviation from normal
Jan.†	15.4	34.2	26.9	36.8	28.4	38.9	30.1	27.2	+2.9
Feb.	33.7	35.1	33.2	40.2	34.4	28.9	34.2	30.1	+4.1
Mar.	50.9	46.6	45.6	52.0	44.7	39.5	46.5	41.4	+5.1
Apr.	49.4	55.0	48.8	55.8	56.0	53.3	53.5	54.3	-0.8
May	58.6	68.8	61.5	63.0	65.8	66.2	64.0	64.5	-0.5
June	70.9	76.8	75.1	72.8	75.7	75.6	74.5	74.5	0.0
July	77.6	77.2	78.9	75.8	79.8	75.8	77.5	77.4	+0.1
Aug.	72.3	81.7	74.7	73.0	76.4	76.6	75.8	74.7	+1.1
Sept.	67.5	61.4	71.1	69.6	71.8	70.8	68.7	67.8	+0.9
Oct.	48.6	60.1	57.6	61.6	57.5	59.4	57.5	54.8	+2.7
Nov.	45.4	44.9	42.2	40.8	43.7	47.4	44.1	42.4	+1.7
Dec.	24.0	39.8	27.0	35.9	35.5	34.3	32.7	32.9	-0.2
Average	51.2	56.8	53.6	56.4	55.8	55.6	54.9	53.5	+1.4

*By courtesy of Mr. George Reeder, U. S. Weather Observatory, Columbia.

†Each year of the experiment was considered as beginning May 1 and hence January, February, March and April really belong to the calendar year following December, but have been placed ahead for the purpose of keeping the normal sequence.

Table 12 and Fig. 14 shows the ratio of soil to water in the runoff from the different plots. When these results are compared with those computed from Babb's results[2], it will be seen that for the most part they are much lower than the ratio of soil to water in the large rivers of the world. This difference can probably be accounted for by the

TABLE 12.—RATIO OF SOIL TO WATER IN THE RUNOFF, BY WEIGHT.

Plot	Treatment	Pounds of water required to remove one pound of soil
1	Uncultivated	57*
2	Spaded 4 in.	31
3	Spaded 8 in.	34
4	Sod	1,904
5	Wheat continually	154
6	Rotation, corn, wheat, clover	297
7	Corn continually	63

*To nearest whole number

fact that a large per cent of the drainage into rivers comes from forests and grass covered lands where the runoff water carries very little soil. That is, it approaches the condition to be found in Plot 4 where the ratio of soil to water is 1: 1,904. Moreover, the runoff as measured

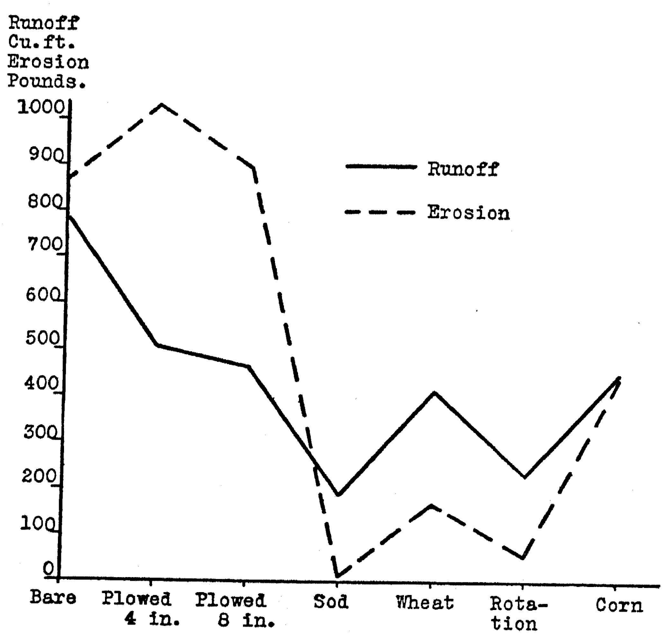


Fig. 14.—Average annual amount of runoff and weight of eroded material from each plot. Note the smaller proportion of soil carried by the water from the cropped plots.

in a stream includes much water supplied by springs, which is practically free of sediment.

Another thing that must be considered as affecting the soil-water ratio of these plots is the fact that the eroded material is caught at the foot of the slope. In the case of much of the most serious soil erosion the soil washed from the sides of the hills is deposited on the more level ground at the foot of the slope, or on the river flood plains. In this respect it would be considered as eroded material in comparison with the results of these experiments, yet it would not be found or measured in the sediment of the large streams. Erosion, as it occurs under farm conditions is very largely a transfer of the surface soil from the hillsides to lower levels where the slopes are more gentle or nearly level. From the standpoint of the agriculture of a region, therefore, the injury from erosion may not be as great as it would seem, since the lower lying soils are enriched by this deposit. The increased production from such a deposit is, however, far less than the resulting decrease in the production of the upland.

Character of rainfall.—During the six years of these experiments there were 256 rains that caused runoff from one or more of the plots. In addition to this there were numerous other light showers that were too light to cause runoff from any of the plots. Table 6 shows the distribution of heavy and light rains during the different years. When it is remembered from Table 7 that the most serious erosion occurred during the second, third, and fifth years, it will be seen that this is closely correlated with the number of heavy rains falling during those years. The fourth and sixth years show the effect of a good distribution of rainfall with only a few heavy rains, even though the total number of rains compared well with the other years. The first year showed both a low rainfall and a very few heavy rains. The amount of erosion during these three years was far below the average.

Table 13 shows that the soil erosion during 16 of the most destructive rains during the six years was more than 50 per cent of the total on five of the seven plots. The loss from Plot 3 reached 69.79 per cent during these sixteen rains. This can be accounted for by the fact that it was only during the times of heavy rainfall that there was a large amount of runoff from this plot. Owing to the more deeply loosened condition of the soil, however, the land of this plot eroded badly if a heavy rainfall followed previous wet weather or light rains. Plot 1 fell below most of the others in the per cent of soil lost during these sixteen heavy rains, because this plot lost soil more frequently and with smaller rains than did any of the other plots.

TABLE 13.—EROSION DURING SIXTEEN OF THE MOST DESTRUCTIVE RAINS OCCURRING WITHIN THE SIX YEARS OF THE EXPERIMENTS.

Plot	Treatment	Lbs. of soil lost during 16 heavy rains	Total lbs. soil lost in 6 yrs.	Percentage of total lost in 16 rains
1	Uncultivated	2174*	5195*	41.84
2	Spaded 4 inches	4052	6184	65.53
3	Spaded 8 inches	3737	5355	69.79
4	Sod	25	42	58.38
5	Wheat continually	550	998	55.09
6	Rotation, corn, wheat, clover	40	343	11.67
7	Corn continually	1630	2662	61.21

*To nearest pound

The low percentage of loss from Plot 6 during these heavy rains was largely accidental. This land was in a rotation of corn, wheat and clover. It was, therefore, more subject to erosion when in corn, but it happened to be in this crop during the first and fourth years of the experiments when the rainfall was well distributed and the total far below normal. This condition doubtless serves to exaggerate somewhat the effect of a rotation in saving soil from erosion.

The rate at which rain falls, also has much to do with the runoff and erosion. For example, in a three-day rainy period, August 10-13, 1918, 2.97 inches of water fell during a total of 9 hours of actual rain. During a single hour, 2.09 inches of rain fell. As a result the erosion from Plot 3 during this three-day period reached 546.6 pounds. This may be compared with a rain of 2.87 inches on September 10, 1922, which occupied a total of 16 hours, the highest hourly precipitation being but 1.14 inches. Such a distribution of the precipitation resulted in the erosion of only 110.1 pounds of soil from Plot 3 or about one-fifth the amount mentioned above.

Loss of fertility by erosion.—During two years of these experiments, September 1, 1920 to August 31, 1922, samples of soil were taken after each rain for chemical analysis. An aliquot of the total soil eroded was taken and a composite sample for each three months obtained. The results of the determinations of nitrogen are shown in Table 14 and indicate that the removal of this important element through erosion may at times be a matter of almost as much concern as its removal through exhaustive systems of cropping. Table 14 shows that the removal of nitrogen from the uncultivated and uncropped plot averaged 98.88 pounds during the two years. This would be nearly as much nitrogen as would be carried away in the grain of a 100-

TABLE 14.—POUNDS NITROGEN REMOVED PER ACRE IN ERODED MATERIAL DURING TWO YEARS, SEPT. 1, 1920 TO AUG. 31, 1922.

Plot	Nitrogen lost		Two-year average
	Sept. 1, 1920 to Aug. 31, 1921	Sept. 1, 1921 to Aug. 31, 1922	
1	75.84	121.92	98.88
2	72.25	118.56	95.40
3	54.79	92.96	73.87
4	0.30	0.80	0.55
5	26.45	32.72	29.58
6	8.53	3.36	5.94
7	26.17	54.56	40.36

bushel corn crop. The loss from the other uncropped plots was also high.

The loss from the land continually in corn, Plot 7, was 40.36 pounds of nitrogen. This loss was much less than on the uncropped land, but was approximately the same as was removed by the corn crops during these years, since the average yield was only 28.8 bushels an acre. Likewise the average wheat yield on Plot 5 of 23.4 bushels an acre removed approximately the same amount of nitrogen in the grain as the 29.58 pounds taken off by erosion. Plot 6 showed an average loss of only 5.94 pounds nitrogen due to the fact that the clover, along with wheat in 1921 and the clover alone in 1922, kept down the amount of erosion and thereby reduced the loss of nitrogen. The greatest saving of nitrogen, however, was on sod land Plot 4 which lost only 0.55 pounds as an average for the two years. This very low amount of nitrogen might easily be much more than replaced by the action of symbiotic bacteria which would be found on the wild legumes growing along with the bluegrass. At any rate, it can be said that the loss of nitrogen by erosion from sod land can be considered as negligible. Other work at this station and elsewhere indicates that the total nitrogen of the soil may even be increased when the land is laid down to permanent sod.

Determinations made on the runoff water indicated that the removal of soluble nitrogen in the form of nitrates was comparatively small. These results are given in Table 15 and show that for the year beginning September 1, 1920, there was a range of from 6.06 pounds of NO_3 per acre lost from Plot 1 to 0.26 pounds from Plot 4. While these determinations cover only a one-year period, they serve to show that most of the nitrogen lost from the soil by erosion, is to be found in insoluble form in the organic matter and is not lost in great amounts from the surface in soluble form. This is probably partly due to the

TABLE 15.—POUNDS NITRATE REMOVED PER ACRE IN RUNOFF WATER DURING THE YEAR, SEPT. 7, 1920 TO AUG. 31, 1921.*

Plot	Treatment	Pounds NO_3 removed per acre
1	Not cultivated	6.06
2	Spaded 4 inches in spring	3.01
3	Spaded 8 inches in spring	2.45
4	Sod	0.26
5	Wheat annually	1.35
6	Rotation, corn, wheat, clover	0.83
7	Corn	0.98

*The results reported in tables 12, 13, 14 and 15 were taken from analyses made by O. B. Price, who did this work as a part of a thesis for the Masters Degree at the University of Missouri, 1922.

displacement of the normal soil solution by the first part of the rainfall which quickly settles into the soil carrying the soluble salts downward from the surface. As more water falls it runs off the surface without coming in contact with the more concentrated or normal soil solution and therefore carries but little soluble nitrate with it. Another reason for this small loss of nitrates from the surface is the fact that the action of the nitrifying bacteria in the surface half-inch of soil is somewhat reduced during much of the year due to the dry condition of this layer. It should be understood that these statements deal exclusively with the nitrogen losses through surface runoff and have no relation to losses which may occur through leaching.

Loss of other elements.—The relative losses of phosphorus from the different plots were similar to the losses of nitrogen, and likewise may be seen from Table 16 to be a matter of serious consideration from the standpoint of the maintenance of soil fertility. The phosphorus loss under continuous wheat was equivalent to that in a 30-bushel wheat crop, and the loss under continuous corn equalled that carried away in a 35-bushel corn crop. The advantage of sod land in preventing losses of phosphorus by erosion is well shown by the small losses from Plots 4 and 6 as compared with the other treatments.

Table 17 shows the amounts of calcium and sulfur lost during the year. The calcium was determined from composite samples covering three-month periods. The sulfur was determined but once on a composite sample covering the whole year. From the figures given in this table it will be seen that the loss of these elements in eroded material may easily exceed the amount lost through ordinary cropping systems. Sampson and Weyl[15] have shown the increased water requirements and also the lower amount of dry weight of different crops produced on eroded as compared with non-eroded soil.

TABLE 16.—POUNDS PHOSPHORUS REMOVED PER ACRE IN ERODED MATERIAL DURING TWO YEARS, SEPT. 1, 1920 TO AUG. 31, 1922.

Plot	Treatments	Phosphorus lost		
		Sept. 1, 1920 to Aug. 31, 1921	Sept. 1, 1921 to Aug. 31, 1922	Two-year average
1	Not cultivated	41.02	53.92	47.47
2	Plowed 4 inches deep. Cultivated	37.74	53.20	45.47
3	Plowed 8 inches deep. Cultivated	26.92	39.60	33.26
4	Sod	0.06	0.12	0.09
5	Wheat annually	10.54	11.12	10.83
6	Corn, wheat, clover, rotation	3.56	0.88	2.22
7	Corn annually	10.28	6.00	8.14

TABLE 17.—POUNDS OF CALCIUM AND SULFUR REMOVED PER ACRE IN ERODED SOIL, DURING ONE YEAR, SEPT. 1, 1920 TO AUG. 31, 1921.*

Plot	Treatment	Pounds calcium lost	Pounds sulfur lost
1	Uncultivated	379.38	100.85
2	Plowed 4 inches	337.89	69.61
3	Plowed 8 inches	225.63	63.67
4	Sod	0.64	——
5	Wheat continually	75.99	19.32
6	Rotation, corn, wheat, clover	41.47	6.98
7	Corn continually	103.37	25.36

Mechanical analysis of eroded soil.—When the eroded soil is cleaned from the tanks it is usually noticeable that in the soil from the uncropped plots and particularly from Plot 1 that the percentage of sand is high as compared with the other plots. That this condition actually exists is shown by the results of mechanical analysis in Table 18.

The lower amount of sand and greater percentage of silt in the eroded material from the cropped land is partly due to the fact that the plant roots and some organic material above ground tend to slow down the flow of water. Also the volume of runoff is lower on these plots

TABLE 18.—MECHANICAL COMPOSITION OF THE ERODED MATERIAL-COMPOSITE SAMPLE, SEPT. 1, 1920 TO AUG. 31, 1921.

Soil separate	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7
Fine gravel	0.20	0.12	0.14	----	0.18	0.16	0.06
Coarse sand	2.80	2.48	2.08	----	0.42	0.50	1.00
Medium sand	3.44	3.20	2.18	----	0.64	0.94	1.44
Fine sand	7.80	4.32	3.10	----	1.48	2.14	1.98
Very fine sand	23.80	19.56	15.36	----	7.84	13.66	19.73
Silt	52.14	61.64	68.20	----	76.90	72.44	69.44
Clay	9.82	8.56	8.04	----	12.54	10.16	6.34
Total	100.00	99.88	99.96	----	100.00	100.00	99.99

and this again reduces the rate of flow. Since the carrying capacity of water varies approximately as the sixth power of its velocity, a slight reduction in the rate of flow may materially affect the percentage composition as shown by an analysis of the eroded soil. Plots which are bare and smooth much of the year, as Plots 1, 2, 3, and 7 should allow the removal of a higher percentage of sand than would be removed from the cropped plots. Likewise Plot 1 should allow the removal of proportionately more sand than Plots 2 and 3, since it averages smoother at the surface, and thus allows a more rapid flow of water down the slope.

DISCUSSION OF RESULTS

In evaluating the results of these experiments it should be borne in mind that they have been secured from a single soil type and on a definite slope of land. The slope which averaged 3.68 feet in 100 was probably no more than an average slope for corn belt lands, yet the plots occupied but a fractional part of the chosen slope and the soil was entirely collected in the catchment-basins. None of it remained on the lower part of the slope, as is common on longer slopes, the grade of which becomes less at the lower level. It is probable, therefore, that the erosion represents maximum losses per unit area of slope under the different systems of cropping and of tillage. It is possible that the loss per unit area would have been greater if the plots had been longer but there is no available evidence having to do with this matter. Again, a different slope would of course have resulted in somewhat different results, especially in the total runoff and erosion from the individual plots, but what would have been secured on a different soil type can only be conjectured. The fact that the experiments covered but six years is also a factor which limits the application of the results. Nevertheless, the records show that the distribution of the average monthly rainfall during this period approached, even if it did not quite reach, the normal. While all of these conditions have a bearing on the results, it seems probable that the major findings will apply to most soils of medium to fine texture, even though a much longer period of years. Some of the results secured conform to the prevalent opinions regarding runoff and erosion, while others are somewhat at variance with these. One of the surprising results is the rather small influence which deep spading exerted in reducing erosion, as compared with shallow spading. It is possible that a longer period of experimentation would have shown a greater influence from the deeper working of the land, yet when one studies the detailed figures of runoff and erosion they appear quite trustworthy.

Another finding which is doubtless of wide application, although not entirely in accord with common opinion is that land bearing sod crops, like clover and grass, absorbs more water than uncropped land, even when the later is kept cultivated. It is generally known that a dry soil surface absorbs water slowly at the beginning of a rain, but these results show that when the soil is dried by a close-growing crop, the total absorption is greater than that of uncropped soil which contains more total moisture. This effect of the close-growing crop is also shown in the results from the rotation system which absorbed much more water than the cultivated land. This is due largely to the interference to the flow of water down the slope and to the absorptive capacity of organic matter and roots at or near the surface.

One of the most interesting results was that the surface inches of rainfall absorbed by uncropped land, or by land growing a cultivated crop, such as corn, was practically constant from year to year, regardless of a wide variation in the yearly precipitation. This is in strong contrast to the absorption by sod land, clover land or rotated land where the surface inches absorbed correspond more closely to the inches of total rainfall.

The rather high rate of erosion during the months of August and September was unexpected. While it is true that the rainfall during these months for the period of experiment, averaged somewhat above normal, yet it is evident that losses to land which is bare and loose at this time of year may be excessive. This would apply to land prepared for wheat or to land from which soybeans or cowpeas have been harvested.

The influence of sod in decreasing erosion and the effect of torrential rains in accelerating it, agreed with general observations.

The losses of nutrient elements through erosion were greater than had been anticipated. The nitrogen losses were especially significant since this element is found largely in the surface soil which is most readily removed through erosion. The losses of the mineral elements is probably of somewhat less importance, yet the comparatively large quantities of phosphorus, sulfur and calcium which may be carried away under corn and wheat farming should be a cause for concern. In view of these facts and of the further consideration that the rate of erosion on more rolling land is undoubtedly far in excess of that found in these experiments, it seems safe to place erosion as one of the most important causes of soil depletion under grain farming systems on the rolling lands of the corn belt.

SUMMARY

1. Experiments covering a six-year period are described, in which the amount of runoff and soil eroded were measured after each rain, from seven plots having different cropping systems or tillage treatments.
2. The plots which were each one-eightieth of an acre in area were elongated in form, and ran up and down a slope averaging 3.68 feet to 100. Concrete tanks at the lower ends served to collect the runoff and eroded soil from each plot.
3. The treatments of plots were as follows:
    1. Uncultivated—weeds kept out by pulling.
    2. Spaded 4 inches deep in spring. Cultivated after rains.
    3. Spaded 8 inches deep in spring. Cultivated after rains.
    4. Bluegrass sod.
    5. Wheat, annually.
    6. Rotation; corn, wheat, clover.
    7. Corn, annually.
4. The average runoff varied from 48.92 per cent of the rainfall on Plot 1 to 11.55 per cent on Plot 4.
5. The land spaded 8 inches deep in the spring absorbed only 2.90 per cent more rainfall than the shallow 4-inch spading. This would indicate that deep plowing of farm lands can be expected to have only a slight advantage over shallow plowing upon the absorption of rainfall.
6. Uncropped land, whether cultivated or uncultivated, absorbed much less water than grass or clover land.
7. Land in a rotation of corn, wheat, clover lost only 14.14 per cent of the rainfall as runoff.
8. The surface inches of rainfall absorbed by uncropped land or by land growing a cultivated crop like corn, was practically constant from year to year for a given soil condition, regardless of a wide variation in the annual precipitation. The absorption by sod, wheat and rotated land was more variable.

9. The average annual rainfall for the six years of the experiments was 35.87 inches or 1.73 inches below the normal. The yearly precipitation varied from 24.25 inches during the first year to 50.44 inches during the fifth year.

10. The seasonal distribution of rainfall during the six years of these experiments was somewhat below normal during the winter and summer months and above normal during the spring and fall months. The spring and fall periods of maximum rainfall were therefore more pronounced than the average of 34 years.

11. The times of maximum runoff and erosion were during March and April and again during August and September. On Plots 2, 3, 4 and 6 more than 50 per cent of the erosion took place during these latter months.

12. On land where no crop was grown the annual erosion from spaded land was greater than from soil that was not stirred.

13. Deep spading (8 in.) reduced the loss from erosion only 13.4 per cent as compared with the shallow spading (4 in.), indicating that deep plowing is less effective in controlling erosion than is usually supposed. The total loss from the deep spaded land without a crop was very high as compared with cropped land.

14. The presence of a corn crop reduced the erosion of deep spaded land by 50 per cent as compared with the uncropped plot, while wheat reduced the erosion by 81 per cent, and rotation reduced it 93 per cent.

15. Sod land lost only 0.68 per cent as much soil as the uncropped soil spaded four inches deep.

16. If farm land should erode as rapidly as the land in these experiments the surface 7-inch layer would be removed at the following rates: uncultivated land in 29 years; plowed 4 inches deep in 24 years; plowed 8 inches deep in 28 years; corn annually in 56 years; wheat annually in 150 years; rotation, corn, wheat and clover in 437 years; bluegrass sod in 3547 years.

17. The amount of runoff water necessary to erode one pound of soil from the surface of the plots varied from 31 pounds on Plot 3 to 297 pounds on Plot 6, and 1,904 pounds in the case of the sod land, Plot 4.

18. The amount of soil eroded was directly correlated with the number of heavy rains occurring during the year. The soil eroded during 16 of the most destructive rains in the six years under consideration was more than 50 per cent of the total erosion on five of the seven plots.

19. Chemical analyses showed that the amounts of nitrogen, phosphorus, calcium and sulphur in the eroded material from corn or

wheat land may equal or exceed the amounts taken off in the crops. There were only small amounts of nitrogen, as nitrates, lost in the runoff water.

20. Mechanical analyses showed that the material eroded from the bare and the cultivated plots contained a higher percentage of sand and a lower percentage of fine material than the soil lost from the other plots.

21. From these experiments it seems evident that farmers of the corn belt can do much toward reducing runoff and the disastrous effects of erosion by planning crop rotations in such a way that the land will be covered with a growing crop a very large portion of the time. The frequent use of clover and grass crops will aid materially in establishing such a cropping system.

ACKNOWLEDGMENTS

The authors wish to express their thanks to Mr. O. B. Price, who has done some of the analytical work reported; Mr. W. Y. Moore, who has throughout most of the work taken care of the plots in the field and to the following men who as students have helped with sampling and moisture determinations: Messrs. J. H. Longwell, J. M. Bewick, J. R. Fleetwood, D. K. Lange, J. S. Berry, and J. C. Caldwell.

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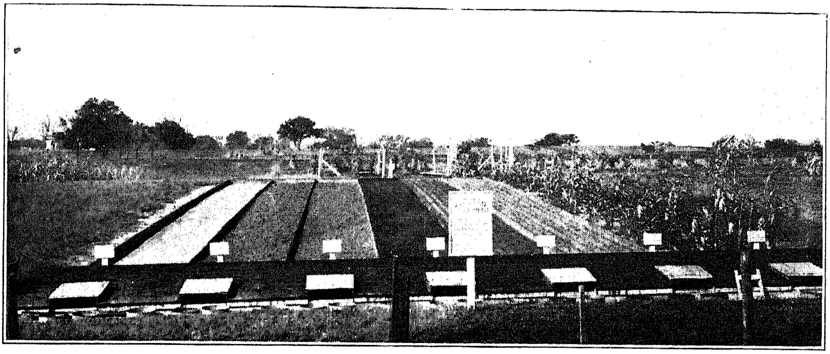

Fig. 15.—General View of Soil Erosion Plots. Fall 1920.

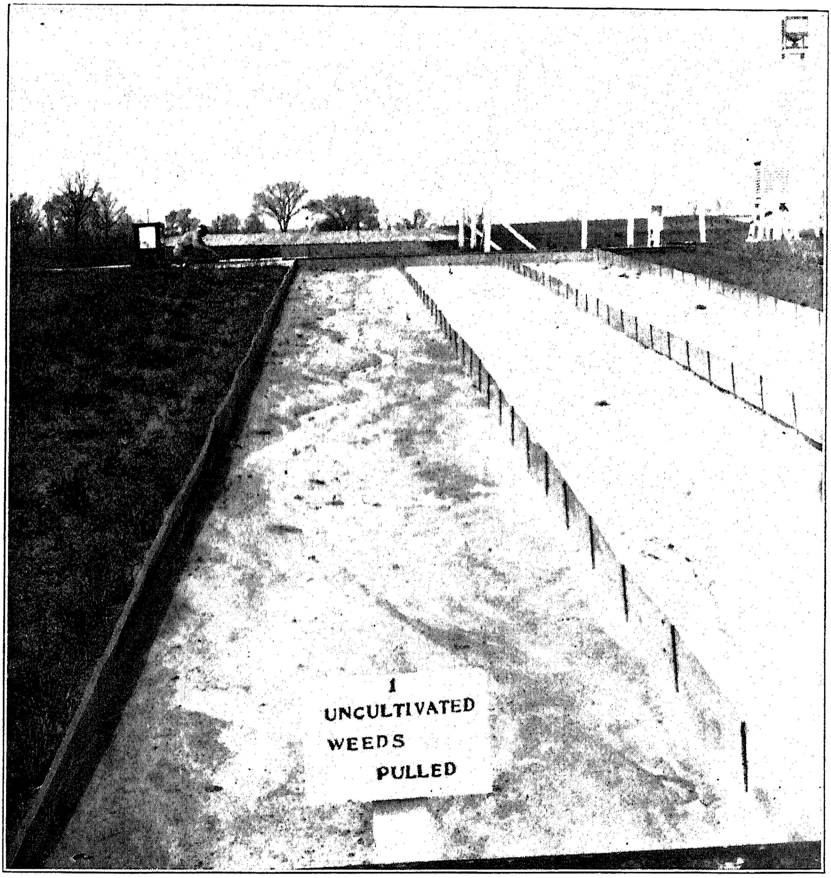

Fig. 16.—View of Plot 1, May 1, 1923. This and Figs. 17 to 22 show the spring condition before the land was spaded in Plots 2, 3, 6 and 7. This was at the close of the six-year period.

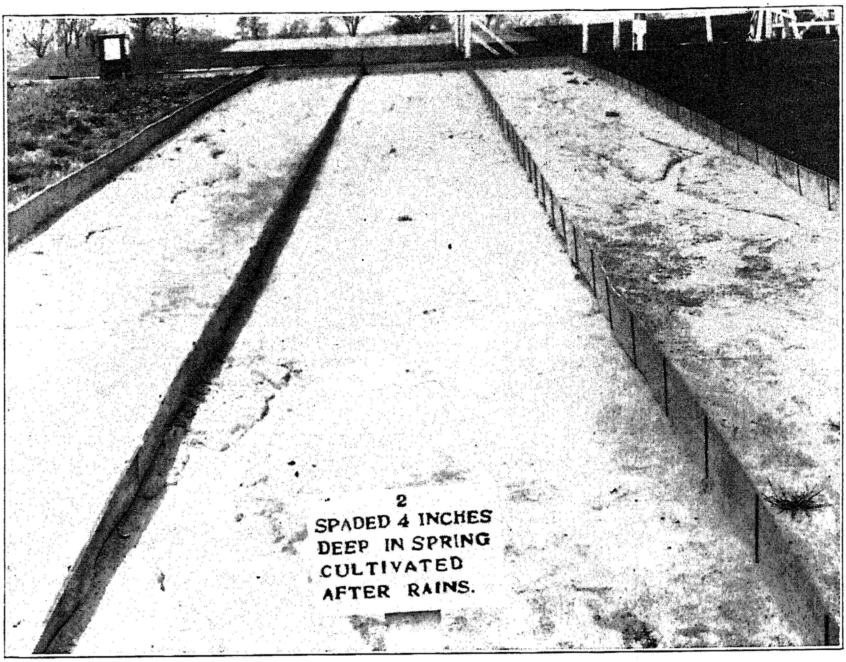

Fig. 17.—Plot 2. Spaded 4 inches deep in spring. Cultivated after rains.

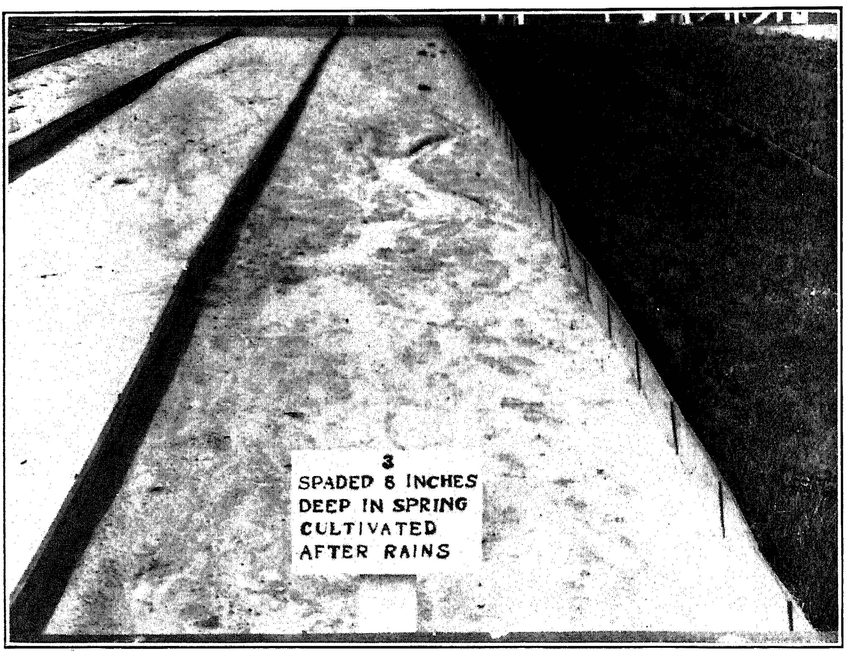

Fig. 18.—Plot 3. Spaded 8 inches deep in spring. Cultivated after rains.

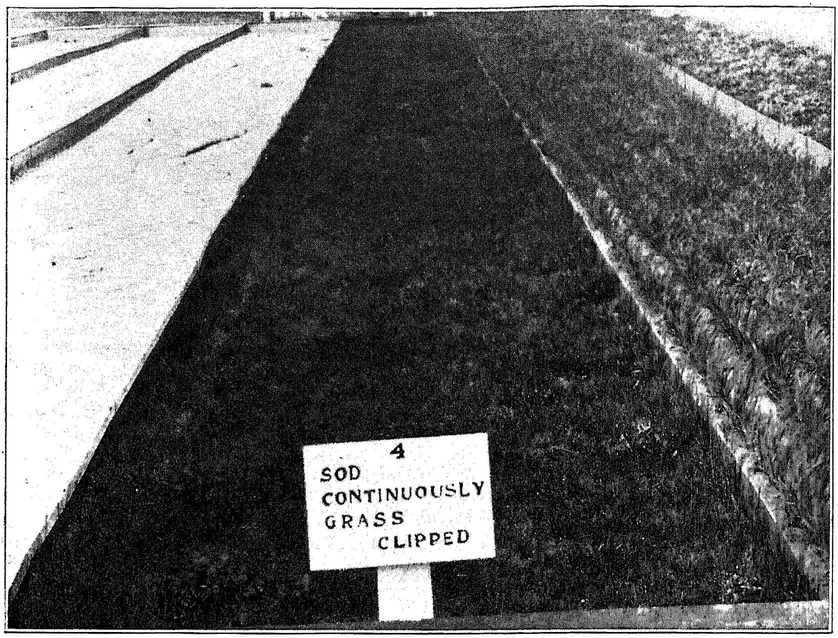

Fig. 19.—Plot 4. Sod continuously. Grass clipped.

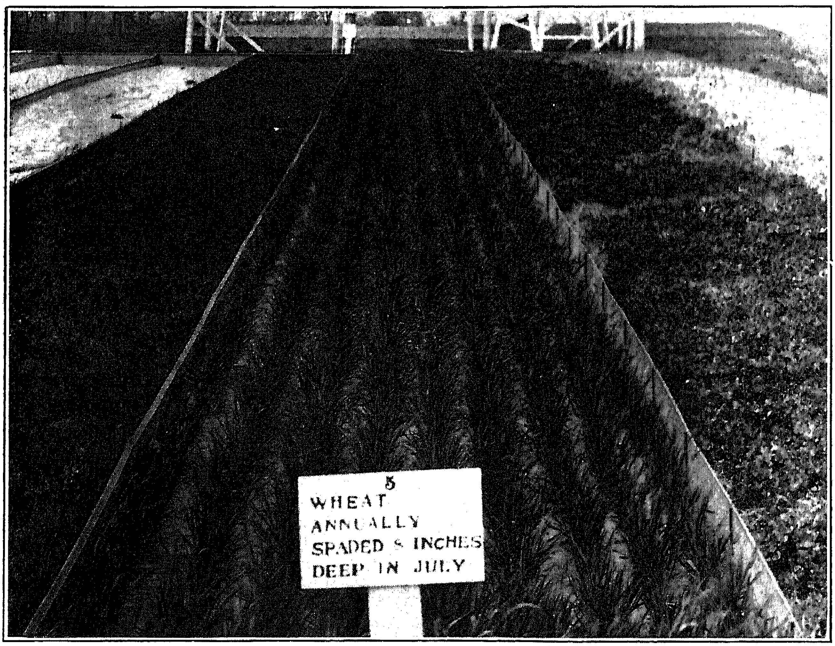

Fig. 20.—Plot 5. Wheat annually. Spaded 8 inches deep in July.

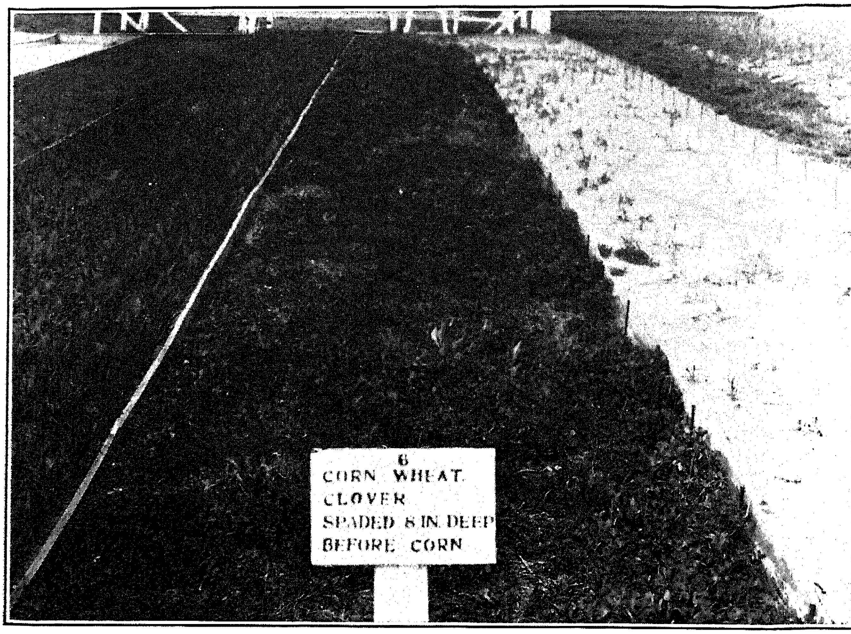

Fig. 21.—Plot 6. Corn, wheat, clover. Spaded 8 inches deep before corn.

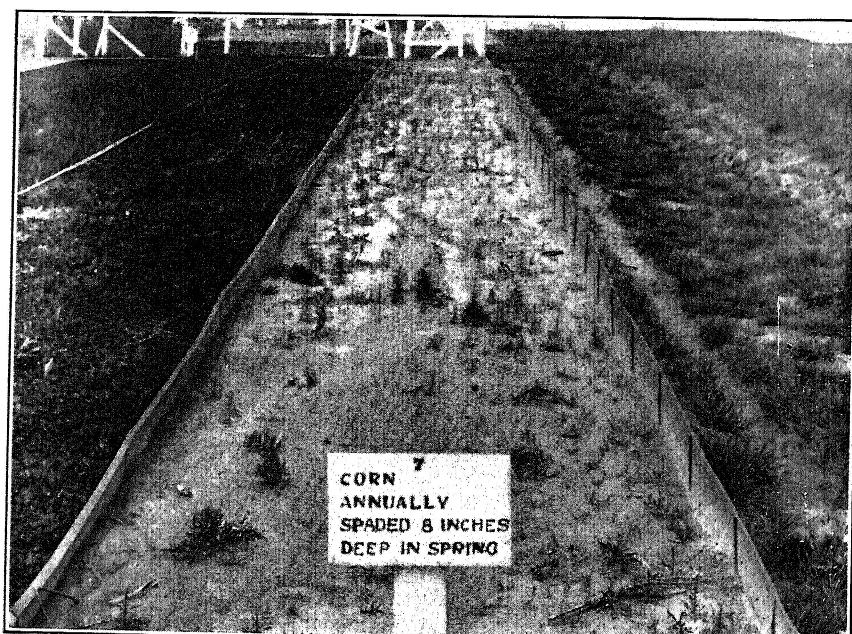

Fig. 22.—Plot 7. Corn annually. Spaded 8 inches deep in spring.