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The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion

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The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion

M. F. Miller and H. H. Krusekopf*

The relation of different systems of cropping and methods of culture to soil erosion and surface runoff has been under investigation at the Missouri Experiment Station since 1917. The first report of this investigation was published in 1923, as Research Bulletin 63. This report summarized the results obtained during the six years between May 1, 1917 and May 1, 1923. In making the summary for this second report, the data for 1917 has been omitted and the fourteen calendar years from January 1, 1918 to January 1, 1932 have been included. This period includes years with an annual precipitation varying from 26.16 inches, during the drought year of 1930, to a maximum of 49.70 inches in 1927. There is little doubt that this 14-year average represents conditions near enough to the normal to make the results reliable. It is therefore proposed to discontinue the original systems of cropping and cultural practices on these plots and use this installation for a study of certain factors within the soil which are of importance in determining the erosion.

Recent Literature

Missouri Research Bulletin 63 published at the end of the first six years of this investigation, summarized the literature on erosion and runoff measurements up to that time. There have been some investigations reported in recent years, dealing directly with the influence of cropping and cover on erosion and runoff losses. Stewart and Forsling[1]† have reported on the range investigation in central Utah established by the United States Forest Service in 1915. In this investigation two large range areas (A and B) have been so managed that one has maintained a much greater plant cover than the other. The runoff from the poorly vegetated tract has varied from two to six times that from the better vegetated tract during different periods, while the erosion losses have been about 2½ to 5½ times as great.

Forsling[2] reports further on this Utah investigation in 1931, confining his discussions largely to the factors influencing the runoff.

Chapline[3, 12] has discussed the influence of erosion on range lands showing how overgrazing allows erosion to carry away much of the surface soil, thus reducing its water-retaining power and fertility. Such

*In the earlier years of this investigation, F. L. Duley, now at the Kansas State Agricultural College, was largely responsible for the plans and details of the work.

†Reference by number to "Bibliography", page 32.

a condition increases runoff and results in the production of large gullies in the valleys as well as changes radically the plant species of the range itself.

Duley[4] reported popularly on the results of the Missouri investigations in Missouri Bulletin 211. Duley[5, 6] also called attention to the influence of early plowing for wheat and the effect of the soybean crop on soil erosion.

Miller[8] summarized ten years results of the Missouri work in the Report of the American Soil Survey Association in 1929. Miller[9] also discussed the relation of the Missouri and other data to the general matter of soil deterioration in Science in 1931.

Lowdermilk[10] has shown the marked influence of forest cover in preventing runoff and erosion. His investigations indicate that one of the important reasons why the removal of forest litter increases runoff is because under such conditions the finer soil particles filter into the surface layers and tend to seal them, thus greatly decreasing the penetration.

Dickson[11] and Conner[12] reporting on some of the investigations of the runoff and erosion experiments at Spur, Texas, showed that with a slope of two per cent the total amount of runoff and erosion for a period from June 1926 to October 1928 was greatest from fallow, uncultivated land; second greatest from fallow cultivated land; third greatest from cotton; with much less losses from Milo maize and Buffalo grass in the order given.

Bennett[13, 14, 15] in connection with exhaustive field studies of erosion losses has shown that plant cover and systems of cropping are of great importance in determining the erosion and runoff losses which may occur. He has called attention to the devastating action of erosion where land is planted continually to cultivated crops or where ranges are overgrazed, such action resulting in great acreages of abandoned land as well as much damage through the filling of water courses.

The Office of Public Roads in cooperation with the North Carolina Experiment Station has for a number of years been carrying on an investigation dealing with erosion and runoff losses. These results, published in mimeographed reports by Bartel[16] have to do with a Cecil fine sandy loam with a grade of nine per cent, a length of slope of 75 feet and an average rainfall of approximately 41 inches. A 3-year average shows an annual acre loss from cultivated, uncropped land of approximately 21 tons, from continuous cotton 20 tons, from continuous corn 13½ tons and from continuous sod only .42 tons.

Unpublished data from the various erosion experiment stations recently established by the federal government in cooperation with the states, show great differences in runoff and erosion losses under different cropping and cultural systems. In general, while these data vary with the soil and the locality, they show very heavy losses from the cultivated crops such as corn and cotton, as well as from cultivated, uncropped land. The losses from land in a crop rotation are much less, and from grass sods and timbered areas they are very low. These cooperative stations as well as some independent state stations are accumulating a mass of data on the factors determining erosion losses and on methods of soil conservation which will point the way to proper systems of erosion control.

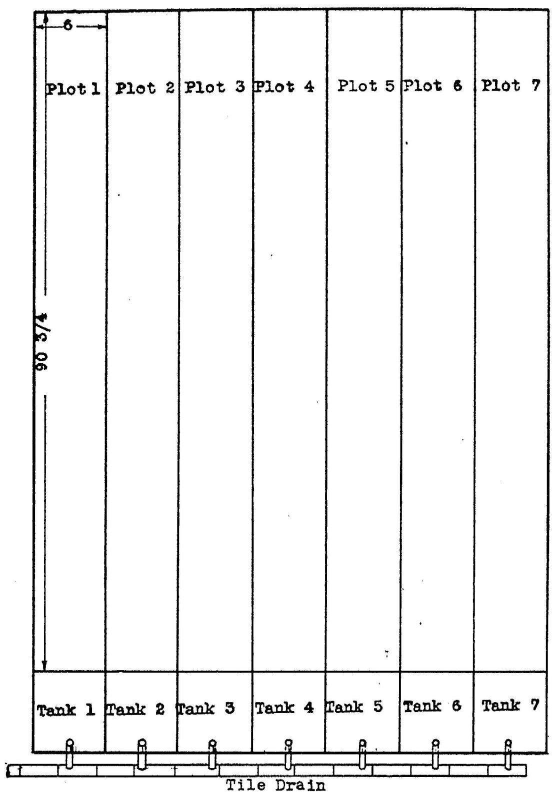

Fig. 1.—Diagram Showing the Layout of the Plots and Catchment Basins Used in this Erosion Investigation.

Plan of the Investigation

The plan of this investigation provided for seven 1/80 acre, elongated plots, (6x90¾ feet) extending up and down a slope, each having a concrete catchment basin at the lower end. The plots were separated by iron partition strips set in the ground and the lower ends of the plots were flush with the top of the catchment basins so as to provide free entrance for the runoff water and eroded soil. (Figure 1). Each basin was constructed with a flat bottom and vertical walls, so that the runoff water could be readily measured, and each was provided with an outlet for draining off the excess water in order that the eroded soil could be collected, weighed and sampled.

The soil type on which the investigation was conducted is classified as the Shelby loam having a rather clayish subsoil of somewhat low permeability and the surface soil of the particular area selected contained less organic matter and was less fertile than the average for the type. The plots were located in an open area with an eastern exposure freely exposed to wind and sun. The total fall from end to end was 3.68 per cent, although it was slightly less than this for the upper 30 feet of each plot and slightly greater for the lower 60 feet. Such a gradient is a moderate one, probably somewhere near an average for corn belt lands in Missouri.

The cropping and cultural systems followed on the seven plots were as follows:

Plot 1. Land uncropped, unstirred, kept free of weeds by shaving them off with a hoe. Occasionally it was necessary to level the surface when small gullies began to form.

Plot 2. Land uncropped, plowed (spaded) 4 inches deep each spring and kept free of weeds by occasional cultivations. A spading fork with a cross bar was used to limit the depth of spading to 4 inches.

Plot 3. Land uncropped, plowed (spaded) 8 inches deep each spring and kept free of weeds by occasional cultivations, the spading fork having a cross bar to maintain the spading depth at 8 inches.

Plot 4. Continuous bluegrass sod.

Plot 5. Continuous wheat. Land plowed (spaded) 8 inches deep in late July. It was cultivated occasionally to keep down weeds and the wheat seeded early in October with the rows running up and down the slope.

Plot 6. Rotation—corn, wheat, clover. Land plowed (spaded) 8 inches deep in spring before corn. It was cultivated after taking off the corn and sown to wheat early in October, the wheat rows running up and down the slope. The clover was seeded on the wheat in the spring.

Plot 7. Continuous corn. Land plowed (spaded) 8 inches deep in spring and corn planted in early May. The corn was removed in October and the land remained bare over winter.

At the end of six years and following the publication of the first report of these investigations, the plan of handling Plot 1 was changed to the continuous production of soybeans. As a consequence, the results from this plot are necessarily omitted from the 14-year averages and the results from the soybean cropping are summarized separately.

The work on all these plots was necessarily done with hand tools. The land was spaded to take the place of plowing and the cultivations were given with a garden cultivator or a hoe, so that the surface was left rather level. The attempt was made to spade those plots requiring it at about the same time each year although weather conditions necessarily caused some variations in this.

No attempt was made in this investigation, to determine the amount of colloidal material in the water which was drained from the basins after the soil had settled. Determinations showed the total amount of suspended material to be small except in times of severe erosion. In the case of the plot in continuous bluegrass the amount was exceedingly small. It was greatest in the case of the cultivated plots where the erosion was heaviest. The error is doubtless proportional to total erosion so that the comparative results are not materially influenced.

Climatological Data.—The two general climatological factors of importance in determining runoff and water erosion are temperature and precipitation. Other factors such as wind movements, humidity and sunshine are of influence only as they affect these two.

TABLE 1.—MEAN MONTHLY TEMPERATURES DURING THE FOURTEEN YEARS OF THE EXPERIMENT

	January	February	March	April	May	June	July	August	September	October	November	December	Average	Deviation from 44-yr. Normal
1918	15.4	33.7	50.9	49.4	68.8	76.8	77.2	81.7	61.4	60.2	44.9	39.8	55.0	+0.9
1919	34.2	35.1	46.6	55.0	61.5	75.0	78.9	74.7	71.1	57.6	42.2	27.0	54.9	+0.8
1920	26.9	33.2	45.6	48.8	63.0	72.8	75.8	73.0	69.6	61.6	40.8	35.9	53.9	−0.2
1921	36.8	40.2	52.0	55.8	65.8	75.7	79.8	76.4	71.8	57.5	43.7	35.5	57.6	+3.5
1922	28.4	34.4	44.7	56.0	66.2	75.6	75.8	76.6	70.8	59.4	47.4	34.3	55.8	+1.7
1923	38.9	28.9	39.6	53.3	62.6	72.9	77.3	76.2	68.2	52.4	45.5	40.2	54.7	+0.6
1924	24.0	32.7	37.8	56.6	57.4	71.8	72.2	77.1	62.7	61.4	45.9	26.6	52.2	−1.9
1925	29.0	37.5	47.0	60.8	60.6	75.8	77.0	75.8	73.8	47.2	41.8	31.0	54.8	+0.7
1926	32.6	38.7	37.8	48.3	67.0	70.0	77.2	76.2	68.5	55.9	39.4	32.2	53.7	−0.4
1927	30.0	40.0	46.0	56.8	63.2	69.5	74.8	70.0	70.9	60.6	46.0	29.2	54.8	+0.7
1928	32.8	36.4	46.0	51.2	65.7	66.6	77.2	75.8	63.8	60.8	44.5	36.2	54.8	+0.7
1929	23.5	25.4	48.5	57.5	61.0	71.2	77.8	76.6	66.9	57.4	38.1	34.4	53.2	−0.9
1930	20.4	44.2	42.8	59.9	64.2	72.0	81.1	78.8	70.6	55.2	46.0	34.0	55.7	+1.6
1931	36.1	41.0	38.4	54.7	60.4	78.0	81.0	75.0	75.2	62.0	52.8	43.4	58.1	+4.0
14-year Average --	29.2	35.8	44.5	54.6	63.4	73.1	77.3	75.9	68.9	57.8	44.2	34.2	54.6	+0.5
44-year Normal --	29.2	31.7	42.6	54.9	64.3	72.8	76.8	75.6	68.2	56.6	43.3	33.2	54.1	
14-year Deviation from Normal --	0	+4.1	+1.9	−0.4	−0.9	+0.3	+0.5	+0.3	+0.7	+1.2	+0.9	+1.0	+0.9	

Temperature.—The influence of temperature on runoff and erosion is exerted primarily through its effect on the evaporation of soil water and on freezing. The more rapid the removal of soil water by evaporation, by percolation or by plants, the greater the opportunity for water penetration. Undoubtedly percolation and plant use of soil water are together much more important than evaporation, yet evaporation is responsible for considerable water removal during the warmer part of the year with a proportionate increase in absorption.

The freezing of the soil during the winter season in the latitude of Columbia is of much importance in lessening the possibility of erosion during the months of December, January, and February, although as the data show these months happen to be months of low precipitation, thus minimizing to a considerable extent the significance of this factor in connection with erosion losses. In regions farther north, where the ground is frozen for longer periods, this factor would doubtless be of much greater importance, while in the southern states where the ground is rarely frozen and where the winter precipitation is high, such erosion losses must be correspondingly magnified.

Table 1 shows the mean monthly temperatures during the 14 years of the investigation. It will be observed that nine out of the twelve months averaged slightly warmer than the normal from the Weather Bureau data.

Precipitation.—In a broad way the total precipitation is an important factor in determining runoff and erosion. However, the distribution of the rainfall, together with the number and size of the torrential rains is of greater importance.

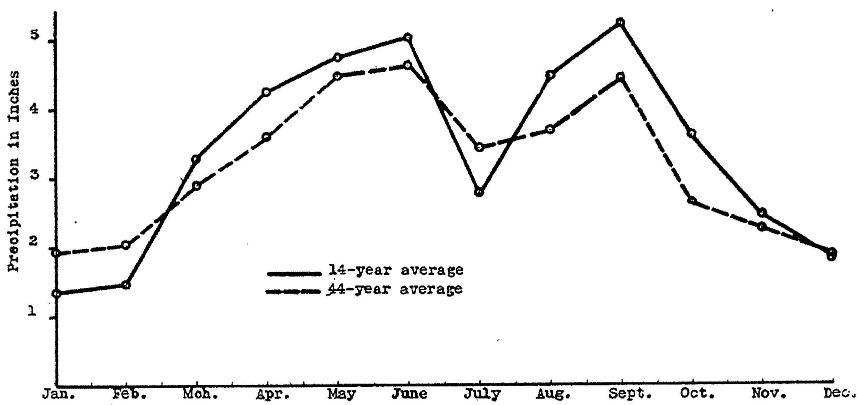

Fig. 2.—Average Rainfall by Months for the 14-Year Period of the Investigation Compared to that of the 44-Year Period From the Local Weather Bureau.

Table 2 shows the monthly precipitation and the average monthly precipitation for the 14 years of the investigation as compared with the average for the 44-year record of the local Weather Bureau. Table 3 shows the average annual precipitation for the 14 years and the deviation of these yearly figures from the 14-year average as well as from the 44-year Weather Bureau record. Figure 2 shows the 14 and 44-year monthly averages compared. It will be observed that these averages for the warmer months of the year (with the exception of July) are slightly higher for the 14-year period than for the 44-year period.

TABLE 2.—PRECIPITATION FOR EACH MONTH DURING THE FOURTEEN YEARS OF THE EXPERIMENT

Month	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	14-year Average	44-year Average for Comparison
January	1.00	0.07	0.71	1.54	1.53	1.40	1.22	0.82	1.43	1.75	0.94	2.09	4.41	.28	1.37	1.94
February	1.30	1.73	0.41	0.45	1.23	1.00	1.95	1.41	2.04	0.57	2.10	1.03	1.82	3.19	1.44	2.06
March	0.64	1.30	5.03	3.37	8.46	3.61	1.81	2.63	2.43	7.65	0.69	4.05	1.03	2.97	3.26	2.89
April	5.07	2.84	3.98	5.51	9.93	4.21	1.46	4.38	4.96	5.17	2.89	5.74	1.55	1.42	4.22	3.59
May	3.95	6.21	4.48	4.01	4.34	1.97	5.11	3.56	2.87	6.68	1.74	11.98	2.88	6.45	4.73	4.47
June	2.68	3.96	1.49	3.18	2.01	6.31	7.72	7.07	2.91	6.11	14.86	7.49	3.10	1.30	5.01	4.60
July	0.73	2.52	2.61	2.69	3.49	3.71	5.70	2.01	4.15	3.07	3.72	1.49	.50	2.53	2.78	3.40
August	7.83	5.37	3.50	5.83	3.30	3.92	3.09	5.11	5.07	5.01	3.22	0.40	2.18	8.86	4.47	3.68
September	9.69	3.31	4.47	10.04	3.79	3.03	4.99	4.88	10.00	2.38	3.33	3.06	3.39	6.69	5.21	4.38
October	1.99	7.68	2.67	2.33	1.50	2.67	2.17	4.63	3.72	5.08	2.86	6.96	2.57	3.15	3.57	2.64
November	2.47	2.84	0.63	1.34	2.37	1.35	1.50	3.16	2.38	4.29	4.68	1.23	2.25	3.94	2.46	2.24
December	2.30	0.55	1.33	1.41	1.38	2.53	4.76	1.88	1.60	1.94	2.04	0.88	.48	2.52	1.83	1.84
Yearly Total	39.65	38.38	31.31	41.70	43.33	35.71	41.48	41.54	43.56	49.70	43.07	46.40	26.16	43.30	40.37	37.80

TABLE 3.—PRECIPITATION DURING EACH YEAR OF THE EXPERIMENT (JAN. 1 TO DEC. 31)

Years of Experiment	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931
Annual Precipitation	39.65	38.38	31.31	41.70	43.33	35.71	41.48	41.54	43.56	49.70	43.07	46.40	26.16	43.30
Deviation from 14-yr. Average[1]	−.72	−1.99	−9.06	+1.33	+2.96	−4.66	+1.11	+1.17	+3.19	+9.33	+2.70	+6.03	−14.21	+2.93
Deviation from 44-yr. Average[2]	+1.85	+.58	−6.49	+3.90	+5.53	−2.49	+3.68	+3.74	+5.76	+11.90	+5.27	+8.60	−11.64	+5.50

[1] 14-year average = 40.37 in. [2] 44-year average = 37.80 in.

It should be noted that the months of greatest rainfall in the latitude of Columbia are, in general, those months when the land in grain crops is most frequently cultivated and therefore subject to the greatest losses. The exception is the month of July. The lower precipitation for July, as it affects erosion, is partly offset by the influence of the torrential nature of many of the rains of this month, which are in the form of violent thunderstorms. Moreover, the average annual precipitation for the 14-year period is 2.57 inches greater than that for the 44-year period and this, coupled with the fact that the 14-year period shows somewhat more than average rainfall during the growing season, would suggest that the losses recorded from the cultivated and cropped plots may be slightly greater than the normal.

Table 4 shows the precipitation during the first, second, third and fourth quarters of the years of the investigation as well as the averages for these quarters for the same period. The data emphasize the statement already made that the months of the cropping season are those of heaviest precipitation.

TABLE 4.—YEARLY RAINFALL BY THREE MONTH PERIODS FOR FOURTEEN YEARS

Year	Jan. Feb. Mar.	Apr. May June	July Aug. Sept.	Oct. Nov. Dec.	Total Rainfall
1918	2.94	11.70	18.25	6.76	39.65
1919	3.10	13.01	11.20	11.07	38.38
1920	6.15	9.95	10.58	4.63	31.31
1921	5.36	12.70	18.56	5.08	41.70
1922	11.22	16.28	10.58	5.25	43.33
1923	6.01	12.49	10.66	6.55	35.71
1924	4.98	14.29	13.78	8.43	41.48
1925	4.86	15.01	12.00	9.67	41.54
1926	5.90	10.74	19.22	7.70	43.56
1927	9.97	17.96	10.46	11.31	49.70
1928	3.73	19.49	10.27	9.58	43.07
1929	7.17	25.21	4.95	9.07	46.40
1930	7.26	7.53	6.07	5.30	26.16
1931	6.44	9.17	18.08	9.61	43.30
Av. of 3 Mo. periods for 14 yrs.	6.08	13.95	12.47	7.85	Average for 14 years 40.37
Av. % rainfall by 3 Mo. periods	15.08%	34.61%	30.96%	19.47%	

Runoff Losses.—The amount of water running off the surface of the soil is naturally a very important factor in determining the erosion. However, the losses of water and soil are not necessarily in proportion since the nature of the cropping system and the cultural practices greatly disturb this relationship. In general, a loose, granular soil, such as one which has been freshly plowed or cultivated absorbs more water than a compact one and a crop which covers the ground well greatly decreases the runoff. Furthermore, systems of tillage such as contour plowing and cultivation are known to have an important influence on runoff although the exact relation to such losses has not been determined.

TABLE 5.—AMOUNTS OF WATER LOST BY RUNOFF FROM EACH PLOT DURING THE DIFFERENT YEARS OF THE EXPERIMENT*

Years of Experment	Total Rainfall in Inches	Cultural and Cropping Systems					
		Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
	In.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
1918	39.65	509.3	522.2	260.5	323.9	411.3	453.9
1919	38.38	532.9	413.7	165.6	365.1	239.6	464.0
1920	31.31	376.2	315.1	67.1	309.0	112.1	310.1
1921	41.70	546.8	478.3	82.4	393.4	177.5	481.4
1922	43.33	775.3	707.4	464.3	816.0	323.1	724.3
1923	35.71	333.7	340.9	138.6	280.2	92.3	309.2
1924	41.48	538.9	509.9	284.9	438.3	275.0	534.0
1925	41.54	784.0	851.8	299.9	596.0	201.6	747.2
1926	43.56	737.4	706.8	296.4	520.3	321.5	639.9
1927	49.70	870.5	999.1	272.5	779.4	664.1	876.6
1928	43.07	684.6	657.0	284.4	596.5	405.2	705.8
1929	46.40	594.3	754.5	493.7	462.4	295.1	918.9
1930	26.16	204.0	189.0	54.8	92.7	67.1	186.9
1931	43.30	585.4	575.9	51.6	188.7	112.5	439.6
Average	40.37	576.6	572.9	229.7	440.1	264.1	556.5

Table 5 shows the yearly and average annual runoff for each system during the period of the investigation. Not only does the runoff from the different systems vary widely each year, but the runoff from any one system varies greatly during different years. Sod is the most effective in controlling runoff, followed by the rotation and by continuous wheat. Corn is only slightly more effective in this respect than cultivated fallow.

TABLE 6.—PERCENTAGE OF RAINFALL LOST BY RUNOFF FROM EACH PLOT DURING THE DIFFERENT YEARS OF THE EXPERIMENT

Years of Experment	Total Rainfall in Inches	Cultural and Cropping Systems					
		Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
	In.						
1918	39.65	28.3	29.0	14.5	18.0	22.9	25.2
1919	38.38	30.6	23.8	9.5	21.0	13.8	26.7
1920	31.31	26.5	22.2	4.7	21.7	7.9	21.1
1921	41.70	28.9	25.3	4.4	21.3	9.4	25.5
1922	43.33	39.4	36.0	23.6	41.5	16.4	36.9
1923	35.71	20.6	21.0	8.6	17.3	5.7	19.1
1924	41.48	28.6	27.1	15.1	23.3	14.6	28.4
1925	41.54	41.6	45.2	15.9	31.6	10.7	39.6
1926	43.56	37.3	35.8	15.0	26.3	16.3	32.4
1927	49.70	38.6	44.8	12.1	34.6	29.5	38.9
1928	43.07	35.1	33.6	14.6	30.5	20.7	36.1
1929	46.40	28.2	35.8	23.4	21.5	14.0	43.6
1930	26.16	17.2	15.9	4.6	7.8	5.7	15.7
1931	43.30	29.8	29.3	2.6	9.6	5.7	22.4
Average	40.37	30.7	30.3	12.0	23.3	13.8	29.4

Table 6 shows the percentage of the total annual precipitation lost as runoff from each system, the averages for the various systems for the 14-year period ranging from 12 per cent for the sod to 30.7 per cent for the land plowed four inches and kept in cultivated fallow.

*All data was originally figured to the second decimal place, and the second figure eliminated in several of the tables.

Plot 1 in the original plan referred to earlier in this report, was kept bare, but uncultivated, during the first six years of the investigation and the data were reported in the first publication. It showed an average runoff of 48.9 per cent of the rainfall or almost 50 per cent. This is much higher than that from any of the other systems for this 6-year period which ranged from 11.5 per cent for the bluegrass sod, to 31.2 per cent for the land plowed four inches deep and kept in cultivated fallow.

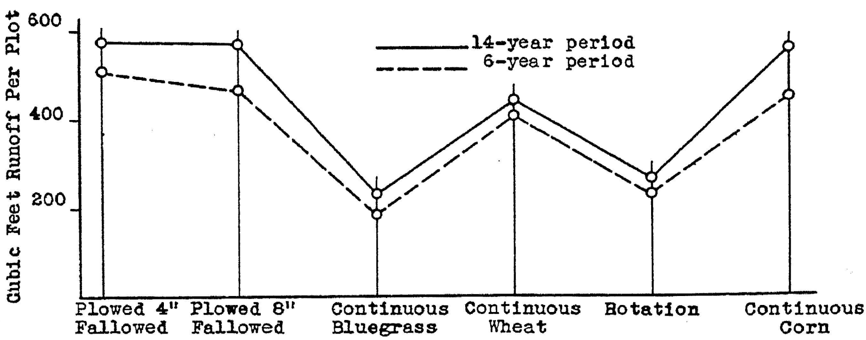

Fig. 3.—Average Annual Runoff Loss From Each Plot for the 6-Year Period and the 14-Year Period Compared.

Figure 3 shows the relation between the runoff losses from the different systems for the 6-year and 14-year periods compared. It will be observed that the 14-year losses are slightly greater than those for six years, but the relative losses are very nearly the same. The 14-year average shows a smaller difference between the amount of runoff from the deep and shallow plowed land and a slightly greater proportional runoff from the land in continuous corn than does the 6-year average.

TABLE 7.—INCHES OF WATER ABSORBED BY THE SOIL OF THE DIFFERENT PLOTS DURING THE DIFFERENT YEARS OF THE EXPERIMENT

Years of Exper-ment	Total Rainfall in Inches	Cultural and Cropping Systems					
		Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
1918	39.65	28.43	28.14	33.91	32.50	30.59	29.65
1919	38.38	26.63	29.26	34.73	30.33	33.10	28.15
1920	31.31	23.03	24.38	29.85	24.51	28.85	24.49
1921	41.70	29.65	31.16	39.89	33.03	37.79	31.09
1922	43.33	26.24	27.73	33.09	25.34	36.20	27.36
1923	35.71	28.36	28.20	32.66	29.54	33.68	28.90
1924	41.48	29.63	30.25	35.21	31.83	35.43	29.72
1925	41.54	24.27	22.77	34.93	28.39	37.10	25.05
1926	43.56	27.31	27.99	37.03	32.10	36.48	29.46
1927	49.70	30.52	27.66	43.68	32.51	35.05	30.37
1928	43.07	28.00	28.58	36.80	30.36	34.14	27.51
1929	46.40	33.32	29.78	35.53	36.22	39.91	26.16
1930	26.16	21.56	21.99	24.95	24.12	24.68	22.04
1931	43.30	30.40	30.60	42.16	39.14	40.82	33.61
Average	40.37	27.67	27.75	35.31	30.71	34.56	28.11

Table 7 shows the inches of rainfall absorbed annually by the land under each system. It will be observed that the sod land, while absorbing in general a large part of the rainfall, has a greater actual yearly variation in absorption than the others. The rotated land is also variable because of the different crops included in the rotation.

The most uniform absorption is that from the continuous corn and cultivated fallow.

TABLE 8.—TOTAL CUBIC FEET OF RUNOFF BY MONTHS AND BY PLOTS FOR THE PERIOD OF THE INVESTIGATION

Months	Average Rainfall	Cultural and Cropping Systems					
		Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
	In.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Jan.	1.37	222.1	172.0	80.8	136.7	83.2	215.0
Feb.	1.44	447.4	329.4	176.6	261.6	156.5	375.9
March	3.26	815.3	787.3	393.1	677.6	352.4	639.6
April	4.22	1153.1	1165.2	597.1	1113.6	594.6	1152.8
May	4.73	583.5	621.0	301.1	618.4	429.7	629.8
June	5.01	1104.0	1184.2	595.5	1013.5	705.6	1236.7
July	2.78	341.0	292.4	130.8	278.8	172.5	299.5
Aug.	4.47	858.4	885.4	197.8	286.6	300.5	693.7
Sept.	5.21	1312.9	1341.6	444.2	919.0	640.5	1288.6
Oct.	3.57	564.8	589.2	169.4	407.9	108.3	690.2
Nov.	2.46	406.9	411.0	70.0	299.1	72.2	397.7
Dec.	1.83	263.5	241.7	60.9	149.6	81.8	172.1
Total	40.37	8072.9	8020.4	3217.3	6161.4	3697.8	7791.6

Table 8 and Figure 4 show the average monthly runoff losses from the different systems. The smaller losses during July are, of course, due in part to a lower rainfall for that month and in part to much evaporation. The greater losses during August and September are largely due to the rather large amount of late summer and fall precipitation and to the greater number of torrential rains during those months.

There is no doubt that the percolation of water downward, which gives room for penetrating water to follow, is an important factor in determining the per cent of runoff, but it is very difficult to study this problem. However, two lysimeters containing blocks of undisturbed soil and subsoil, to a depth of four feet, showed an average percolation of 22.7 per cent and 20.7 per cent respectively of the total rainfall during five years of this experimental period. These lysimeters bore no crop and they were arranged to receive all the rain that fell so that there was no runoff. It is evident therefore that the percolation movement through this subsoil is comparatively slow, almost 80 per cent of the water evaporating rather than percolating through. A similar lysimeter experiment at the Rothamsted Experiment Station in England,

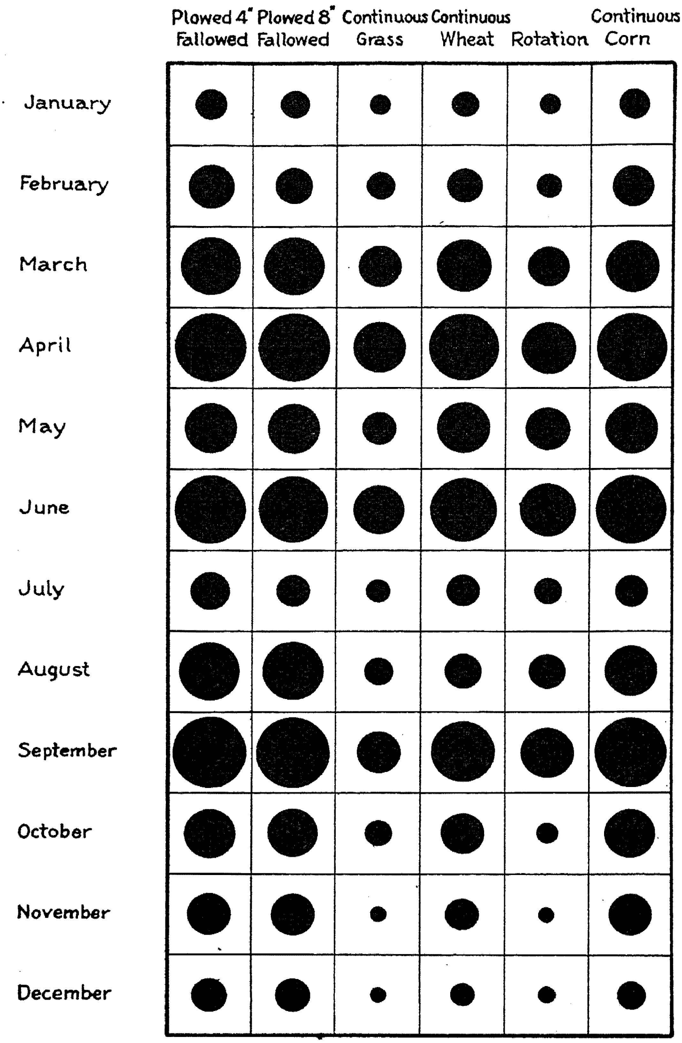

Fig. 4.—The Black Areas Show the Relative Average Monthly Runoff From Each Plot.

with a five foot column of undisturbed soil and subsoil showed the percolation to be almost 50 per cent of the yearly rainfall. Wollny[17] who made somewhat similar studies in England, Germany and Switzerland showed an average percolation of 41 per cent of the rainfall. It is probable, therefore, that the rather heavy subsoil beneath the land on which these erosion investigations have been carried out has resulted in a somewhat less penetration and a greater runoff than would be anticipated from most soils.

Erosion.—The effects of cropping and cultural practices on erosion losses are strikingly shown in the results of this investigation. Naturally these results apply to a single soil type (Shelby loam) with a given gradient (3.68 per cent) and a constant length of slope (90¾ feet). It should be noted that with a longer slope the losses would probably be greater.* Furthermore, 90 feet approximates the normal interval for terraces on Shelby loam having this degree of slope. Consequently, the losses which take place may be those to be expected from the land between terraces on this soil type under the various cropping and cultural systems followed. In other words, the soil eroded under these systems represents that which would normally accumulate in the terrace channel, or in the case of terrace gradients so steep that the channel is self-scouring, it would be that carried off the field through the terrace outlet. These results therefore have a very direct bearing on the erosion losses from terraced land as well as from slopes of similar length where terraces are not used.

TABLE 9.—POUNDS OF SOIL ERODED FROM EACH 1/80 ACRE PLOT DURING EACH YEAR OF THE EXPERIMENT AND TOTAL FOR FOURTEEN YEARS (1918-1931)

Years of Exper-ment	Total Rainfall in Inches	Cultural and Cropping Systems					
		Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1918	39.65	1751.9	2037.3	23.7	143.3	41.1	732.6
1919	38.38	724.3	455.0	6.1	61.2	54.2	521.4
1920	31.31	803.8	500.1	2.4	222.5	65.1	314.0
1921	41.70	1010.1	676.9	1.9	115.0	22.4	302.4
1922	43.33	1426.7	1196.0	2.3	359.0	12.4	505.3
1923	35.71	502.7	544.7	1.6	127.5	51.7	313.0
1924	41.48	1065.7	1119.8	3.9	563.4	29.5	486.1
1925	41.54	772.6	873.7	3.6	66.9	10.7	353.0
1926	43.56	1375.9	1371.1	10.4	475.2	123.3	520.7
1927	49.70	1412.5	1183.6	3.1	177.3	268.6	709.1
1928	43.07	1604.6	1876.7	37.7	587.3	122.0	952.6
1929	46.40	854.6	861.1	12.4	65.3	103.4	574.8
1930	26.16	83.1	123.5	.6	27.6	26.7	57.7
1931	43.30	1189.1	1558.6	11.2	541.3	44.3	561.1
Total	565.29	14577.6	14378.1	120.9	3532.8	975.4	6903.8
Average	40.37	1041.2	1027.0	8.6	252.3	69.7	493.1

Tables 9 and 10 show the erosion losses in pounds per plot and tons per acre. The ton losses are shown graphically in Figure 5. It will be observed that the greatest losses are from the cultivated fallow lands, followed by those from continuous corn, continuous wheat, rotation and bluegrass sod. The negligible annual loss of 0.3 tons from the bluegrass

*Unpublished data from the Missouri Experiment Station indicate that the erosion per unit area in continuous corn on this type of soil is greater from long than from short slopes.

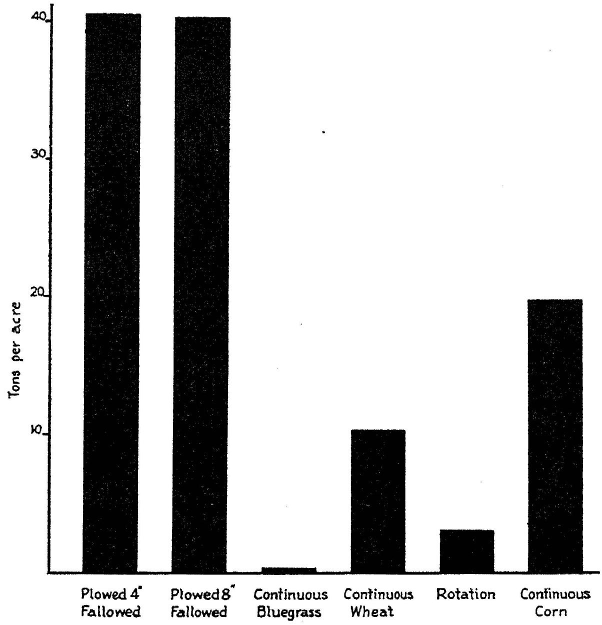

Fig. 5.—Annual Erosion Loss for Each System.

sod is in strong contrast to that of the cultivated fallow land with 41 tons and of corn with almost 20 tons.

Comparison of Erosion Losses

There are various interesting comparisons in these results. For instance, the 41 ton annual loss from cultivated fallow land is cut in half where corn is grown. Evidently the effect of the corn is to reduce the water in the soil, thus increasing water penetration, and to bind the soil granules through the action of the roots, thus directly decreasing the erosion. Wheat, a crop which covers the ground well during much of the year, allows a loss of only about one-half that from continuous corn. The 3-year rotation further reduces the loss to less than one-third that from continuous wheat and about one-seventh that from continuous corn. Finally, bluegrass sod reduces the loss to around 1/60 of the loss from corn. In other words, under the conditions of this experiment it would take 60 years to remove as much soil from land in bluegrass as that removed in one year from land in continuous corn. This fact indicates the tremendous dislocation of nature's processes in the transformation of nature's sod to continuous corn or other cultivated crop.

Figure 6 shows the relation between the erosion losses for the 6 and 14-year periods. It will be observed that the relative losses are practically

TABLE 10.—TONS OF SOIL ERODED PER ACRE FOR EACH SYSTEM BY YEARS AND TOTAL FOR FOURTEEN YEARS (1918-1931)

Years of Experiment	Total Rainfall in Inches	Cultural and Cropping Systems					
		Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
		Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
1918	39.65	70.1	81.5	1.0	5.7	1.6	29.3
1919	38.38	29.0	18.2	.2	2.5	2.2	20.9
1920	31.31	32.2	20.0	.1	8.9	2.6	12.6
1921	41.70	40.4	27.1	.1	4.6	.9	12.1
1922	43.33	57.1	47.8	.1	14.4	.5	20.2
1923	35.71	20.1	21.8	.1	5.1	2.1	12.5
1924	41.48	42.6	44.8	.2	22.5	1.2	19.4
1925	41.54	30.9	35.0	.2	2.7	.4	14.1
1926	43.56	55.0	54.8	.4	19.0	4.9	20.8
1927	49.70	56.5	47.3	.1	7.1	10.7	28.4
1928	43.07	64.2	75.1	1.5	23.5	4.9	38.1
1929	46.40	34.2	34.4	.5	2.6	4.1	23.0
1930	26.16	3.3	4.9	----	1.1	1.1	2.3
1931	43.30	47.6	62.3	.5	21.7	1.8	22.4
Total----	565.29	583.2	575.0	5.0	141.4	39.0	276.1
Average per yr..	40.37	41.6	41.0	.3	10.1	2.7	19.7

the same. However, as in the case of the runoff, the difference between the four and eight-inch plowing is less for the longer than for the shorter period. The losses from the continuous wheat and continuous corn are slightly greater for the 14-year period. On the whole, however, the results from the two periods are very similar.

One of the surprising results of this work is the small difference which was found in the erosion losses from land plowed at different depths. In the beginning of this investigation it was expected that the erosion from the 8-inch plowing would be much less than that from the 4-inch plowing. However, the results of the 14 years show very little difference between the two. It is likely that a greater variation in the depths, such as three-inch versus nine-inch plowings would have shown a greater difference. There is also reason to expect that the soil profile

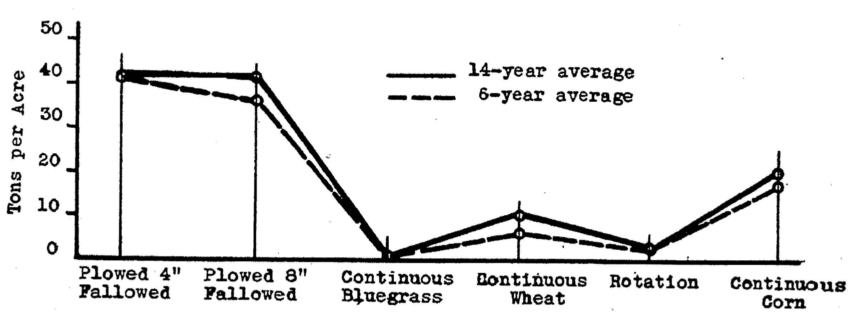

Fig. 6.—Average Annual Erosion Loss From Each System for the 6-Year Period and the 14-Year Period Compared.

exerts an important influence, particularly the depth of the surface soil and the compactness of the subsoil. Nevertheless, these results throw some doubt on the rather general belief that deep plowing is an important factor in erosion control for Missouri conditions.

TABLE 11.—TOTAL POUNDS SOIL ERODED PER MONTH AND PER PLOT DURING FOURTEEN YEARS

Months	Average Rainfall	Cultural and Cropping Systems: Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
	In.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Jan.	1.37	140.6	66.2	5.5	40.7	23.1	88.0
Feb.	1.44	163.6	125.8	2.2	91.6	11.3	68.3
March	3.26	1071.5	711.1	5.9	262.4	56.4	478.1
April	4.22	1792.7	1606.7	13.1	483.0	237.1	931.3
May	4.73	789.5	771.6	6.6	61.6	84.6	369.7
June	5.01	2551.2	2620.3	44.2	442.6	233.5	1719.2
July	2.78	974.5	758.5	2.2	92.3	87.0	585.1
Aug.	4.47	2754.1	3305.6	19.2	369.7	106.9	853.7
Sept.	5.21	3435.8	3481.9	17.7	1340.7	116.8	1357.1
Oct.	3.57	598.5	584.0	1.2	175.6	10.4	314.9
Nov.	2.46	272.5	322.6	2.3	162.2	5.9	126.4
Dec.	1.83	32.5	23.3	1.0	9.8	2.4	12.2
Total	40.37	14577.0	14377.6	121.0	3532.2	975.4	6904.0

The relative monthly erosion from the different systems is shown in Table 11 and Figure 7. The average percentage of erosion per month is given in Table 12. The results are outstanding in showing a very small amount of erosion from any of the systems during the late fall and winter months, these amounts dropping to almost negligible figures during December, January and February. This is, of course, due to the small amount of precipitation during these months, as has been shown, and to the fact that the ground is frozen during much of this time. Likewise the large losses during the months of April, June, August and September, particularly on the cultivated fallow land, are very outstanding.

TABLE 12.—PERCENTAGE OF EROSION TAKING PLACE FROM EACH PLOT DURING EACH MONTH OF THE YEAR

Month	Cultural and Cropping Systems: Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
January	1.0	.5	4.6	1.1	2.4	1.3
February	1.1	.9	1.8	2.6	1.4	1.0
March	7.3	4.9	4.9	7.4	5.8	6.9
April	12.3	11.2	10.8	13.7	24.3	13.5
May	5.4	5.4	5.4	1.7	8.7	5.3
June	17.5	18.2	36.5	12.5	23.9	24.9
July	6.7	5.3	1.8	2.6	8.9	8.5
August	18.9	23.0	15.8	10.5	11.0	12.4
September	23.6	24.2	14.6	38.0	12.0	19.7
October	4.1	4.1	1.0	5.0	1.1	4.6
November	1.9	2.2	1.9	4.6	.6	1.9
December	.2	.2	.9	.3	.2	.2

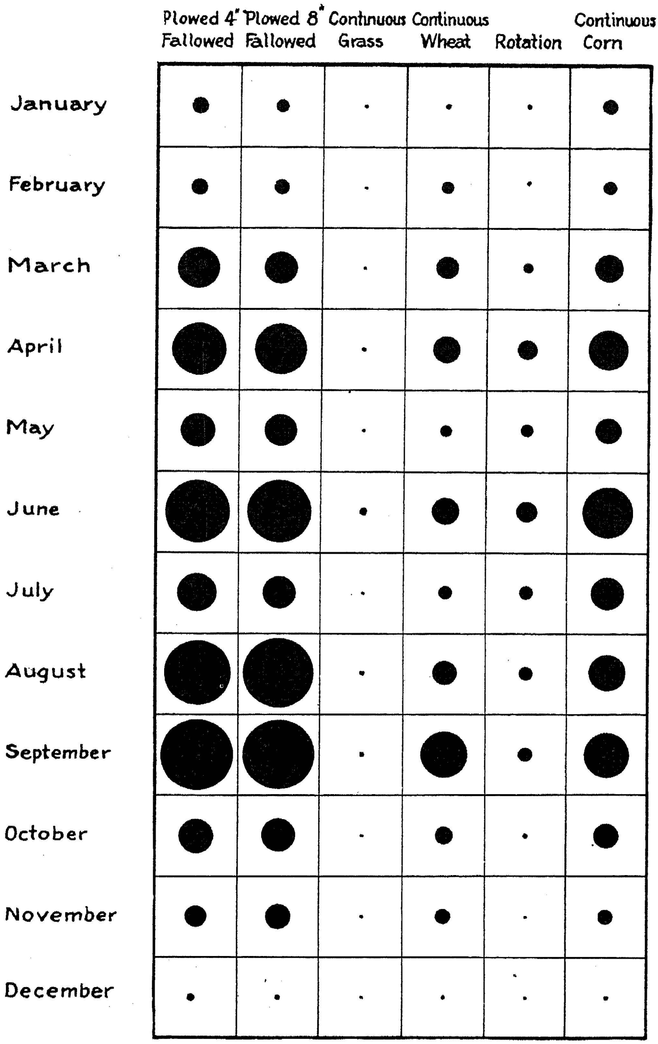

Fig. 7.—The Black Areas Show the Relative Monthly Erosion from Each Plot.

Losses from Continuous Corn vs Corn in Rotation

One of the most interesting results of this investigation is the influence of a crop rotation upon the erosion and runoff from corn land. To show this influence it is necessary to compare the losses from corn in rotation with the losses from corn grown continuously. Moreover, in order to make these results comparable it is necessary to confine the comparison, not only to those years (1920, 1923, 1926 and 1929) when the rotated land was in corn, but also to the six months of these years, April to September inclusive. These months include that period of the

TABLE 13.—AVERAGE RUNOFF AND EROSION FROM THE PLOT IN CONTINUOUS CORN AND THE ROTATION PLOT FOR THOSE SEASONS WHEN THE ROTATION PLOT WAS IN CORN—1920, 1923, 1926 AND 1929. THE DATA ARE SUMMARIZED FOR THE MONTHS OF THE CORN GROWING SEASON IN EACH CASE

	Corn in Rotation		Continuous Corn	
	Runoff Cu. ft. per plot	Erosion Lbs. per plot	Runoff Cu. ft. per plot	Erosion Lbs. per plot
April	180.3	18.1	525.9	471.7
May	96.8	17.4	325.9	95.9
June	108.5	80.6	347.8	502.6
July	47.6	64.9	151.7	208.4
August	78.0	53.1	110.6	72.2
September	152.5	82.8	235.3	144.1
Total	663.7	316.9	1697.2	1494.9

Runoff from continuous corn = 2.5 times that from corn in rotation.
Erosion from continuous corn = 4.7 times that from corn in rotation.

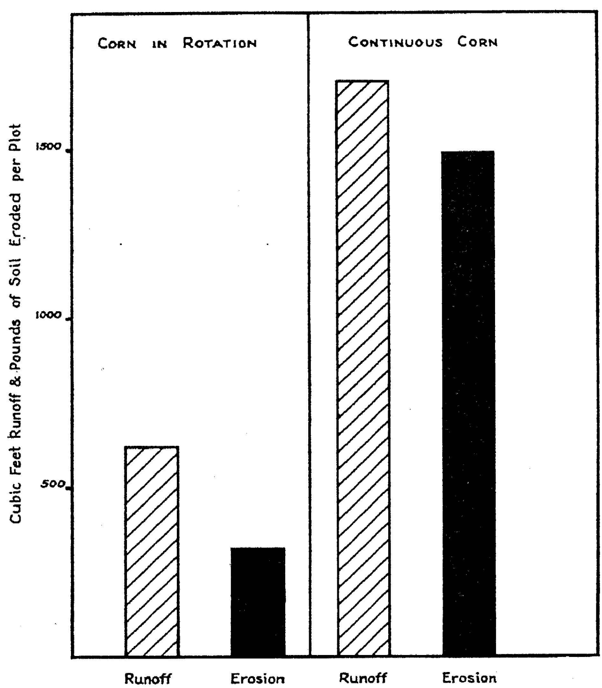

Fig. 8.—Total Runoff and Erosion Losses Under Continuous Corn vs. Corn in Rotation for the Months of the Corn Growing Season.

year when both plots are given over to the production of the corn crop. Table 13 shows the data for both runoff and erosion for corn in rotation and for continuous corn. Figure 8 shows the total runoff and erosion for these periods in graphic form. As compared with continuous corn the rotation has had a profound effect in decreasing both the runoff and erosion. The land in continuous corn lost 2.5 times as much runoff water and 4.7 times as much soil as that in rotation.

The cause for this difference in runoff is probably found in the greater penetration resulting from the more open structure of the soil immediately following clover. In the case of the erosion, the lessened runoff accounts for a part of the difference observed and it is probable that the more granular condition of the rotated land and the greater amount of organic matter it contains are also factors.

It is evident that the influence of a good crop rotation in controlling erosion is not entirely due to the larger portion of the time when crops cover the ground but also to the influence of the rotation on the soil itself. Investigations are in progress with the idea of determining something definite regarding the fundamental reasons for these differences.

Erosion from Clover and Bluegrass Compared

Another comparison which is of interest is that of the losses from clover sod during those years when the rotated plot grows this crop as compared with the losses from the continuous bluegrass sod. If one uses the same 6-month periods, April to September inclusive, the runoff from the clover sod is only 1.05 times that from the bluegrass while the erosion is 4.2 times as great. The larger erosion from the clover is probably due to the more open nature of the stand as compared with the dense growth of the bluegrass.

Summary Figures

A general summary of some of the most important data from thsi investigation is given in Table 14. This shows not only the total amounts of soil eroded per acre annually from each system for the period of the investigation, but also the total annual runoff per acre and certain other relations.

One of the interesting sets of data is that showing the number of units of runoff water required to remove one unit of soil under the various systems. It will be observed that in the case of the cultivated fallow land only about 34 pounds of runoff water is required to remove a pound of soil, but in the case of the cropped land this amount is much larger, particularly where the crops cover the ground well. The extreme case is, of course, the bluegrass sod from which over 1600 pounds of water is required to remove one pound of soil. In other words, the water from the

TABLE 14.—GENERAL SUMMARY OF RUNOFF AND OF SOIL ERODED PER ACRE DURING FOURTEEN YEARS

	Cultural and Cropping Systems					
	Plowed 4" Fallowed	Plowed 8" Fallowed	Continuous Bluegrass	Continuous Wheat	Rotation Corn, Wheat and Clover	Continuous Corn
Average no. tons soil eroded per acre annually	41.64	41.08	.34	10.10	2.78	19.72
Surface inches of soil eroded annually ---	.291	.287	.0023	.070	.019	.138
Average no cu. ft. runoff per acre annually	46,132	45,836	18,379	35,209	21,129	44,524
Average percent runoff annually ----	30.7	30.3	12.0	23.3	13.8	29.4
Pounds runoff required to erode 1 lb. soil---------	-----34.4	34.8	1,666.9	109.1	236.5	70.3
No. of years to erode 7 in. of soil---------	24	24	3,043	100	368	50

unprotected or cultivated land comes off very muddy while the water from the bluegrass sod is usually almost clear.

The relation of runoff to erosion for the different systems is shown in Figure 9. In the case of the cultivated land the erosion is high as compared with the runoff while the reverse is true in case of the continuous wheat, rotation and continuous bluegrass.

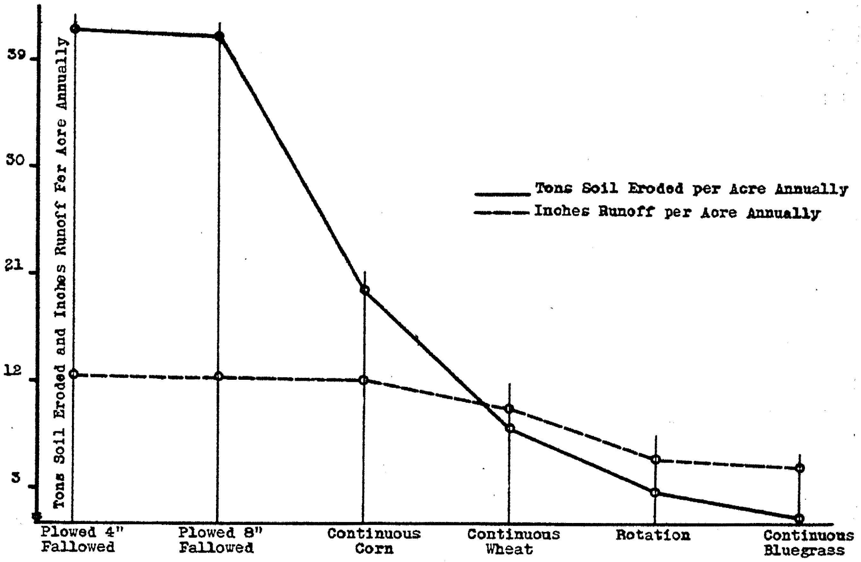

Fig. 9.—Relation of Runoff to Erosion Losses for Each System.

Another significant set of figures in this table has to do with the calculated number of years required to remove the surface seven inches of soil under the different systems. The surface seven inches is used as a basis because this layer is often spoken of as the "plow land" or that turned by the plow. Also in the case of this particular slope the surface soil layer is not much deeper than seven inches. It will be observed that in the case of the cultivated fallow land this soil layer would be lost in about 24 years and in the case of the continuous corn in about 50 years, or about the active lifetime of the average farmer. Wheat increases the period to 100 years, while a good crop rotation would require over 360 years for this layer to be removed, a rate almost negligible. The extreme case is that of continuous bluegrass which so holds the soil that on this slope over 3000 years would be required to remove the seven inch layer. It must be remembered in each case, however, that the length of this slope is only 90 feet and that with a longer slope the losses would probably be somewhat greater and the time for removing this layer correspondingly less.

TABLE 15.—NUMBER OF RAINS CAUSING RUNOFF DURING THE FOURTEEN YEARS OF THE EXPERIMENT

Years of the Experiment	Total Rainfall Inches	No. of Rains Causing Runoff	No. of 1 to 2 in. Rains in 24 Hrs.	No. of Rains 2 in. or over in 24 Hrs.
1918	39.65	29	5	2
1919	38.38	46	8	2
1920	31.31	40	5	0
1921	41.70	53	8	2
1922	43.33	48	8	2
1923	35.71	24	10	2
1924	41.48	30	8	2
1925	41.54	31	13	1
1926	43.56	29	8	1
1927	49.70	24	13	3
1928	43.07	19	5	5
1929	46.40	17	6	3
1930	26.16	10	5	0
1931	43.30	20	8	3
Total	565.29	420	110	28

The Relation of Torrential Rains to Erosion

It is, of course, common knowledge that torrential rains usually result in much soil erosion. Table 15 shows the number of rains causing runoff during the 14-year period together with the distribution of medium and heavy rains by years. Table 16 shows the amount of erosion per plot from the 25 heaviest rains all of which were over 2 inches in 24 hours. It will be observed that in the case of all systems, excepting

TABLE 16.—EROSION DURING TWENTY-FIVE OF THE MOST DESTRUCTIVE RAINS OCCURRING WITHIN THE FOURTEEN YEARS

Treatment	Pounds of soil lost per plot during 25 destructive rains	Total pounds of soil lost per plot in 14 years	Percentage of total lost in 25 rains
Plowed 4 in., Fallowed	7,643	14,577.6	52.4
Plowed 8 in, Fallowed	8,076	14,378.1	56.1
Continuous bluegrass	82	120.9	67.8
Continuous wheat	2,055	3,532.8	58.1
Rotation: Corn, wheat and clover	367	975.4	36.9
Continuous corn	3,625	6,903.8	52.5

the rotation, these heavy rains were responsible for over half of the erosion. In the case of the rotation it happened that some of the most destructive rains occurred during the years when this land was in clover sod, thus reducing their erosive effect.

Loss of Nutrients in Eroded Material

No attempt has been made during the course of this investigation to keep a complete record of the total amounts of plant nutrients removed in the eroded soil. Naturally such figures would apply to a single soil with a particular degree and length of slope only, and to a limited number of cropping and cultural treatments. Two years' data for nitrogen, phosphorus, calcium and sulfur were reported in Research Bulletin 63. The average data from two additional years measurements are given in Table 17. However, the rotated land was in corn in 1926

TABLE 17.—AVERAGE POUNDS OF PLANT NUTRIENTS IN ERODED MATERIAL REMOVED PER ACRE ANNUALLY DURING TWO YEARS MAY 1, 1926 TO MAY 1, 1928

Treatment	Nitrogen	Phosphorus	Potassium	Magnesium	Calcium	Sulfur
Plowed 4 in. Fallowed	118.13	37.75	1245.55	171.94	458.51	46.72
Plowed 8 in. Fallowed	100.16	36.17	1202.07	179.13	425.31	42.76
Continuous bluegrass	.60	.16	2.67	.22	1.07	-----
Continuous wheat	32.39	9.42	264.00	42.67	106.23	8.55
Rotation: Corn, wheat, clover	26.36	6.20	213.86	29.18	86.08	5.97
Continuous corn	65.90	18.00	605.30	87.29	220.84	16.66

and in wheat in 1927. Clover was, of course, seeded in the wheat carrying over to May of 1928. As a consequence these figures would probably not represent an average year for the rotated land but a year with somewhat greater than average losses. It is probably unsafe to draw very definite conclusions from a two year period although when the different cropping and cultural systems are considered the results are of value in a comparative way. As a matter of fact, these data represent somewhat larger losses of nitrogen, phosphorus and calcium, but less losses of sulfur, than those previously reported. These data also include figures for potassium and magnesium.

Taking continuous corn as an example, the amount of nitrogen removed annually in eroded material would equal about that which is found in a 45-bushel corn crop. The amount of phosphorus would represent about that found in an 80-bushel corn crop and the amount of potassium that in ten crops of corn of 85 bushels each. In the case of continuous wheat the nitrogen removed is equal to that in a 17-bushel crop of wheat, the phosphorus is about that in a 30-bushel crop and the potassium that found in nine crops of 25 bushels each.

It must be remembered that this slope is a very moderate one, but even with such a slope the losses under a cultivated crop like corn, or even a small grain crop, such as wheat, may represent as much nitrogen and usually much more phosphorus and potassium than is carried off in the crop itself. With a greater slope the losses would naturally increase. Moreover, they would vary with soils of different degrees of fertility as well as with different slopes.

When the losses under a good cropping system are considered the amounts of nitrogen and phosphorus removed are very much less than the losses through crops of fair yields. The amount of nitrogen equals that carried in about an 18-bushel corn crop and the phosphorus that in a 28-bushel crop although the potassium loss is still high. Under grass the nutrient losses are negligible even for potassium.

The magnesium, calcium and sulfur losses under corn are high as compared with the amounts carried in the crop. The calcium losses are large, even in the case of the rotation. Of course, the excessive losses are from the cultivated fallow land. These various losses are in most cases very much larger than those through crops.

It can be said in general that on such a slope the losses of nutrient elements through erosion may be very high from bare soil of good quality and that they are still very serious from corn land, while a good cropping system or sod may reduce them to amounts that are of little significance. On steeper slopes the losses would, of course, be greater and in systems where cultivated crops are the principal ones grown the losses may be much greater than through crop removal.

A matter which should be considered in connection with these nutrient losses is that they are doubtless largely from the silt, clay and organic particles of the soil rather than from the sand which is principally quartz. While the runoff water carried some of these nutrients in solution, determinations[7] showed that the losses from this source, except for calcium and sulfur and to a certain extent for potassium, were very small.

Physical Composition of the Eroded Material

Determinations of the physical composition of the eroded material were made during the year September 1, 1920 to September 1, 1921.

These results were reported in Research Bulletin 63, pp. 40-41. In general they show that the uncropped land and the land in corn, where a bare soil surface is exposed, allow more of the sand particles to wash off than where the land is covered. The eroded material carrying the most sand was that from the plot kept bare and uncultivated during the first six years. It would be expected that the velocity of the runoff water would be greater on bare soil and this greater velocity would result in the removal of a larger proportion of the sand particles than if the velocity were lower.

The Influence of Soybeans on Runoff and Erosion Losses

Plot 1 of the original installation was kept bare and uncultivated for the first six years and the results were published in the first report of this investigation. However, because of the interest in soybeans and their relation to erosion losses this plot was seeded to soybeans each year for the remainder of the period. During the first four years of the period (1924 to 1927 inclusive) the beans were sown in rows, at corn planter width, running up and down the slope. During the second 4-year period (1928 to 1931 inclusive) the beans were sown with a grain drill running up and down the slope, and with rows 8 inches apart. These are the two most common methods of seeding soybeans and it seemed important to determine the runoff and erosion losses under the two systems However, since it is customary to follow soybeans with a small grain crop, the beans for both periods were followed by rye as a winter cover.

Table 18 shows the results for the first 4-year period, with the beans in rows, along with those from continuous corn for comparison. It also shows the results for the second 4-year period with beans drilled, as compared with the results from continuous corn.

TABLE 18.—AVERAGE ANNUAL RUNOFF AND EROSION LOSSES FROM CONTINUOUS SOYBEAN VS. CONTINUOUS CORN WHERE THE SOYBEANS ARE FOLLOWED BY A RYE COVER AND THE CORN LAND LEFT BARE

Years 1924-1927	Runoff (Cu. ft. per plot)	Runoff loss from soybeans as per cent of loss from corn	Erosion (lbs. per plot)	Erosion loss from soybeans as per cent of loss from corn
Continuous corn	699.3	84	517.2	94.3
Continuous soybeans in rows	587.8		488.0	
Years 1928-1931				
Continuous corn	562.8	74.3	536.5	43.7
Continuous soybeans in drills	418.7		234.9	

It will be observed that the losses from the beans in rows are much greater than those from the beans in drills. However, these represent two different periods so that it is more accurate to compare these two sets of data with those from continuous corn for the corresponding periods. With these comparisons the erosion from beans in rows was 94 per cent of that of the continuous corn. It will be seen, therefore, that soybeans sown in rows and cultivated, even when followed by a rye cover, allowed almost as much erosion, under the conditions of the trial, as did continuous corn. It is possible that without the rye cover the loss from the soybeans would have been greater than from the corn.

During the second soybean period, when the beans were drilled, the erosion loss was much less than where they were in rows, averaging only 43 per cent of that from continuous corn. It may be said, therefore, that the erosion from beans in drills was only about half that from beans in rows. These figures have a very important bearing on the methods of seeding soybeans on rolling land. The smaller erosion from the land in drilled beans is undoubtedly due in part to the binding effect of the roots and possibly in part to the greater amount of rainfall intercepted by the beans when drilled with the narrower spaces.

Discussion

The results of this investigation show most outstanding differences in the amounts of runoff water and eroded soil from different systems of cropping and cultural practices. It must, of course, be remembered that these results apply to one soil type only and to one length and degree of slope. A greater degree and length of slope would doubtless show increased losses, while different soil types would probably show greater or less losses depending upon the nature of the soil profile. Nevertheless, the general principles should have rather wide application and furnish information which will be of assistance in determining proper methods of erosion control.

The eroded soil is that which would accumulate at the bottom of the slope, at least in part, thus deepening the soil layer at that point or it would be all or in part washed into the drainage channels and probably carried from the field. At best erosion results in an unequal distribution of the surface soil of a farm and a decreased opportunity for its complete utilization for cropping purposes.

It is of importance to consider too, that the length of slope used in this investigation is about the interval which, with the existing grade, would be recommended between terraces on this soil type. In case the land were terraced, therefore, the eroded soil would be washed into the terrace channels under the different cropping systems. In case the terraces had only a slight grade the soil would largely remain in the terrace channels and would later be thrown on the terraces during the course of terrace maintenance. The terraces would therefore delay the time when the soil would leave the field. On the other hand, if the terraces had a grade which provided for a self-scouring channel this soil would largely be removed from the field through the terrace outlet. The data therefore show what losses may be expected between the terraces under the cropping systems followed.

The distribution of the rainfall in central Missouri has an important bearing on erosion and runoff losses since it is heaviest during the growing season when land is usually prepared and cultivated. This, together with the fact that the annual precipitation for the period averaged about 2½ inches greater than normal for Columbia, probably resulted in slightly greater annual losses than would be expected from this soil type.

It is rather generally thought that a cultivated soil is very efficient in increasing penetration and curtailing runoff. The results show that while the cultivation increases penetration as compared with bare uncultivated land, crop rotation and continuous grass are far more effective in this respect. It is interesting to observe too, that the rotation of corn, wheat, and clover was almost as effective as the bluegrass.

The widespread in the erosion losses from the different systems is most interesting, varying from an annual acre loss of 41 tons for the cultivated fallow land and 19.7 for continuous corn to 2.78 tons for a good crop rotation and 0.34 tons for the continuous sod. These figures show the very important effect of cultivation in favoring erosion losses and the similarly important influence of rotation and bluegrass sod in curtailing it. They point the way to effective efforts in erosion control through a control of the cropping system.

The failure of the deeper (8-inch) plowing to show an appreciable advantage over the shallower (4-inch) plowing, as regards both runoff and erosion, is one of the surprising results of this investigation. However, it should be remembered that these results apply to a single soil and set of conditions only. It is probable that a greater difference in the two plowing depths would have had a greater influence in favor of the deeper plowing. Moreover, quite different results might have been secured with a different soil type, particularly one with a shallower surface soil.

The rather high erosion losses from cultivated land during the fall months is a matter that should be given special consideration. It means that land prepared early for fall sown wheat or other small grain may be subject to severe erosion and crops which are harvested and leave the land bare at that time may allow the soil to suffer unduly.

The fact that a rotation including clover results in much less erosion than continuous corn cannot be entirely explained by the greater cover which the rotation provides. This is shown by a comparison of the erosion from these two systems during the six months growing period of those years when both are in corn. During this period the continuous corn land loses soil in larger amounts than the amount of runoff warrants. The rotation actually renders the soil less erosive, probably through an improvement in granulation and in maintaining a large amount of organic matter.

The loss from continuous soybeans in rows was not quite as large as was anticipated. However, the beans were followed by a rye cover and the corn was not. When beans were drilled with a grain drill the loss was somewhat less than half that from continuous corn although here again the beans were followed by rye. It is probable that without a rye cover the loss from beans in rows would equal or exceed that from corn. It would seem therefore that in order to curtail such loss the beans should, where possible, be drilled.

According to the results of this investigation the statement sometimes made that the amounts of nutrient elements in the eroded material exceed those taken off in crops is subject to certain limitations. The statement will indoubtedly hold for corn and small grain grown continuously on moderate to steep slopes of this soil type, but with a good cropping system the losses through erosion are apt to be less than through crops. There is no doubt, however, that in both the corn belt and cotton belt such losses through erosion, are very severe and on steep slopes with improper cropping systems they far exceed those due to crop removal.

Summary

1. An investigation covering a 14-year period is described, the object of which was to determine the influence of different systems of cropping and cultural treatment on surface runoff and soil erosion. The soil on which the investigation was carried out was a rather poor quality of Shelby loam having an average grade of 3.68 per cent.

2. The plots, which were 1/80 acre in size, were 6 feet wide and 90¾ feet long extending lengthwise up and down the slope and ending in concrete catchment basins to receive the runoff water and eroded soil. There were originally seven of these with different cropping and cultural systems, but only six were carried without change for the 14-year period. The treatments of the seven plots were as follows:

Plot 1. Land uncropped and left bare of weeds by pulling or shaving off with a sharp hoe. (After the first six years, when the first report of this investigation was published, this plot was changed to continuous soybeans).
Plot 2. Land plowed 4 inches deep in spring and kept in cultivated fallow.
Plot 3.—Land plowed 8 inches deep in spring and kept in cultivated fallow.
Plot 4.—Continuous bluegrass sod.
Plot 5.—Continuous wheat.
Plot 6.—Rotation: corn, wheat, clover.
Plot 7.—Continuous corn.

3. The average yearly precipitation for the 14-year period was 40.37 inches as compared with a 44-year average of the local Weather Bureau of 37.80 inches or about 2½ inches above normal. The average monthly precipitation during the period was somewhat above the 44-year normal for all months excepting January, February, July and December.

4. During the 14-year period the runoff varied from 12 per cent of the rainfall for the bluegrass sod to 30.7 per cent for the land plowed 4 inches deep and kept in cultivated fallow. That from the continuous corn was 29.4 per cent, from the continuous wheat 23.3 per cent and that from the rotation 13.8 per cent or only slightly more than from the sod. There was very little difference in the runoff from the shallow and deep plowed land, the runoff from the 4 inch plowing being only 0.4 per cent above that from the 8-inch plowing.

5. The average annual erosion per acre varied from 41 tons for the land plowed 4 inches deep and left in cultivated fallow to the almost negligible quantity of 0.34 tons for the continuous bluegrass sod. The annual erosion from continuous corn was 19.74 tons per acre or about one-half the amount from the cultivated fallow; that from continuous wheat was 10.10 tons or about half the amount from continuous corn; that from the rotation was only 2.78 tons or less than one-third the amount from continuous wheat.

6. The influence of the deep plowing in diminishing erosion losses was almost negligible, the 8-inch plowing losing annually only 0.56 tons per acre less soil than the 4-inch plowing. For the conditions of this investigation, therefore, the results fail to substantiate the common belief that deep plowing is markedly better than shallow plowing in erosion control.

7. Expressing these erosion losses in terms of the years required to remove the surface seven inches, or the so-called "plow soil", they would represent only about 24 years for the cultivated fallow land, 50 years for continuous corn, 100 years for continuous wheat, 368 years for the rotation and a little over 3000 years for the continuous bluegrass.

8. During the six months of the corn production season, April to September, the erosion loss from continuous corn averaged 4.7 times that from corn grown in the rotation of corn, wheat and clover. Similarly the runoff from the continuous corn was 2.5 times that from the rotated corn.

9. The number of units of runoff water necessary to remove one unit of soil varied from 34 for cultivated fallow to 1666 for continuous sod. In general the units of runoff necessary to remove a unit of soil from the cultivated land was much less than from the cropped land.

10. A 4-year experiment with soybeans in rows 3½ feet apart, running with the slope and an experiment of similar length with soybeans drilled 8 inches apart (all beans followed by a rye cover), showed that the runoff from the beans in rows was 84 per cent and that from the drilled beans, 74 per cent of the runoff from continuous corn during the same years. Similarly the erosion from the beans in rows was 94 per cent and from the drilled beans 43 per cent of that from continuous corn.

11. The annual losses of plant nutrients in the eroded soil from continuous corn or wheat, as determined during a 2-year period, were shown to be as great or greater than those through the crop grown, but under a good cropping system or grass these erosion losses were in most cases reduced to amounts much less than those through crops.

12. Mechanical analyses of the eroded material from the different plots showed that the uncropped plots and the one in corn, lost more sand than the others due evidently to the greater velocity of the runoff water on the bare soil surface.

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