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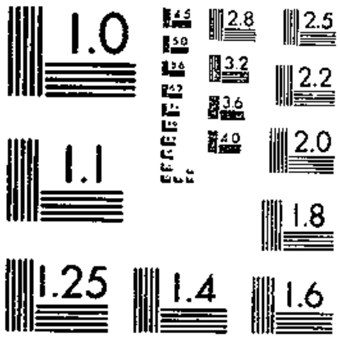

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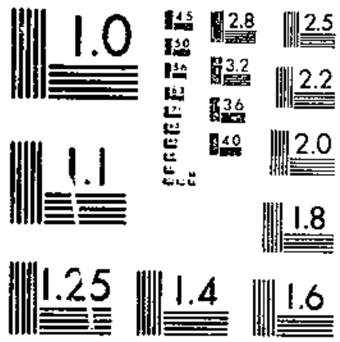

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WASHINGTON, D. C.

Investigation in Erosion Control and the Reclamation of Eroded Land at the Missouri Valley Loess Conservation Experiment Station, Clarinda, Iowa, 1931–42[1]

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The United States Department of Agriculture, Soil Conservation Service, in cooperation with the Iowa Agricultural Experiment Station

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[1] Submitted for publication December 1946.
[2] See acknowledgment of cooperation, bottom of opposite page.

SUMMARY AND LAND USE RECOMMENDATIONS

The loessial soils of the Missouri River Valley were broken out of the original prairie vegetation from 60 to 80 years ago. In this relatively short period of time as much as 50 percent of the original fertile topsoil has been lost by sheet erosion. Sheet erosion has done the most damage to farm land; but gully erosion, particularly in the steeper area adjacent to the bluffs, ranks a close second. Gully development in these soils is almost phenomenal. Gullies cut back several hundred feet a year in places and make it necessary to relocate roads, bridges, fences, and farm buildings. The large gullies are most spectacular because of size and difficulty of control; but the small gullies and depressions that are developing in practically every cultivated field cause far greater loss of soil productivity.

The investigations at the Clarinda Soil Conservation Experiment Station were designed to determine the factors affecting runoff and erosion and to develop methods of control. Four primary factors influence erosion: (1) Rainfall—amount, intensity, and distribution; (2) slope—length and degree; (3) vegetation—type and amount; (4) soil. There are also many secondary factors which directly or indirectly affect soil erosion. Among these are the 1-year tenancy system, the large proportion of mortgaged land, and large capital investment.

Runoff and erosion increase with intensity of rainfall, if the amount of rainfall is constant and sufficient to cause runoff. Likewise with intensity of rainfall constant, soil erosion increases as the amount of rainfall increases. Given a definite amount and intensity of rainfall, runoff and erosion vary widely depending upon the distribution of the rainfall in relation to factors such as the type and amount of vegetation, moisture content of the soil, the type of soil and numerous other interrelated factors which influence the infiltration rate and susceptibility of the soil to erosion.

Long slopes are more of an erosion hazard than short slopes. On a Marshall silt loam soil with a 9-percent slope, doubling the length of slope increased soil losses by 2.6 and runoff by 1.8. Although the percentage of total rainfall lost as runoff decreased with length of slope, the total volume of water flowing over the lower part of the slope materially increased. This explains the increased erosion with increased length of slope. Specific data were not obtained on the Marshall soil to show the relationship of steepness of slope to runoff and erosion. However, data obtained by other investigators show that on the average soil losses increase as the .6 power of the percent slope with type and amount of vegetation, amount and intensity of rainfall, and other factors influencing the absolute values.

The type and amount of vegetation is probably the most important single factor influencing runoff and erosion. Soil losses were negligible and runoff was materially reduced with good pasture sods and meadow crops, regardless of length or steepness of slope. These include bluegrass, red clover, alfalfa, and bromegrass. Small grains are much more of an erosion hazard, particularly during April and May, than sod crops but cause about one-half as much erosion as corn grown in a rotation with oats and clover. Soil loss from continuous corn is twice as much as from corn grown in a corn-oats-clover rotation. About 3.5 years are required to lose an inch of topsoil under continuous corn. Under continuous corn, erosion was 1.4 times as fast from eroded soil as from normal soil. Soil and water losses are seasonal and are related to the amount and intensity of rainfall and the amount of protection which the vegetation affords at different seasons of the year.

A continuous corn cropping system decreased the original carbon content of the soil 16 percent; whereas a rotation of corn, oats, and clover maintains the carbon content at the original level. In the investigations recorded in this publication continuous bluegrass or alfalfa did not increase the carbon content above the original level. It was, however, equally as effective as the rotation in maintaining the carbon content.

As an 11-year average, continuous corn on desurfaced soil yielded 6.6 bushels per acre; continuous corn on normal soil 28.5; and corn in a corn-oats-clover rotation 42.9 bushels per acre. The effect of rotation on corn yields became more evident with time and with favorable weather conditions. In fact, corn in rotation outyielded continuous corn by 36.2 bushels per acre during the period 1940–42. The average annual yield of hay for the period 1933–42 from continuous alfalfa and red clover was 3.3 and 1.5 tons per acre, respectively.

The annual application of 8 and 16 tons per acre of barnyard manure or a leguminous green manure materially reduced soil and water losses and increased yields of corn. The second 8-ton increment was somewhat less effective in reducing the loss of soil and water than the first 8 tons.

Soils of the Missouri Valley region in general are deeper and more permeable through the entire profile than soils in other regions, provided the surface does not crust and seal over. Marshall and closely related soils contain amounts of organic and inorganic material which over a period of time have been conducive to the development of a favorable structural condition that is resistant to damage resulting from tillage practices and the beating action of raindrops. On the other hand many of the other soils in the region are high in silt and low in clay and organic matter. This condition is not conducive to stable structure formation and, together with steeper slopes, intensifies the erosion problem. These other soils also have a lower water-holding capacity. For this reason the cropping systems and management practices are necessarily somewhat different from those on the heavier Marshall soil. The deep loessial soils in the Missouri Valley region have a high potential fertility. The surface soil as well as the subsoil responds rapidly to good soil management practices. This fact has made possible the exploitation of soils in this region at a rate far exceeding that in regions where the subsoil responds slowly to management practices.

The cropping system common to the Missouri Valley region is one which includes corn on the land from one-half to three-fourths of the time. This is particularly conducive to erosion during the months of May and June when most of the rains of high intensity occur. The length of slope and steepness of slope are also factors that have contributed to the excessive loss of soil from the intertilled acreages. In recent years the value of a good cropping system that includes legumes regularly in the rotation has been recognized. More and more farmers are following this practice. However, with the present rotations it has not been possible to reduce the loss of soil to the point where productivity can be maintained over a period of time. It therefore will be necessary to revise the present rotations to include more close-growing crops or to adopt other conservation practices. Some of the measures which have been found particularly effective in reducing loss of soil and water are contouring, strip cropping, and terracing.

In the Missouri Valley region the lister is commonly used for planting corn. The furrow thrown up by the lister is particularly effective in reducing loss of soil and water if the rows are on the contour. Listing of corn on the contour reduced soil and water losses to 20 percent of those from uphill and downhill listing. Contour surface planting of corn reduced soil and water losses by about 50 percent. Contouring also increased yields of corn by about 10 percent. Saving of soil and water on the contoured area by listing also saved the young corn plants that usually wash out when the rows run uphill and downhill.

On slopes up to 10 percent that are not too irregular or over about 200 feet long, listing on the contour will give adequate control provided a good cropping system is adopted, a good job of contouring is done, and the depressions and waterways are allowed to remain in permanent vegetation. Most of the slopes range from 300 to 600 feet in length and under these conditions contouring alone is not sufficient to control erosion.

The relationship between land slope and the capacity of surface-impounding treatments is shown. As the land slope is increased, impounding is decreased so rapidly that a terrace which will impound 2.5 inches on level land will impound less than one-fourth as much on a 15-percent slope. This is an important consideration in connection with the design of control measures for different land slopes. The configuration of the surface for different tillage and conservation practices determines the capacity to impound water. The infiltration rate of the soil materially affects and influences the need for and the type of control measure recommended.

Strip cropping is another very effective measure for conserving soil and water and has been tried in limited areas, but was not found satisfactory in many years due to the excessive damage that occurs from hot winds during the summer and also from damage by grasshoppers and chinch bugs.

Terracing, although more difficult to establish than contouring or strip cropping, was found to give nearly complete control from losses of soil and water on Marshall soils. Under these conditions it is necessary to determine the type of rotation needed in order to produce the maximum yields over a considerable period.

Level terraces operate satisfactorily where located on Marshall and other permeable soils. Level terraces are easier to build to grade than terraces with a graded channel and do not require a terrace outlet. The latter, however, is a distinct advantage in removing the excess water that accumulates on the less steep ridge tops above a steeper and more irregular topography which in many cases makes it difficult if not impossible to establish a satisfactory terrace outlet. On the lower parts of slopes and other locations, where the impermeable soils such as the Shelby occur, level terraces have not been found practical. On such

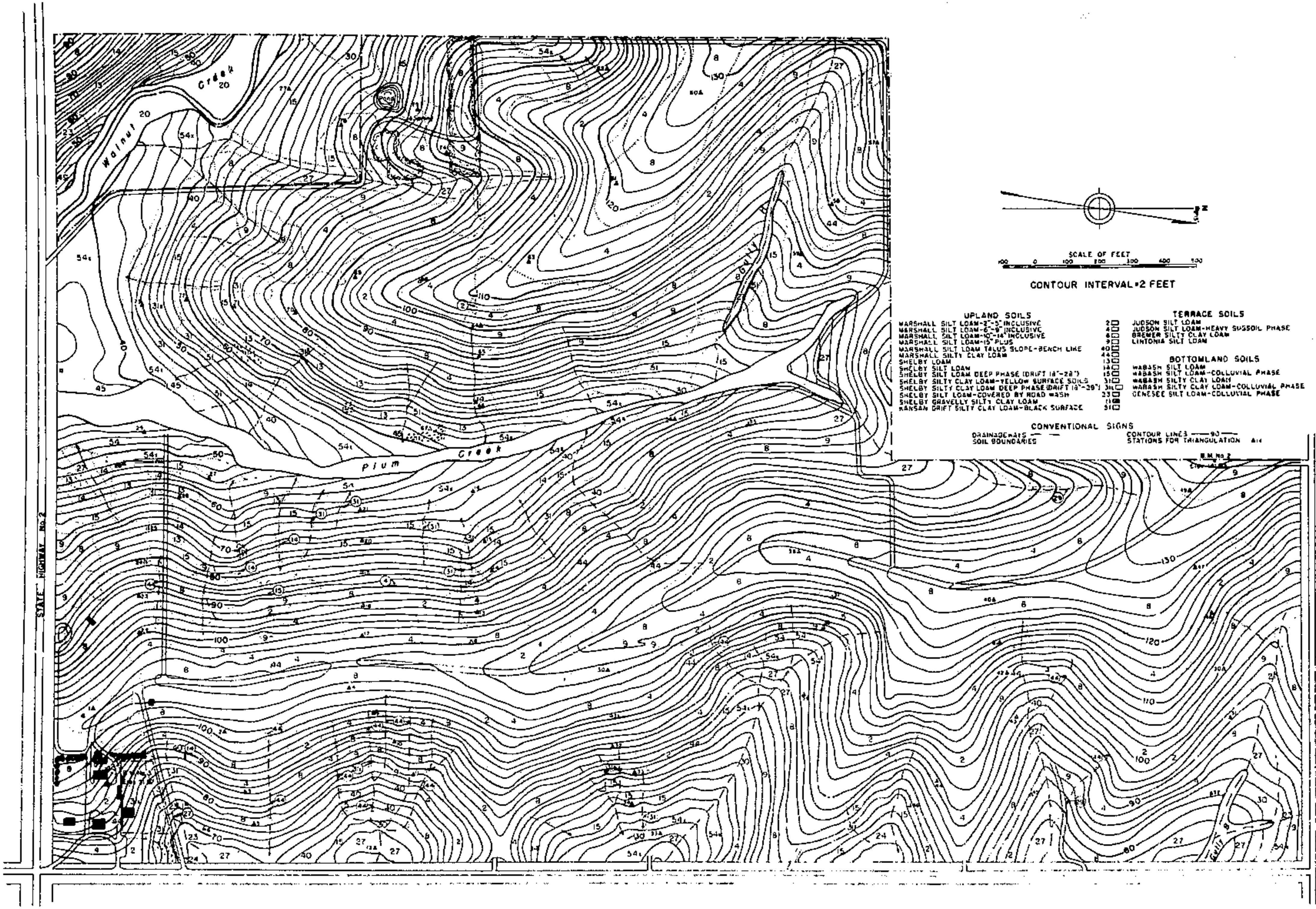

FIGURE 1. Map of the Soil Conservation Experiment Station, Missouri Valley loess region; soils and topography.

soils crops drown out in the terrace channel during unusually wet seasons.

Despite the lack of consistent data, it appears that the wider the terrace spacing the greater will be the soil and water losses. However, for the 4-, 5-, and 6-foot vertical interval study soil and water losses were very small in all cases, averaging less than 1 ton per acre annual soil loss and 3 percent of the total precipitation as runoff.

The moisture content was 4.6 percent greater under the channel of two level terraces than under the ridges, and 2.7 percent greater than under the middles. The middles held 1.9 percent more moisture than the ridges. Similar results were obtained for graded terraces. Under the conditions of these experiments there was little or no evidence that water held in the channel of level terraces moved enough laterally to affect the moisture content of the profile samples taken on the terrace ridge, a distance of approximately 10 feet from where the samples were taken in the terrace channel.

Factors responsible for the high acreage planted to corn in the Missouri Valley region have been: Failure to appreciate the value of grasses and legumes as feed for livestock; the high valuation of the land; and the development of large-type machinery. A better understanding of the value and uses of grasses and legumes is needed to convert many of the steep rolling areas now cropped to intertilled crops into permanent vegetation or longer rotations.

The importance of including a legume and grasses in the rotation to maintain the organic-matter content and the structure of the soil and thus cause it to take up water more rapidly are also points that need further consideration. It is recognized that conservation cannot be accomplished by any set rule for all farms. Each farm is a problem in itself. Under certain conditions one or more conservation measures may give the answer to the problem. Under another set of conditions all known conservation practices may be needed if soil losses are to be reduced to an allowable minimum and the productivity of the soil is to be maintained over a period of time.

INTRODUCTION

The results of 5 years of investigations at the Clarinda, Iowa, Soil Conservation Experiment Station were summarized in Technical Bulletin 558 of the United States Department of Agriculture. This publication summarizes the results of experimentation for the 12-year period 1931–42.

This station, located 10 miles west of Clarinda, Iowa, on State Route No. 2, (fig. 1), is 1 of the 10 original places where experimental work was established under authority of the Buchanan amendment to the agricultural appropriations bill for the fiscal year 1930 (*41*).[3] The research work in soil conservation is conducted in cooperation with the State agricultural experiment stations. Investigations on the Marshall silt loam soils in the Missouri Valley loessial region were designed to study (1) the factors affecting losses of soil and water and (2) the development of practical methods of controlling these losses. This in-

[3] Italic numbers in parentheses refer to literature cited, p. 72.

cludes experiments relating to the amount, distribution, and frequency of rainfall; different types of vegetation; soil treatments; tillage practices; cropping systems; length and steepness of slope; contouring, strip cropping, and terracing; and check dams.

Since the earlier publication gave a comprehensive discussion of the problems involved and the details of experimental design and procedure, only brief summaries of these conditions will be given here.

PROBLEM AREA

Distribution of Loessial Soils in the Missouri Valley and Associated Areas

The Clarinda Soil Conservation Experiment Station was selected to represent the soils of the Missouri Valley loessial region. These soils comprise some of the most fertile soils of the United States; their principal areas are shown in figure 2. They border the Missouri River Valley and occupy parts of the States of Missouri, Kansas, Iowa, Nebraska, Illinois, Minnesota, and South Dakota. This area coincides with the more intensive portion of the Corn Belt.

It is recognized that the results from this station apply specifically to the Marshall silt loam and closely related soils which represent only

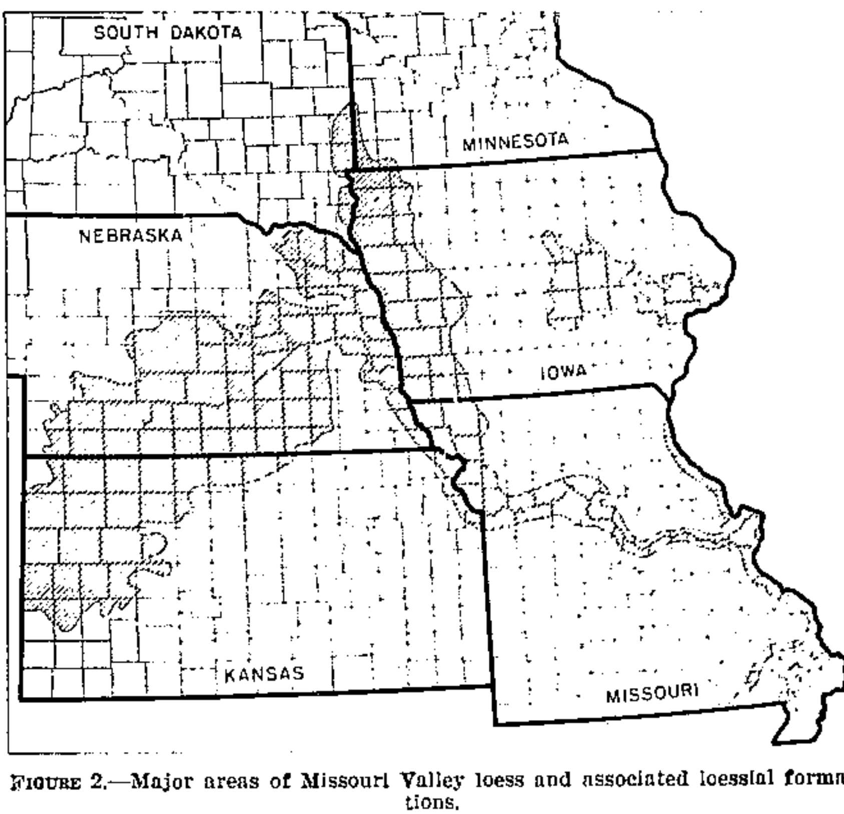

Figure 2.—Major areas of Missouri Valley loess and associated loessial formations.

a part of the area as shown on the map. However, by applying general principles developed on factors affecting soil and water losses on the Marshall soils, and a knowledge of the specific physical and chemical characteristics of the other loessial soils in the region it is possible to use the data obtained on the Marshall soils as a guide in solving problems that arise in connection with other soils. Further investigations are needed to answer specific problems on other soils in the region.

Loessial soils in Iowa.—The loessial soils of Iowa are generally divided into three important groups, the Missouri loess, the Mississippi loess, and the southern Iowa loess. The Missouri loess may be further subdivided into the lighter colored, more rolling bluff lands, and the darker colored prairie lands. The light-colored bluff lands are extremely permeable, very deep, and readily absorb water. However, because of the steep topography and certain physical properties, such as a high degree of dispersion, they are highly erodible and especially susceptible to erosion when exposed to the elements through tillage.

The dark-colored prairie soils of the Missouri Valley loess are represented principally by the Marshall series. These soils are deeper on the western margin where they approach the bluffs and become increasingly more shallow to the eastward as they finally fade out by merging with the drift of the central portion of the State. In the eastern part of the State the Mississippi loess is represented primarily by the Tama series. This soil does not differ greatly from the Marshall series except that it is almost devoid of lime, whereas the Marshall generally has an appreciable lime content. The Tama series may in certain instances be somewhat heavier in texture than the Marshall and somewhat less absorptive of water. In general, however, the erosion problems on the Mississippi loess are not outstandingly different from those on the Missouri loess.

The southern part of the State, generally described as southern Iowa loess, contains at the present time perhaps 50 percent of its area as exposed drift. This area with its heavier subsoil and very low rate of water intake is characterized by excessive erosion and widespread gullying. The erosion problems of this area are being studied more fully at the Soil Conservation Experiment Station near Bethany, Mo.

Loessial soils in Nebraska.—The loessial soils in Nebraska are the soil cover of loess hills and loess plains. The soils of the loess-hill area adjacent to the Missouri River are not greatly different in chemical and physical properties from those on the eastern side of the same river in Iowa. However, the loessial soils of Nebraska, particularly in the western part, frequently are characterized by a zone of lime accretion, and in this respect differ from the soils of southern Iowa, which do not ordinarily show excess carbonates.

Stewart and Gross (*39, p. 14*) state:

The soil of the western portion of the loess-hill area and that bordering the sand hills contains a higher percent of sand than the soil of the eastern part. In the west, the soil is also lighter in color in both the surface and subsoil. That portion of the loess hills south of the Republican River is steep and rolling. Canyon lands bordered by level irregular tablelands make up much of the area of southwest Nebraska and this region might be classified as loess plains and canyon lands.

The Loess Plains stretching in triangular shape from Seward County west into Gosper County is an extensive level area. The *soil-forming material* of this area is thought to be of the same origin as that of the loess hills. The soil is very fertile. Due to the level topography, erosion is not usually a problem and large farm machinery can be used to advantage. In parts of the loess plains a "clay pan" has been developed by the percolation of water carrying small soil particles into the subsoil where they have lodged making a tough "clayey" layer which prevents rapid penetration of water into the subsoil. Small grains, because of the fact that they ripen earlier, do relatively better than corn on such "clay pan" soils.

The western margin of the loess area borders upon the sand hills and in this respect is distinctly different from the eastern margin within the State of Iowa, as well as southeastern Nebraska. In the latter areas the loessial soils border on glacial drift of heavy texture.

The erosion problem along the margins of the region where it borders upon or overlies these heavy soil formations is quite different from that where it borders upon or overlies the sandy material in western Nebraska. With the permeable subsoil conditions on the westerly margin there is ready downward movement of water, and the erosion problem along the margins does not differ appreciably from that within the loessial area proper. On the eastern boundaries, however, because of the heavy subsoil, the erosion problem becomes increasingly difficult from the heart of the loessial area to the margins and finally into the area of glacial drift.

Loessial soils in Missouri.—The distribution of the brown loess (bluff lands) and the dark loess (prairie lands) in Missouri is portrayed by Krusekopf (*15*). Within the confines of Missouri the loess forms an almost unbroken belt of upland soils along the Missouri and Mississippi Rivers. The dark-colored soils, however, are located principally in the belt along the Missouri River extending from the northwestern corner of the State to Boone County in the central portion of the State. Krusekopf estimates the total area of the brown loess in Missouri at approximately 1,500,000 acres, and states that it occurs in 41 of the 114 counties of the State. He states further (*15, p. 7*): "It is probable that no other State in the Union contains so large an area or has them so widely distributed."

The area of the dark soils can be estimated from the fact that they are of appreciable extent in 18 counties in the northwestern portion of the State.

The brown loess in its steeper slopes and general rough topography is particularly susceptible to erosion. To some extent these adverse conditions have been mitigated by the high permeability of this soil. However, when the surface is exposed through cultivation, as is rather common in connection with the extension of the corn-growing region into bluff area, large quantities of soil are lost during intensive rains. The dark-colored soils, of which the Marshall silt loam is the principal type, present approximately the same erosion problems as those found in the same belt to the northward within the confines of Iowa. For the most part this soil grades off to the eastward into the heavy types of the glacial drift, and in these margins the infiltration of water is greatly reduced by reason of the heavier subsoil. Consequently, gullies are more pronounced and sheet erosion is more active on this eastward margin.

The loessial soils in the eastern part of the State are represented largely by the Memphis series and in some smaller areas by the Clinton series. The Memphis in general is a lighter colored soil than the Marshall, but having been developed under higher rainfall conditions is more highly weathered and is characterized by a subsoil of a brown to yellow-brown, fairly heavy silty clay. It is not compact but is less granular than the corresponding horizon in the Knox or in the Marshall series. The Memphis soils which extend farther south into Mississippi are particularly erodible. Large gullies are formed which are characterized as the "pinnacle" type by reason of the prominent pinnacles of subsoil protruding from the margins and bottoms of deep canyonlike drainageways.

As a whole, therefore, the erosion problem on these types is a serious one. This is particularly true in the light of Krusekopf's statement (*15, p. 54*):

> The loess soils represent the most valuable single soil resource of Missouri. They cover approximately one-eighth the area of the State, but in their relation to the agriculture of the State they occupy first place.

Loessial soils in Kansas.—The distribution of the various soil groups in Kansas including loess is shown by Throckmorton (*40*). The soils of the bluffs adjacent to the Missouri River Valley are described as typically deep and have an open subsoil which permits deep penetration of water and roots. The fertility is high except in those areas where erosion is active. The topography varies from rolling to distinctly hilly. These soils are extremely subject to erosion. In some areas as much as 18 inches of the soil has been removed by the action of water since the land was placed under cultivation.

The northern wind deposits (northwestern Kansas) are grouped and described by Throckmorton separately (*40, pp. 97-99*):

> Except in the vicinity of streams these soils are level to rolling * * *. They are relatively young, do not have a clay-pan development, and have subsoils which are sufficiently open to a great depth. These soils are high in plant food materials * * *. There are many areas within this region adjacent to the streams where the wind-laid soils have been eroded away * * *. These wind-deposited soils are subject to erosion by both wind and water and, therefore, must be handled with considerable care. There are many fairly large areas of these soils in the north-central part of the State that have been severely injured by water erosion.

TYPE OF EROSION

Although sheet erosion has caused the greatest damage to farm values and to the agriculture of the region as a whole, gullies are also common and are a serious problem in some sections of the region. In cultivated fields the practice has been to plow in the small gullies at the time the seedbed is prepared for intertilled crops. This is conducive to even greater soil losses and more rapid gully formation than if the gully had been undisturbed. The loose soil that was plowed in is readily washed out by the concentration of runoff water in the depressed area during the next heavy rain. In numerous fields where this practice has been followed gullies have developed to the point where they cannot be crossed with farm machinery (fig. 3). Because of this practice a single field soon becomes two or more fields and as such is no longer an economical unit to farm. The field then is either abandoned or used for pasture. This, however, does not solve the problem because a gully once started continues to grow. Eventually it develops to the place where it becomes a major control problem. Some conservation-minded farmers leave grass strips in

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the depressed areas (fig. 4), to prevent further cutting. Small gullies are also being sloped and seeded. Earth and concrete structure has been used in some cases on the larger gullies, but excessive cost has limited its use by the individual farmer. In the steeper bluff areas of the region gullies several miles long with depth and width of 200 feet or more are not uncommon. These gullies develop rapidly, extending as much as 100 feet or more in a single year. Replacement and relocation of bridges and roads in these areas is frequent with costs in excess of those required for normal maintenance. Not only is the damage excessive due to cutting of the gullies, but there may be even greater damage to the drainage ditches and bottom land from the soil that washes down from the gullies and upland.

In general, erosion within the Missouri Valley loess region has progressed to such an extent that more than 50 percent of the original covering of surface soil, known as the A horizon, has been removed (*42*). Loss of topsoil on the loessial soil of this region is not as serious as on soils in other regions where the subsoil is unproductive and responds more slowly to good soil management. Even with subsoils that are responsive to good management, erosion has taken its toll of organic matter and other nutritive materials, crop yields have declined, drainage ditches have been clogged, moisture relationship has been disturbed, and value of farm land has declined. Considerable progress has been made by State and Federal agencies in getting good soil management practices adopted. Much work remains to be done, however, before the best land use for different soils of the region is known and before these practices are adopted on individual farms.

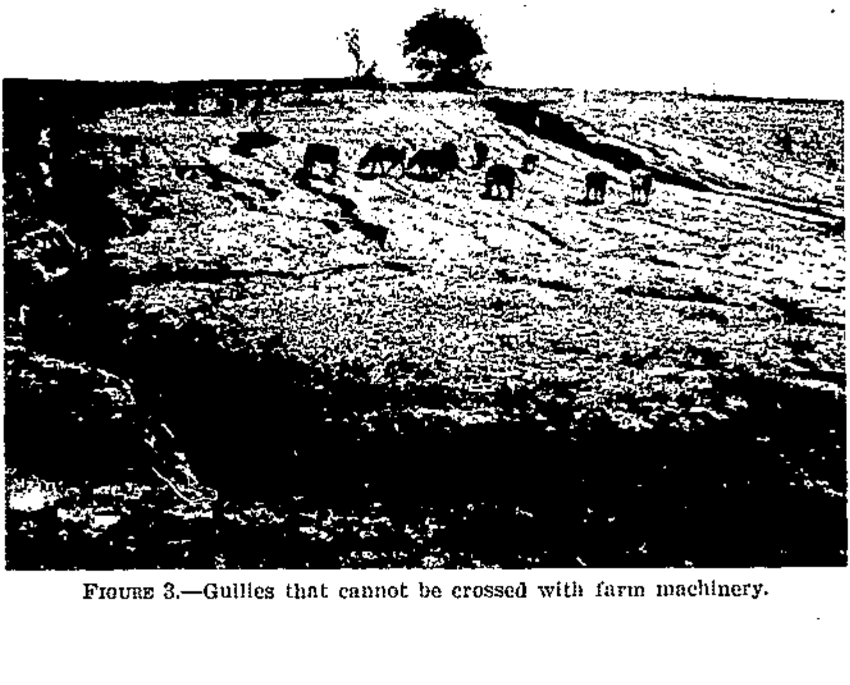

FIGURE 3.—Gullies that cannot be crossed with farm machinery.

FIGURE 4.—Grassed strips left in depressed areas prevent further cutting.

SOME FACTORS AFFECTING EROSION

A large number of interrelated factors affect the degree and extent of erosion that occurs in any region. Chief among these are:

1. Rainfall—amount, intensity, and distribution
2. Slope—length and steepness
3. Vegetation—amount and kind
4. Soil—type and condition

There are other factors such as the large proportion of mortgaged land in the region, 1-year tenancy systems, and heavy capital investments which necessitate intensive tillage in order to cover the carrying charges. These problems directly or indirectly influence the farming system of the region. They also have influenced the degree and extent of erosion.

A knowledge of the importance of each of these factors when considered alone, or in combination with each other, is necessary for developing wise land use recommendations that have as their ultimate aim the maintenance of a permanent agriculture.

DESCRIPTION OF THE PROJECT

HISTORY

Public interest in soil erosion and water conservation in 1930 led to an appropriation for the investigation of soil erosion and water conservation. A committee of three members of the Department of Agriculture and two members from the State experiment stations was appointed by the Department's director of scientific work to formulate plans and recommendations for the work.

Among other recommendations of this committee was that field and laboratory studies of various methods of controlling soil erosion and conserving soil moisture be developed. The project in the Missouri Valley loessial region discussed in this publication was the eighth field project established under the provisions of the act.

The Division of Agricultural Engineering in the Bureau of Public Roads, and the Bureau of Chemistry and Soils were given immediate responsibility for the inauguration of the work. Through the cooperation of the Iowa Agricultural Experiment Station, which leased the farm at Clarinda, and through the further cooperation of the chambers of commerce of Clarinda and Shenandoah and the Page County Farm Bureau, which assumed the responsibility for the payment of the taxes on the farm, the site was made available in March 1931.

Description of the Farm

The farm, consisting of 200 acres, is situated about midway between the towns of Shenandoah and Clarinda, on State Highway No. 2, in Page County, Iowa. It was selected for experimental work because it is representative of the Marshall silt loam and associated loessial soils of rolling topography in the Missouri River Valley. At the time of its assignment for erosion investigations, it had been under the plow for not more than 75 years. The farm was tenant-operated and had been misused to a considerable extent. As a result, it was in a rundown condition. Crop history indicates that during the 10 years preceding establishment of the farm, corn was grown approximately 75 percent of the time. There was no sign of practices that would have been helpful in reducing soil and water losses. As a result, relatively large areas had lost half or more than half of the original topsoil by sheet erosion. Serious gully erosion had occurred in some fields. In some places all of the loessial material had been washed away, exposing the underlying glacial till (Shelby series). Besides the smaller gullies, which were brought under control by blading in, terracing, and contour farming, there were two gullies that were so large that special control measures were required. These gullies are referred to as Plumb and Walnut Creek (fig. 1). Walnut Creek drains a 294-acre watershed, 34 acres of which lie within the farm boundary. The banks of this intermittent stream were fairly well stabilized by grasses and trees. The gully was fenced to prevent livestock from trampling the banks and caving them in; additional plantings of trees, shrubs, and brambles were made and the area maintained as a wildlife refuge. Plum Creek drains a 125-acre watershed, of which 89 are within the farm boundaries. The bed of this intermittent stream was not stabilized. A plan for the control and reclamation of this gully was, therefore, carried out and will be discussed in more detail subsequently.

Principal Objectives

The primary purpose of the Missouri Valley soil-erosion project discussed in this publication is to study the factors affecting soil and water conservation and methods of control. It is desired to learn the methods that may be used for retarding the losses of soil and water, and particularly the practicable methods of retarding the movement of soil-carrying water. It is also desired to learn what methods may be used to renew the fertility of eroded lands so that they may be returned to a profitable type of agriculture.

Fundamental to these major purposes are the data being acquired relating to the effects of erosion and water losses upon crop yields; the type of agriculture most suited to the problem area, and that will at the same time have a mitigating effect upon soil and water losses; the cost of control measures for retarding soil and water losses in relation to the monetary damage caused by such losses; and the general practicability of wide application of various specific conservation measures to the soils of the Missouri Valley loess problem area.

Precipitation

Average annual precipitation at the experiment station for the 11-year period 1932–42 was 28.33 inches (table 1). This was 2.31 inches below the 1932–42 average at the town of Clarinda, 10 miles east of the station. The 1932–42 average for the farm was 5.39 inches below the 71-year average recorded by the U. S. Weather Bureau at Clarinda.

Annual precipitation at the station by years for the 10-year period, 1932–42, is shown in figure 5. A comparison of the actual rainfall with the normal rainfall is shown in table 1. It is to be seen that in 1934 and 1936 rainfall was considerably below normal, whereas, 1941 with a total of 44.6 inches was 16.2 inches above the 11-year average.

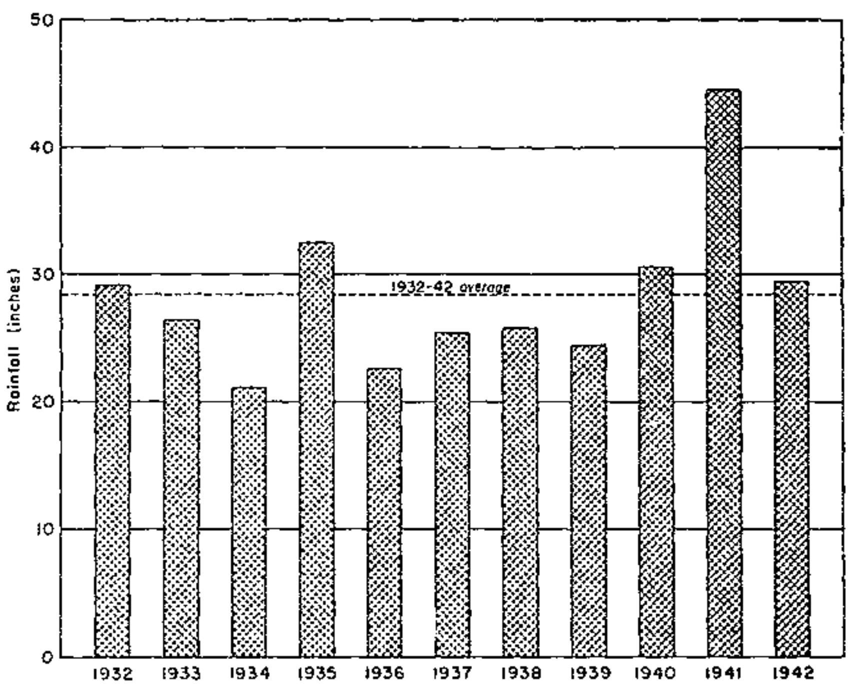

Figure 5.—Annual precipitation, Soil Conservation Experiment Station, Clarinda, Iowa, 1932–42.

TABLE 1.—*Monthly rainfall at the station, 1932–42, and normal monthly rainfall at Clarinda, Iowa*[1]

Month	Year											Average 1932–42	Clarinda, average (71 years)
	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942		
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Jan.	1.13	0.32	0.51	0.84	1.72	1.81	0.16	0.57	0.61	1.21	0.21	0.83	0.87
Feb.	.72	.08	.26	.54	.22	.23	.54	.79	.78	.50	1.25	.54	1.18
Mar.	.44	3.96	.11	.26	.19	1.57	.87	2.61	1.70	.76	2.27	1.26	1.62
Apr.	2.33	.91	.72	.01	1.48	3.42	3.03	1.68	3.90	3.58	.84	2.05	2.86
May	3.42	3.05	2.55	7.88	4.36	4.59	5.40	1.24	1.30	3.13	5.76	3.88	4.16
June	5.26	4.11	2.37	7.06	2.48	3.12	2.05	8.70	2.92	9.81	5.78	4.88	4.76
July	2.32	2.27	1.23	1.41	.82	6.01	1.87	4.01	7.27	.19	1.32	2.61	4.16
Aug.	8.10	5.99	2.14	2.79	1.07	1.84	5.97	1.03	6.55	1.61	3.31	3.81	3.86
Sept.	1.00	4.21	4.82	5.14	6.01	.83	3.08	.39	.86	10.43	5.51	3.93	4.60
Oct.	1.20	.87	2.84	3.03	1.14	1.30	.26	1.28	1.46	10.73	1.43	2.32	2.85
Nov.	1.14	.42	3.54	2.50	.34	.50	2.30	.37	2.30	.59	.52	1.32	1.73
Dec.	1.08	1.08	.13	.29	1.50	.32	.38	.58	1.16	2.01	1.34	.90	1.07
Annual	29.04	26.37	21.22	32.35	22.02	25.60	25.91	24.15	30.81	44.55	29.54	28.31	33.72

[1] 71-year average, U. S. Weather Bureau, 10 miles from station.

TABLE 2.—*Intensity of rainfall, 1932–42*[1]

Intensity class (inches per hour)	1932		1933		1934		1935		1936		1937	
	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total
	Inches	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*
Over 2.00	2.47	10.27	1.52	6.34	2.07	12.06	2.11	7.88	1.53	9.62	4.54	24.63
Over 1.75	4.95	20.57	2.98	12.43	3.36	19.57	3.09	11.54	2.45	15.41	5.55	30.11
Over 1.50	7.82	32.50	3.62	15.10	3.75	21.84	3.53	13.19	2.89	18.18	6.38	34.62
Over 1.25	9.68	40.23	4.32	18.02	4.50	26.21	4.91	18.34	3.31	20.82	7.22	39.18
Over 1.00	11.30	46.97	6.48	27.03	5.65	32.91	6.15	22.97	5.09	32.01	8.20	44.49
Over .75	12.14	50.46	10.33	43.10	6.83	39.78	7.85	29.33	5.40	33.96	9.47	51.38
Over .50	13.17	54.74	12.02	50.15	8.44	49.16	10.21	38.14	7.10	44.65	11.12	60.34
Over .25	16.36	68.00	15.23	63.54	10.08	58.71	14.15	52.86	9.55	60.06	12.19	66.14
Over .00	24.06	100.00	23.97	100.00	17.17	100.00	26.77	100.00	15.90	100.00	18.43	100.00

Intensity class (inches per hour)	1938		1939		1940		1941		1942		Total	
	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percent of total	Hourly rainfall	Percentage
	Inches	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*
Over 2.00	2.34	11.74	3.26	17.78	6.83	28.27	8.90	26.34	4.40	20.17	45.17	19.03
Over 1.75	2.87	14.39	3.74	20.39	7.75	32.08	11.29	33.42	5.58	25.58	56.60	23.84
Over 1.50	3.19	16.00	4.14	22.58	8.59	35.55	12.34	36.53	6.27	28.75	63.91	26.92
Over 1.25	3.74	18.76	5.32	29.01	9.33	38.62	13.94	41.26	7.06	32.37	74.23	31.27
Over 1.00	5.03	25.22	6.38	34.79	10.55	43.67	16.49	48.81	8.24	37.78	88.62	37.33
Over .75	6.31	31.64	7.12	38.83	11.28	46.69	18.43	54.55	9.48	43.47	101.30	42.67
Over .50	7.85	39.37	8.88	48.42	12.60	52.62	21.47	63.55	10.93	50.11	122.18	51.46
Over .25	11.17	56.02	12.05	65.71	14.81	61.30	26.41	78.17	14.37	65.89	155.19	65.37
Over .00	19.94	100.00	18.34	100.00	24.16	100.00	33.78	100.00	21.81	100.00	237.41	100.00

[1] Includes only rains of 0.20 inch and over.

Average monthly precipitation for the 11-year period is shown in figure 6. The highest average monthly precipitation occurred in May, June, August, and September, respectively.

The relative intensity of the rainfall for the various years is shown in figure 7 and table 2. The lowest average intensities were in 1934 and 1936; the highest average intensities in 1937, 1940, 1941, and 1942.

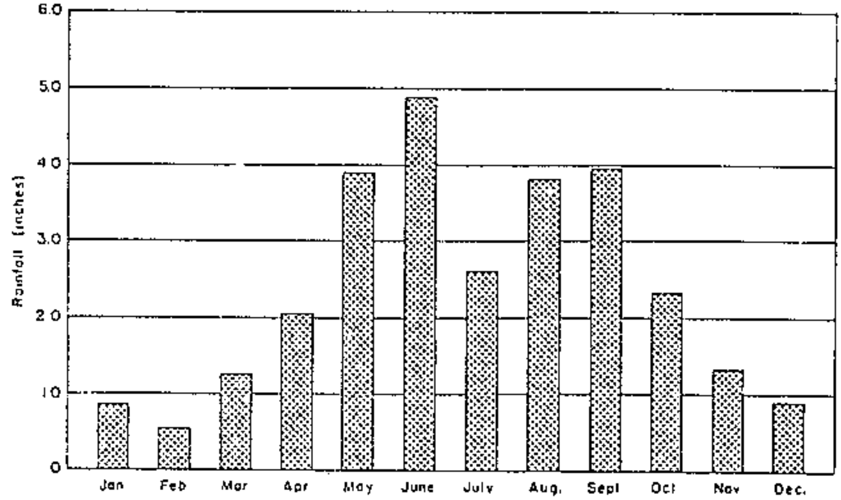

FIGURE 6.—Average monthly precipitation, Soil Conservation Experiment Station, Clarinda, Iowa, 1932–42.

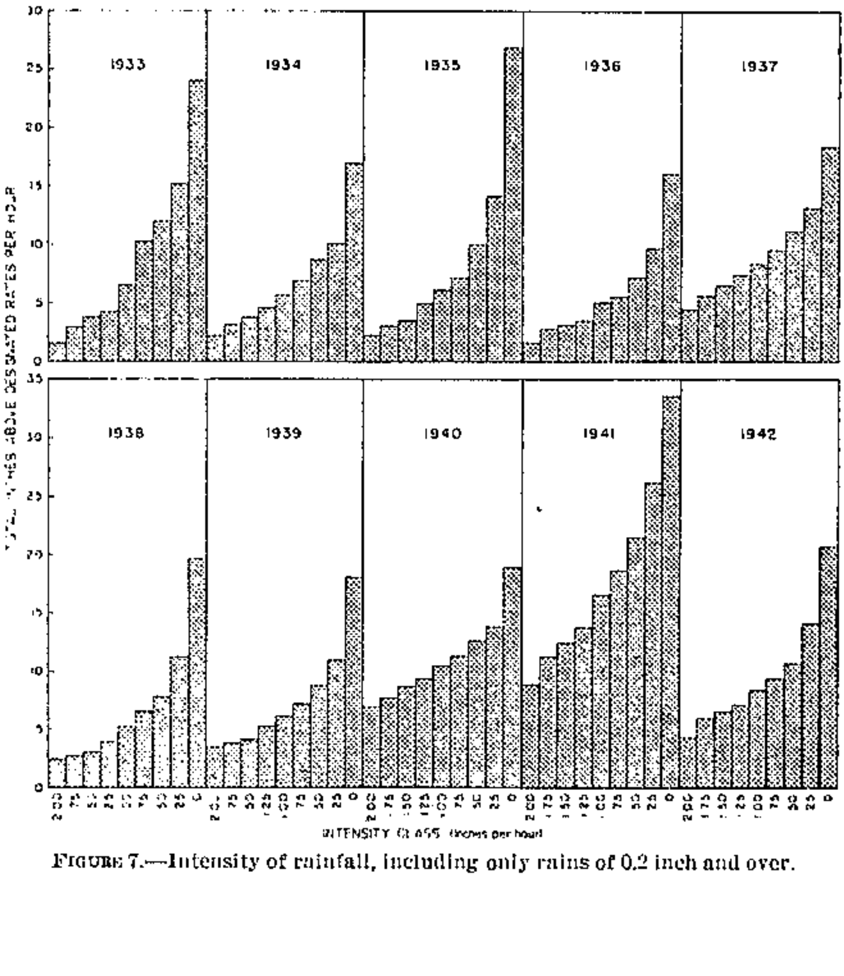

FIGURE 7.—Intensity of rainfall, including only rains of 0.2 inch and over.

Expected frequency of intense rainfall in Iowa.—The expected frequency of intense rainfall in Iowa has been shown by Mavis and Yarnell (*16*). From the available Weather Bureau records they have prepared the expected frequency curves presented in figure 8. Curves of this character are extremely valuable in planning erosion-control work and particularly in the design of erosion-control treatments.

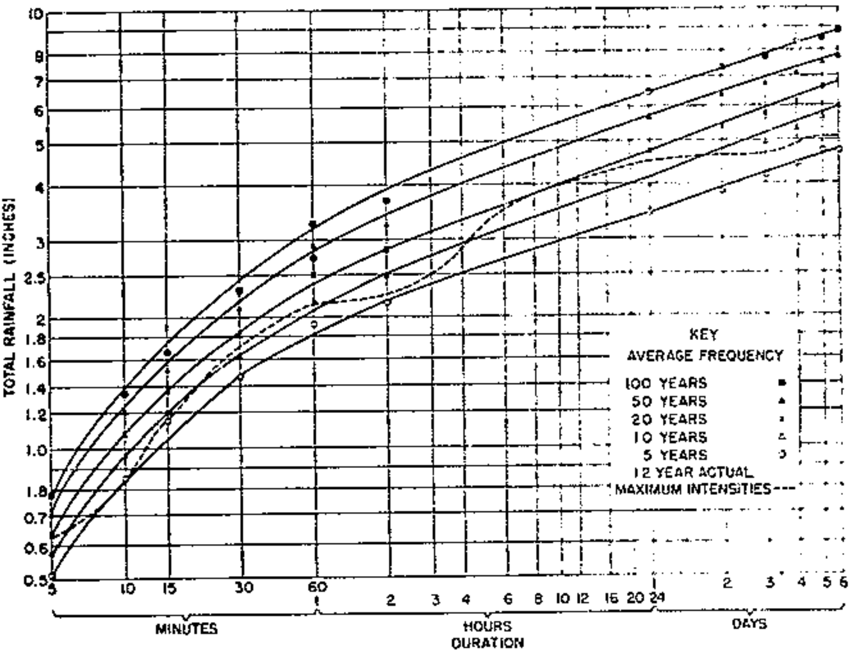

FIGURE 8.—Expected and actual frequency of intense rainfall in Iowa (records to Jan. 1, 1942). Adapted from chart presented by Mavis and Yarnell (*16*) and actual data of station.

Other climatological records.—For other climatological data the reader is referred to the records of the Weather Bureau and particularly of the Iowa section. In addition to the precipitation records there are thus available daily maximum and minimum temperature readings from eight stations within a 50-mile radius (three are within a 25-mile radius) of the station. At numbers of points within the State there are also records of barometric pressure, relative humidity, wind velocity and direction, evaporation, and percentage of sunshine. The important station, at Omaha, Nebr., is about 55 miles distant.

For the period covered by these experiments there is one outstanding climatological period that must be noted, namely, the unprecedented drought of 1934. In that year, days having temperatures of 100° F. or higher averaged 21 for the State, and totaled 36 for Page County. This was about twice the number heretofore recorded. The summer was the hottest of the 62 summers of record. Every station in the central, south central, southwest, and west central portions of Iowa established new all-time high-temperature records. Almost complete destruction of crops occurred. It will be seen that several abnormal records were obtained at the experiment station during this period and immediately following these excessive temperatures.

PURPOSE AND PLAN OF EXPERIMENTS

One of the primary purposes of the experiments at the Clarinda Station is to obtain measurements of not only the total amount but also of the intensities, durations, and frequencies of precipitation. It is desired to know the seasons of the year at which maximum rains occur; also the likelihood of their occurrence at one or another period.

Following the measurement of precipitation it is desired to determine the forms of relative loss of precipitation waters. A certain quantity of these waters is held on the canopy of the vegetative cover; another quantity is retained on the surface of the ground under certain conditions; additional quantities enter into the ground; and still other fractions are lost as surface runoff. Insofar as practicable it is desired to determine the amount of water vapor lost as evaporation from the soil and as transpiration from growing plants. The quantitative determination of these various amounts of water as they may be lost in one form or another is important. It is also important to determine the factors that affect the proportion of loss, for example, as runoff or percolate, or as soil evaporation or transpiration from the plant. It is also the purpose of the experiments to determine the factors that affect the density of runoff or the amount of soil carried by a given quantity of water. Such factors include crop cover, type and character of root development, soil, slope, and rainfall characteristics.

Each of these studies (cited above) must, of course, be pursued with reference to some specific condition, such as the soil type or the degree of slope, or the crop growing on the area, and its treatment. Each of these in turn must be studied in their relation to rains of recorded intensities, durations, and total amounts.

In addition to the factors cited above it is desired to determine the most satisfactory mechanical methods of controlling erosion.

In order to provide information on the methods and costs of constructing terraces, detailed time studies were made during the construction period and the efficiency of the operation was improved where possible.

For the entire period of the experiment observations have been made to determine and put into practice the best methods of gully and terrace-outlet control. In addition, the operation of farm machinery on terraced land has been studied with modification of either the machinery or the terraces in mind so that such operation could be carried out more satisfactorily.

An experiment of a more fundamental nature has been the measurement of the rate of soil movement down the slopes, designed to provide information on any retardation of the rate of such movement as a result of the construction of various types of terraces.

A large number of experiments have been started to determine the most advantageous combinations of terrace design features. These experiments included studies of vertical intervals between terraces,

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grade of terrace channels, and length of terraces. The findings indicate how a terrace may be laid out on the lands of the problem area in such a way that the least possible soil will be lost from the land while at the same time the surface water is led away rapidly enough to prevent damage to crops.

Five experiments have been instituted that deal primarily with factors other than the mechanical methods, such as terracing, of controlling erosion. These five experiments will be discussed first, followed by a discussion of the experiments primarily concerned with mechanical methods. Inasmuch as each of these experiments and the various treatments followed in them will be referred to frequently in succeeding pages it is desirable to describe each briefly at this point. Frequent reference to the map of field E in figure 9 will be necessary for a full understanding of these experiments. The arrangement of the various lysimeters is shown separately in figure 10.

Control plots, experiment 1.—The control plots known as experiment 1 are nine in number, seven of which are 1/100 acre in size, the other two being, respectively, 1/200 acre and 1/50 acre, representing the comparison of slope length. The average land slope is 9 percent. The measurement of soil and water losses from these plots is based upon the entire catchment of runoff and eroded material in concrete basins or tanks. These are of sufficient size to retain the greatest losses it is estimated will occur during the course of the experiment. The plots are located upon the most uniform soil and slope that the 200 acres of the station afford. The profile has been studied in detail in the laboratory of the Bureau of Chemistry and Soils and chemical and physical analyses have been reported elsewhere (*17, 18*).

The treatments of plots in this experiment are as follows:

Plot 1, continuous corn, slope length 36.3 feet, 1/200 acre.
Plot 2, continuous corn, slope length 145.2 feet, 1/50 acre.
Plot 3, continuous corn, slope length 72.6 feet, 1/100 acre.
Plot 4, rotation (corn, oats, and clover), slope length 72.6 feet, 1/100 acre.
Plot 5, rotation (corn, oats, and clover), slope length 72.6, 1/100 acre.
Plot 6, rotation (corn, oats, and clover), slope length 72.6 feet, 1/100 acre.
Plot 7, continuous alfalfa, slope length 72.6 feet, 1/100 acre.
Plot 8, continuous bluegrass, slope length 72.6 feet, 1/100 acre.
Plot 9, continuous corn, artificially eroded soil (12 inches of surface removed), slope length 72.6 feet, 1/100 acre.

In the measurement of soil and water losses from the experiment the turbid supernatant water is drawn off from the tanks, weighed, and sampled. Then the total amounts of soil-free water and water-free soil are determined as based upon samples in triplicate. Subsequently, the total amount of heavy eroded material is likewise drawn off, weighed, and sampled. Finally, the total amounts of water-free soil and soil-free water are determined. Samples are also obtained for the determination of certain chemical properties of the eroded material.

In planting corn it is customary to plant five kernels to the hill and to thin each hill later to a stand of three plants. Rows are spaced 3 feet apart in plots, and hills are spaced 3½ feet in rows.

Lysimeters, experiment 1–B.—Inasmuch as the control plots provide information only upon surface losses it was early found desirable to determine the effects of certain treatments on the movement of water through the profile. It was considered of first importance to de-

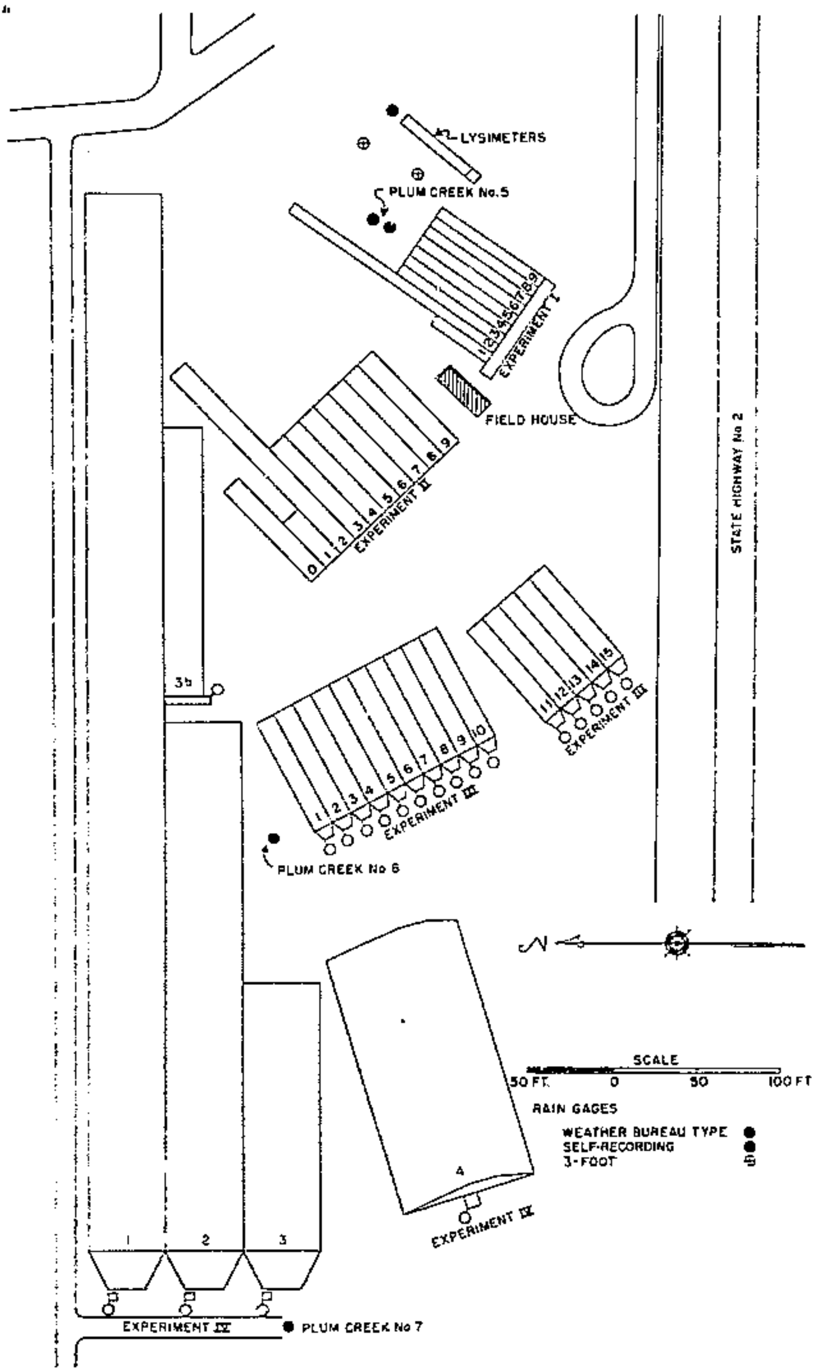

FIGURE 9.—Diagram of experiments carried on in Field E.

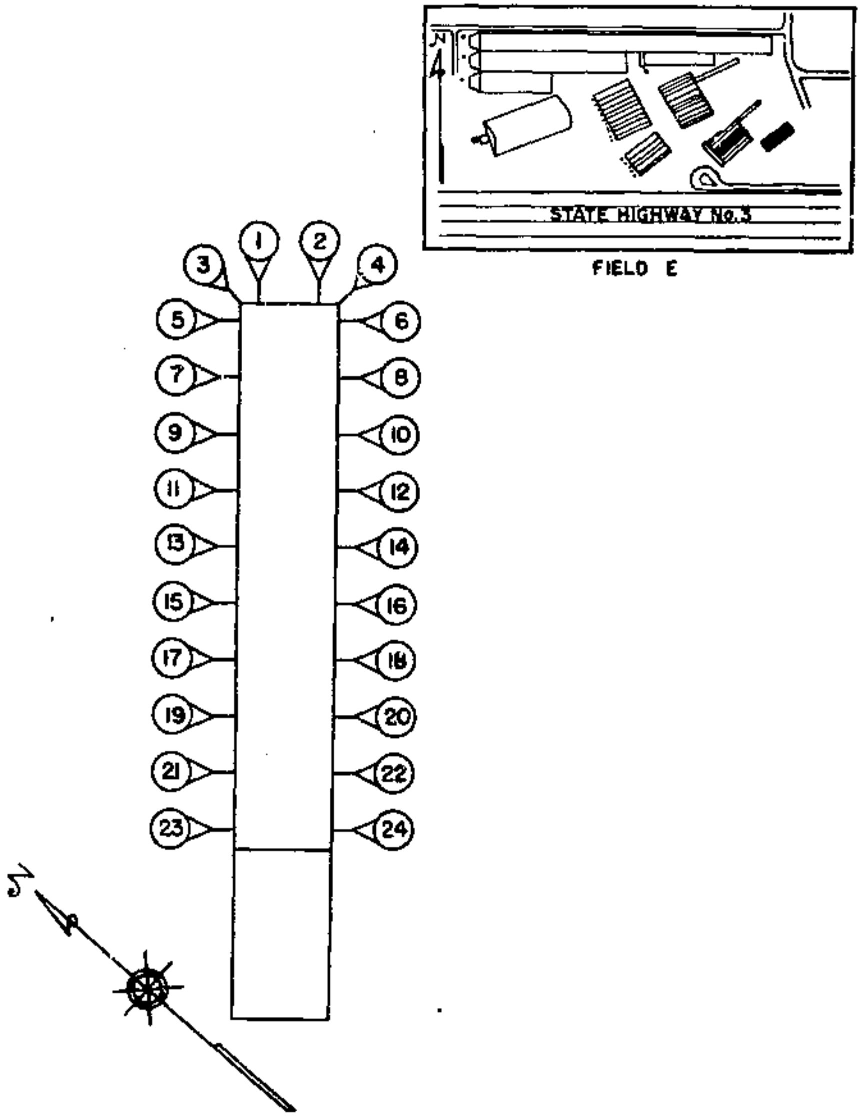

FIGURE 10.—Location and arrangement of lysimeters in Field E.

termine such losses on soil of normal structure. Inasmuch as normal movement of moisture through the profile was being measured, also, it was considered essential to maintain a slope of definite degree, permitting free surface runoff. The method of constructing these special lysimeter units has been described elsewhere (*22*).

Two soil series are included in the experiment and the treatments in general are comparisons in triplicate with and without the incorporation of organic matter in the surface 6 inches of soil. The organic matter which is used in all except one treatment consists of 16 tons an acre of well-rotted stable manure. In one of the treatments the organic matter consists of green sweetclover of a dry-matter content equivalent to one-half the dry-matter content applied to the other units. The treatments are shown in table 3.

TABLE 3.—*Treatment of soil on lysimeters, experiment 1–B*

Lysimeter Nos.	Soil type	Treatment
1, 3, 5	Marshall silt loam	Fallow.
2, 4, 6	do	Fallow plus 16 tons manure per acre.
7, 9, 11	do	Corn.
8, 10, 12	do	Corn plus 16 tons manure per acre.
13, 15, 17	do	Bluegrass sod.
14, 16, 18	do	Corn plus green manure (green sweetclover having dry-matter content equivalent to one-half of the manure application).
19, 21, 23	Shelby silt loam	Fallow.
20, 22, 24	do	Fallow plus 16 tons manure per acre.

Measurements of percolate were made regularly and not less frequently than once each week. Measurements of runoff were made for each rainfall period and in a manner similar to the method used in experiment 1. The fallow units in the series were cultivated and the soil was handled in the same manner as the units planted to corn, with the exception that weed seedlings following last cultivation are removed by pulling as soon as they make their appearance. Buffer treatments around the exterior of each unit were similar to the treatments on the units themselves.

Soil-moisture studies, experiment 2.—Soil-moisture determinations were made regularly for a number of different conditions and comparisons on the farm.

A series of plots handled identically with those of the control plots of experiment 1 were utilized for the purpose of recording moisture variations under such conditions as prevailed from time to time within the control experiment. Soil samples for moisture determinations were taken at depths of 0 to 6 inches, 6 to 12 inches, 12 to 24 inches, 24 to 36 inches.

A series of determinations of soil moisture are made on terrace ridges, the interterrace spaces and terrace channels, and on unterraced areas at points on corresponding contours in the field.

A series of determinations are also made upon plots 3 and 4 of experiment 4, in which there is a comparison of contouring listed corn and listed corn with rows running in the direction of slope.

The frequency of moisture determinations in all of the plots described is such as to give, as nearly as possible, a continuous record of varying moisture content depending upon prevailing precipitation. It would be desirable to obtain more frequent determinations if facilities were available.

Effect of organic matter upon runoff and erosion and upon the renewal of fertility in eroded soils, experiment 3.—The early stage of erosion upon the normal profile of Marshall silt loam primarily causes losses of nitrogen and organic matter. This leaves a profile which is still rather rich in calcium, phosphorus, and potassium. It is of interest, therefore, to determine to what extent the fertility of such eroded soil may be improved by additions of organic matter. It is also of interest to determine what may be the effects of such treatments upon soil and water losses. The study of these factors is being made on 15 plots, consisting of 3 series of 5 plots each. One series of plots is left fallow; another series is planted to continuous corn; and the third series is planted to a rotation similar to that of the main farm, namely, corn, oats, and clover. The plots are 72.6 feet long and 10.5 feet wide, and are located on a 9-percent slope. The area chosen for the experiment includes a uniform soil profile from which 12 surface inches of soil were removed before the experiment. The removal of this soil not only provided extreme conditions in regard to erosion for subsequent study but also permitted improvement in uniformity of slope and possibly some improvement in uniformity of soil profile as well. The type of measuring equipment used for determining soil and water losses is shown in figure 11.

The treatments for each series include:

1. Check
2. Manure, 8 tons per acre
3. Manure, 16 tons per acre
4. Green manure, in the form of sweetclover, in quantity such that the dry-matter content is equivalent to that of low rate of manure
5. Green manure, sweetclover, in quantity such that the dry-matter content is equivalent to that of high rate of manure

The sweetclover is cut from other areas, weighed, sampled, and incorporated within the surface 6 inches of soil in the same manner and at the same time as the manure application, which normally is 7 to 10 days prior to corn planting.

Length of slope and direction of row, experiment 4.—Owing to the fact that the comparison of length of slope in experiment 1 includes slopes differing in length by comparatively small amounts, experi-

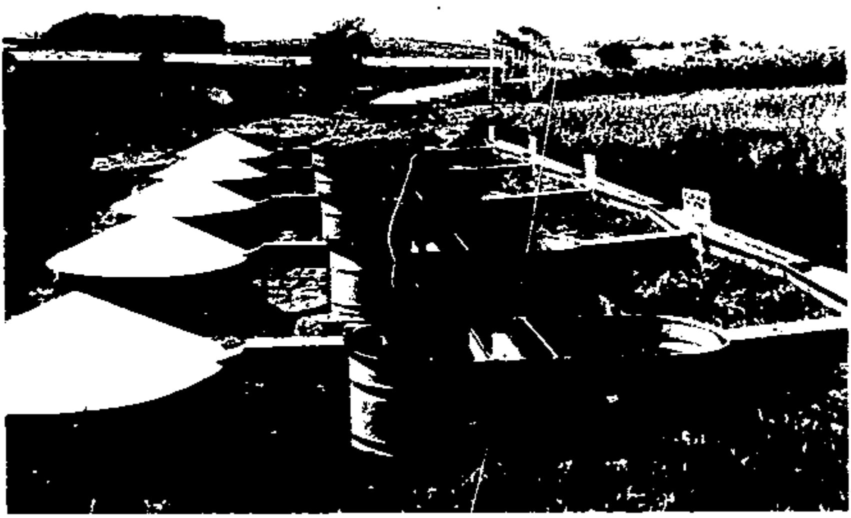

FIGURE 11.—Equipment for measuring soil and water losses. The silt is deposited in the tanks at the right. The water and the suspended silt run into the round tanks at the left.

ment 4 was set up to include a comparison of longer slopes. Plot 1 of this experiment has the greatest length of slope—630 feet—that could be established on the station property. Plot 2 of this experiment is one-half the length of plot 1, or 315 feet, and plot 3 is one-fourth the length of plot 1, or 157.5 feet. All of these plots are 42 feet wide, or of sufficient width for 12 corn rows. Plot 3–B was later established to duplicate the length of plot 3 but nearer the top of the slope where the soil is in a somewhat more permeable condition. The area available for this plot permitted a width one-half that of the others, or 21 feet.

On all of these plots corn is grown continuously with an intervening winter cover crop of rye and vetch. The rows are planted in the direction of the slope, using the ordinary horse-drawn loose ground lister, the commonly used type of planter in this locality.

In comparison with these plots, another, No. 4, is laid out with the rows on the contour. This plot has a length of slope equal to that of plot 3, or 157.5 feet, and to give satisfactory length of contoured row the width is 84 feet, or twice that of plot 3. Cultural practices on this plot are identical with those of the other plots of the experiment and tillage operations are carefully planned to be completed on the same day, and without the possibility of intervention of storms which might occur at a stage when tillage operations were only partly completed.

On these plots square-notch divisors are in use, installed in tandem so that the sample passing through the first divisor is again subdivided, giving a sample of runoff approximating one one-hundred forty-fourth of the total runoff. The exact fraction used is based on the calibration tables made on this divisor unit by the hydraulic laboratory, University of Iowa, Iowa City, Iowa.[4]

Infiltration studies, experiment 5.—As one of the primary purposes of water conservation is to retain a high proportion of the precipitation upon the land, attention was early directed toward the determination of factors which affect the rate of intake of water into the soil. Lysimeters (the first of which was constructed for this purpose in 1930) were used in this experiment. In addition, runoff data studied in relation to rainfall intensity were used and early in 1934 further attention was given to the quantitative measurement of water intake using a method of direct application of water to soils of field structure. Subsequently, this study was enlarged since it was found to be a matter of great importance in the design of erosion-control measures (*10, 19, 24*).

RESULTS OF EXPERIMENTS

Control Plots, Experiment 1

The nine control plots of experiment 1 are located in field E as shown in figure 12. Installation of the experiment was made in 1931 and it was formally placed in operation November 1, 1931. The first record of runoff was made November 23.

[4] Yarnell, D. L., calibration of square-notch divisors, U. S. Dept. Agr., Bur. Agr. Engin. [Mimeographed]

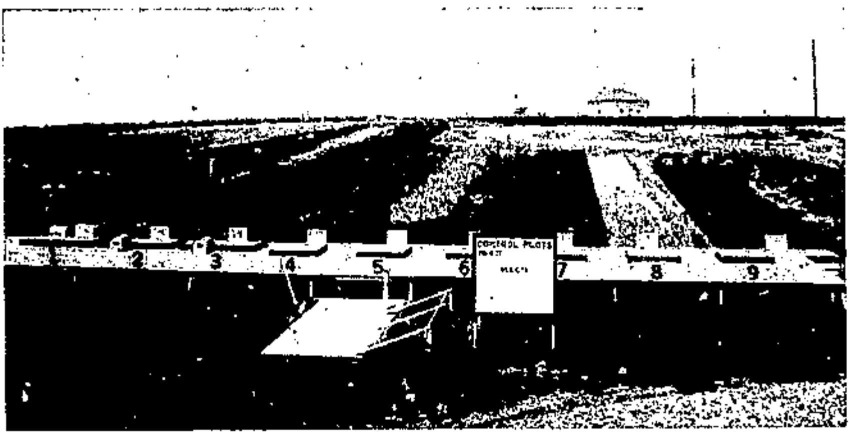

FIGURE 12.—View of the nine control plots showing condition of crops in July 1938.

During the period of the fall and winter of 1931–32 all the plots of this experiment were under like treatment, that is, they were planted to oat, stubble, and mixed native grasses. During the spring of 1932 the various crop treatments were applied at the successive proper dates for seeding oats, clover, corn, bluegrass, and alfalfa. Until June 1, 1932, therefore, the vegetative cover called for by the plan of experiment had not been established. Therefore, only the results for 1933–44 are averaged in this report.

Each of the plots of this experiment has a width of 6 feet. This was the standard width specified by the plans of the control plots of each of the early stations. It is obviously too narrow a width for satisfactory operation. In the corn plots there is room for but two rows of corn. In the oats, clover, and alfalfa plots, border effects are frequently noticed.

RUNOFF AND EROSION

During the period of operation from January 1, 1933, to December 31, 1942, 162 records of runoff and erosion have been taken on this experiment. These 162 records show a total rainfall of 165.1 inches and a precipitation for the period, including snows and all other storms not producing runoff, of 282.5 inches.

A summary of the results from January 1, 1933, to December 31, 1942, is presented graphically in figure 13. The individual runoff and erosion records are given in tables 27 to 48, appendix. Plots 1, 2, and 3 give a comparison of length of slope as already explained in the section under the heading Purpose and Plan of the Experiment. They are shown in figure 12. Although the differences in length are comparatively small and it is not expected that large differences in runoff will be found from such small differences in slope length, it is interesting, nevertheless, to note that the percentage runoff is greatest from the short slope and least from the long slope but that the tendency is reversed in the case of erosion.

This tendency for the greatest percentage of runoff to occur on the short length of slope and the greatest amount of erosion on the longest slope is borne out also in experiment 4 which will be discussed later. Obviously, the increased erosion on the long slope is due in part at least to increased volume and velocity of runoff.

Plots 3 and 9 of this experiment are alike in treatment except that plot 9 had been artificially eroded to a depth of 12 inches prior to the inauguration of the experiment. The total amount of runoff from the normal soil under corn was 52.9 inches while that on eroded soil under corn was 57.2 inches. The total amount of erosion on the normal soil was 382.9 tons per acre while on the eroded soil it totaled 516.0 tons per acre. Nevertheless, in going over the totals by individual years it will be found that in 1935 and 1936 the erosion was greater from the corn on normal soil. Furthermore, study of the individual records reveals that in 63 of the 162 cases runoff from the normal soil has exceeded that from eroded soil.

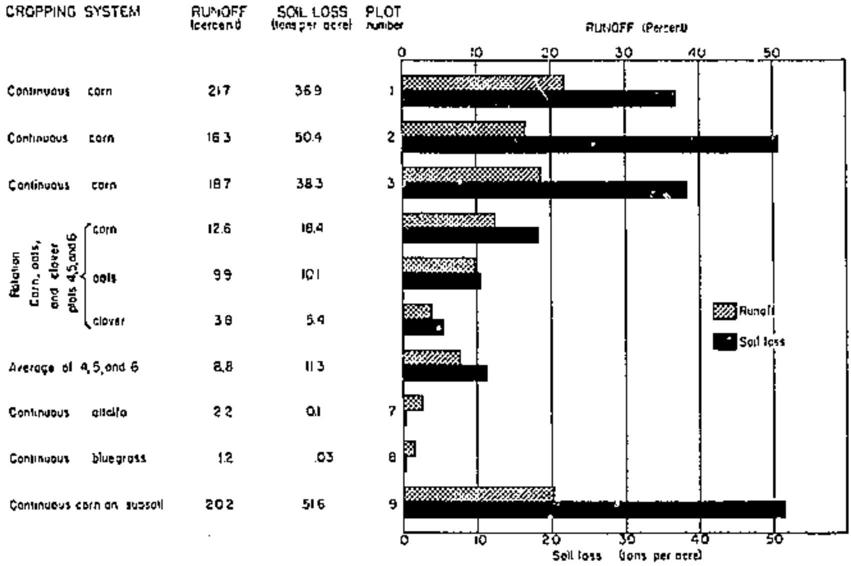

FIGURE 13.—Average annual runoff and soil loss from control plots for the 10-year period 1933–42, on Marshall silt loam; average slope 9 percent; total precipitation for entire period, 238.7 inches.

These results are apparently associated with certain physical properties of the two soils. It will be noted that the density of runoff from the eroded plot is commonly greater than from the normal soil. This may be explained by the greater ease with which the subsoil is dispersed because of lack of organic matter and less protection of the soil surface from the beating action of raindrops by the smaller corn plants on the eroded soil (fig. 14). Thus the relative erosion as well as runoff fluctuates with rainfall amounts and intensities, type and amount of vegetation, length and steepness of slope, and varies from storm to storm and from year to year.

The type and amount of vegetation probably is the most important single factor affecting runoff and erosion. The percentage of total rainfall lost as runoff from continuous corn (on subsoil) was 19.8; continuous corn, 18.2; rotation corn, 12.4; rotation oats, 9.9; rotation clover, 3.7; continuous alfalfa, 2.1; and continuous bluegrass, 1.2. The effect of vegetation on soil losses was even more pronounced with average annual losses of soil in tons per acre of 51.6, from continuous corn (on subsoil); 38.3 from continuous corn; 18.4 from rotation corn; 10.1 from rotation oats; 5.4 from rotation clover; 0.01 from continuous alfalfa; and 0.03 from continuous bluegrass.

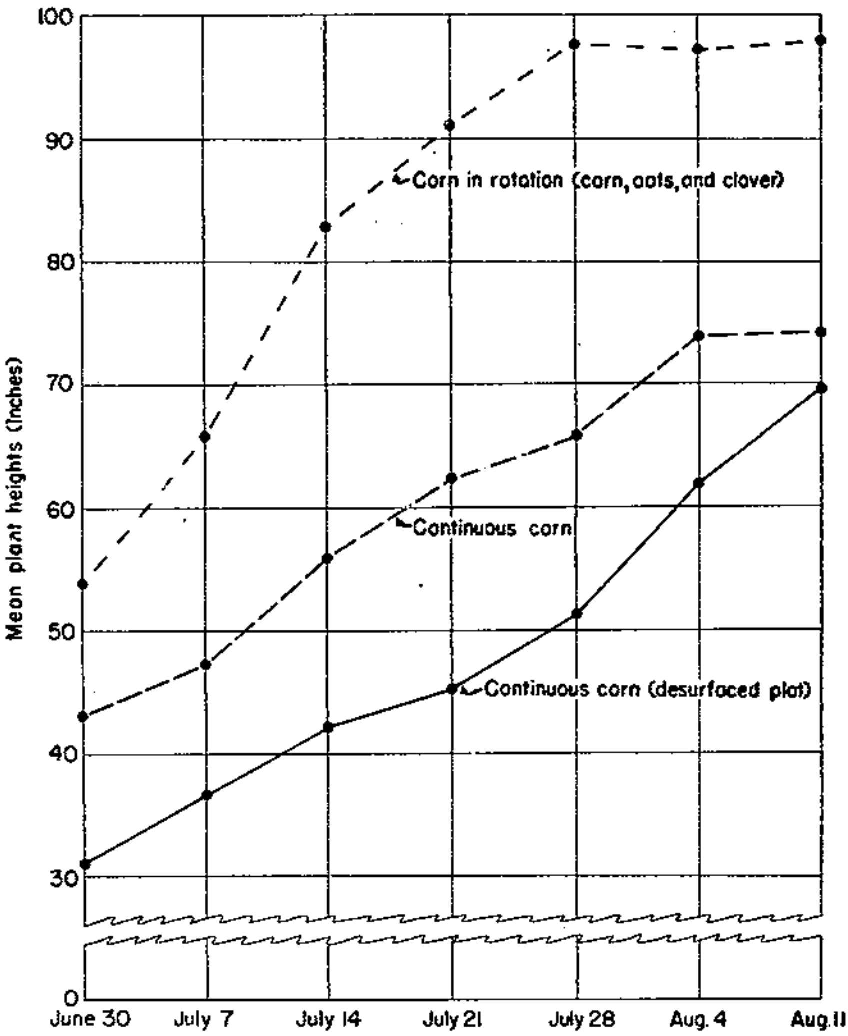

FIGURE 14.—Effect of cropping system on height of corn on the control plots of the Missouri Valley loess region.

From these data it is apparent that average annual soil loss from rotation clover is 5.4 tons per acre; whereas the loss from alfalfa and bluegrass is 0.01 and 0.03 tons per acre, respectively. The much higher loss from clover than from alfalfa or bluegrass is explained by the failure of clover seeding in 1936 and 1937, because of the severe drought and damage from grasshoppers. The severe soil losses occurred the following spring when the plots were reseeded to oats with a sweetclover catch crop. Detailed erosion records, tables 27–48, appendix, show that 52 tons per acre or 96 percent of the 54.2 total soil loss from clover during the period 1933–42 occurred during 1937 and 1938 when attempts were made to reestablish meadow seedings that failed because of drought and damage from grasshoppers in the summers of 1936 and 1937. It is recognized, of course, that failures of clover seedings are to be expected from time to time. However, from the weather records it is evident that these experiments were conducted during a period when droughts were more frequent than are to be expected over a period of time. Furthermore. runoff and erosion from oats was unusually high in 1937 (45 percent of total for the period 1933–42, tables 27–48, appendix), because of a few intense rains that came at a time when land seeded to oats was particularly susceptible to erosion. This type of rain did not occur again during any other year while these experiments were in progress and is more frequent than would be expected as a long-time average. It is evident, therefore, that an average annual soil loss of 5.4 tons per acre from clover, for the period 1933–42, is probably considerably higher than would be the case if records were available for a long period of time. If the soil losses for 1937 and 1938, years when clover seeding failed, are omitted then the average annual soil loss from clover is 0.2 tons per acre, a value more nearly in line with losses from alfalfa and bluegrass. Perhaps a value in between 5.4 and 0.2 would more nearly represent the long-time average.

The value of clover in the rotation in reducing runoff and erosion is evident not only from the small losses during the period when clover is on the land, but also by comparing the 38.3 tons per acre soil loss from continuous corn with the 18.4 tons per acre loss from corn which follows clover in the rotation. This 52-percent reduction in soil loss may be explained first, by the fact that the clover protects the soil surface from January 1 until the time of plowing for corn; second, by the increased capacity of the soil to absorb water and resist the dispersing action of raindrops because of a more favorable structural condition; and, third, by the fact that the larger corn plants on the rotation plots give greater protection to the soil surface throughout the growing season. As an average of the entire period there were about 2 pounds of soil per cubic foot of runoff from corn which followed clover in a corn, oats, clover rotation. On the other hand, in the continuous corn plots, over 4 pounds of soil were carried in each cubic foot of surface runoff.

Seasonal occurrence of runoff and erosion.—A few rains are responsible for most of the soil losses shown in figure 15. There were 128 storms during the period 1933–42, each of which produced runoff from some plot of the control series. Half of the storms caused less than 5 percent of the soil loss; whereas 18 percent of the total soil loss occurred during 2 storms, and 60 percent during 16 storms. It is evident, therefore, that it is necessary to design erosion-control measures to take care of a relatively few intense storms.

The seasonal effects of the various types of vegetative cover on runoff and erosion are especially significant. It is evident from figure 16, which shows the seasonal rainfall by various intensities for 1932–42, that the heaviest rains occurred during the months of June, July, August, and September, respectively; also that May and

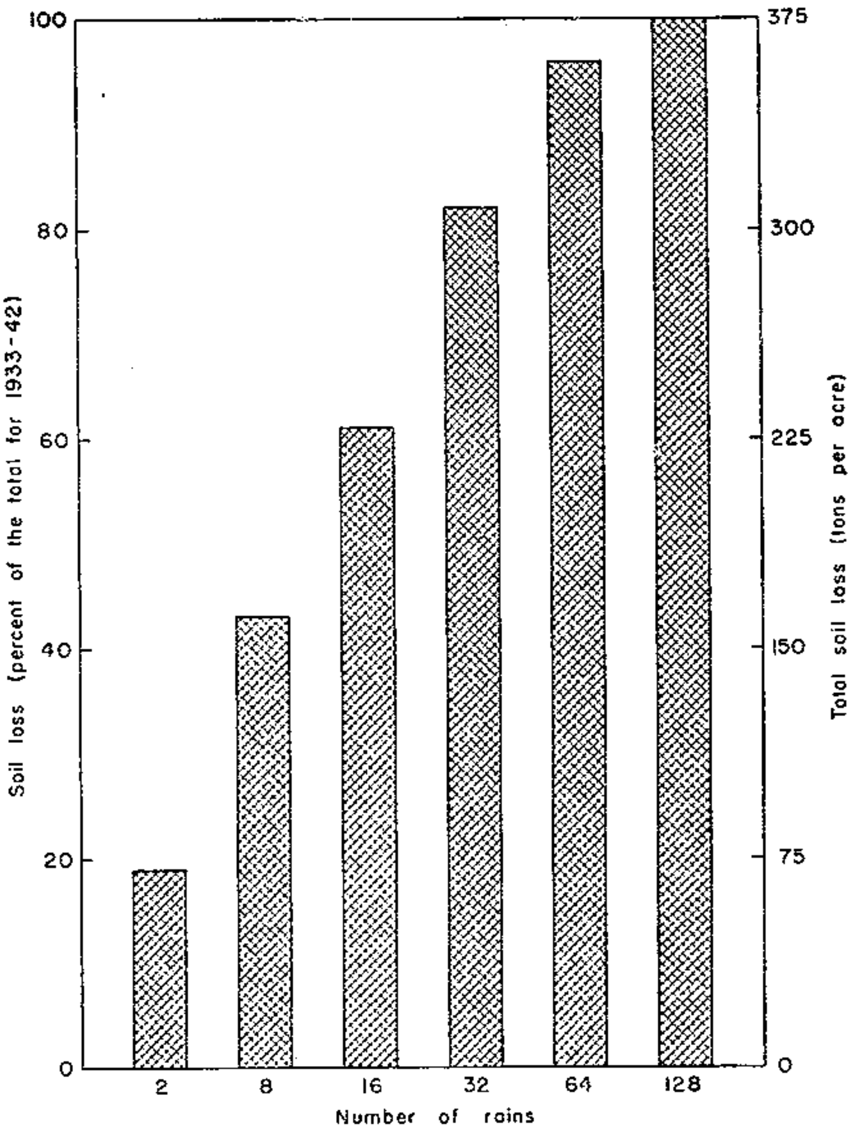

FIGURE 15.—This chart shows the extent to which a few rains cause most of the soil loss.

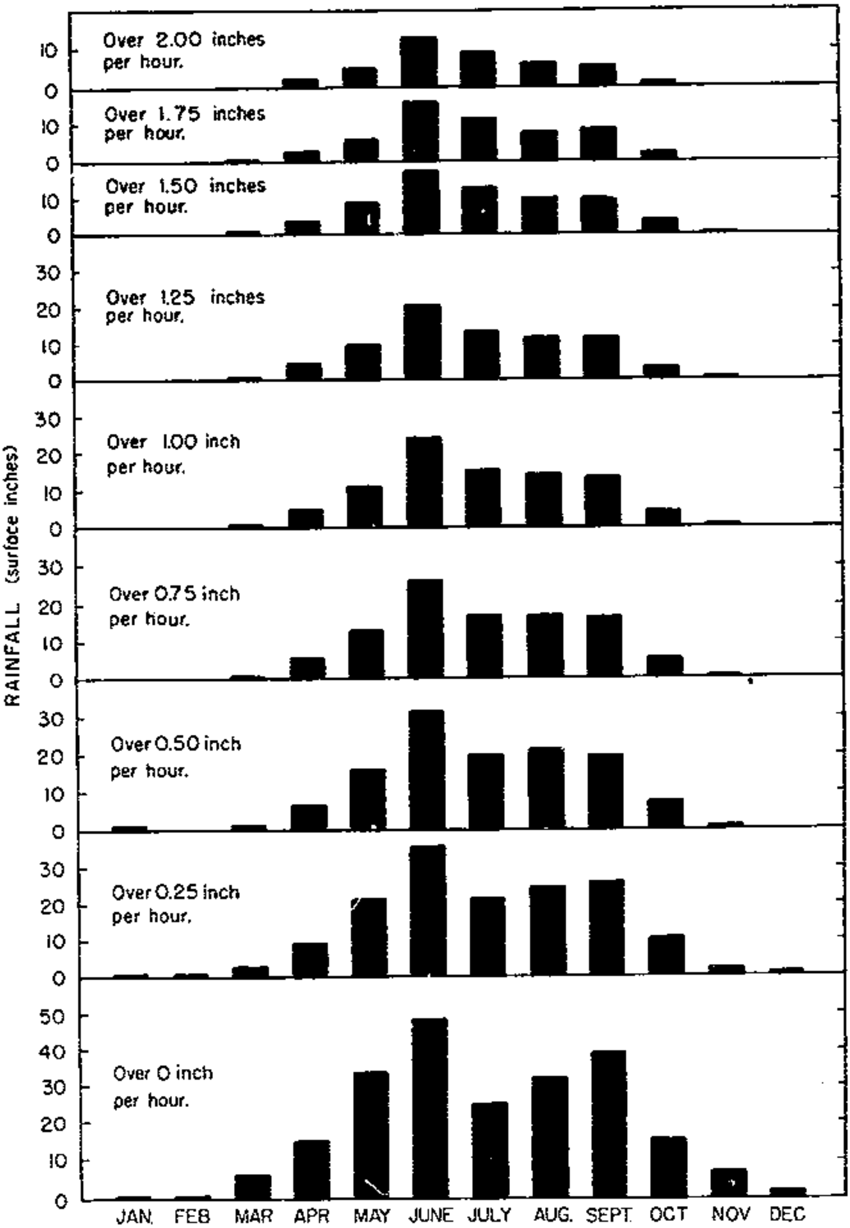

FIGURE 16.—Seasonal occurrence of rainfall for 1933–42, divided into intensity classes; includes only rains of 0.2 inch and over; Soil Conservation Experiment Station, Missouri Valley loess region.

October are months which normally have rains of sufficient intensity to produce runoff. Figure 17, however, shows that the peak runoff occurs at different seasons for different vegetative covers. It shows, for example, the greatest runoff from bluegrass and alfalfa occurred during March and February when the ground was frozen. The great-

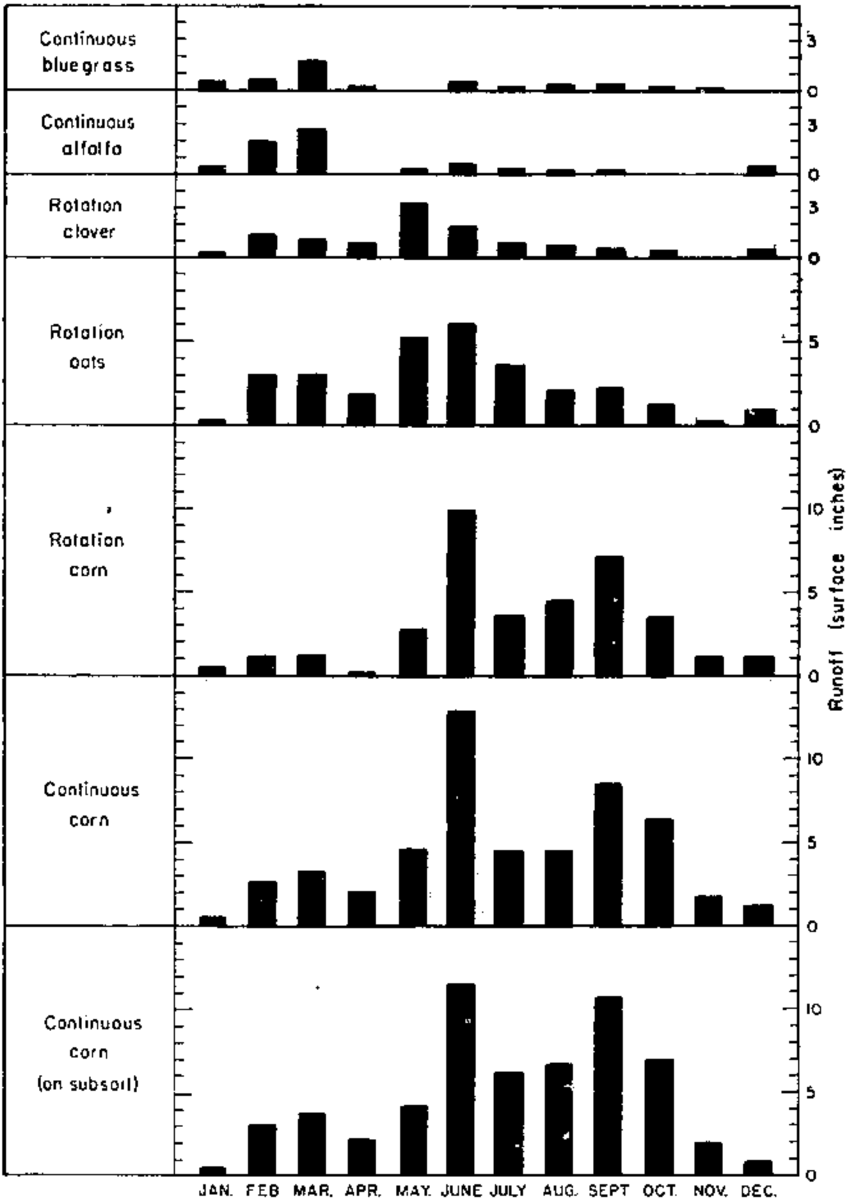

FIGURE 17.—Seasonal occurrence of runoff for control plots on Marshall silt loam, Soil Conservation Experiment Station, Clarinda, Iowa, 1933–42.

est runoff from oats resulted from rains in June and May with those in July, September, and March producing appreciable quantities of runoff. In the case of corn the greatest runoff occurred during June. September, August, October, July, and May have also been months when rather large quantities of runoff occurred.

Knowledge of the seasonal occurrence of erosion is of great practical importance. Figure 18 shows that erosion from land in bluegrass,

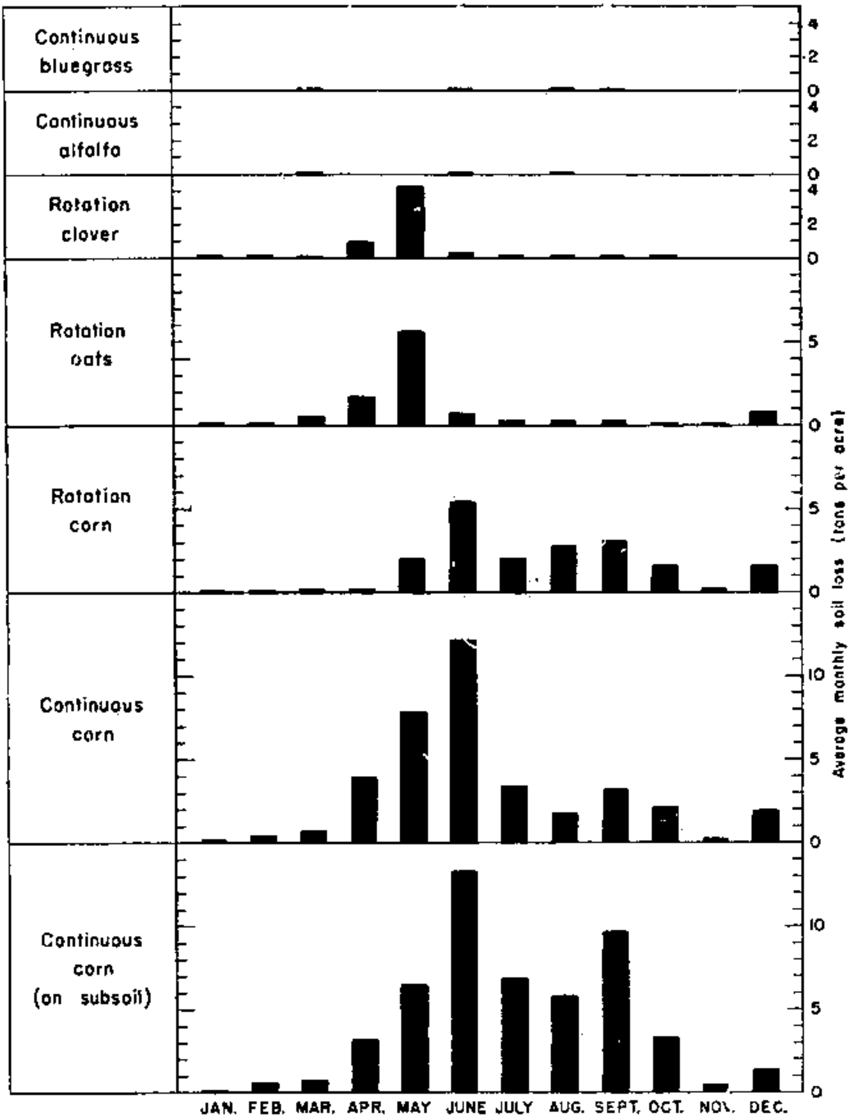

FIGURE 18.—Seasonal occurrence of erosion on control plots of Marshall silt loam, 1933–42.

alfalfa, and clover was extremely slight at any season of the year even though appreciable quantities of runoff occurred from these crops. In the case of oats the greatest erosion occurred during May. May and June were the months during which the greatest runoff occurred. Following this developmental period in the oat crop, however, very little erosion occurred in succeeding months. In the case of (rotation) corn, erosion parallels closely in seasonal occurrence, the runoff losses. June is the month of greatest erosional losses with September, May, and August next in order. It is apparent as between a cultivated crop, such as corn, and a crop of close vegetation, such as oats, that marked differences in protective effects may be expected. Thus the oats provide a greater protection against erosion than against runoff. Corn, on the other hand, provides protection primarily to the extent of canopy interception and the water which reaches the land surface still has an erosive effect.

In addition to the effect of close-growing crops and canopy interception on runoff, there is also the factor of moisture use by these crops. No doubt the withdrawal of water from the soil by the growing crops permits an increase of infiltration, especially where rains follow in close succession during the growing season. The relative effectiveness of this factor in different crops, however, was not made a part of this study.

Uncontrolled variation within the experiment.—It is important to know the extent of the uncontrolled variation of any experiment. The control-plot experiment under discussion has no check plots and resort must be had to other methods for determining the extent of uncontrolled variation. There are two plots in experiment 1 that, during the first 13 months of operation, received identical treatment. Plot 3, in continuous corn, and plot 4, in corn at the start of the rotation of corn, oats, and clover, had like treatment from November 1931 throughout 1932. During this period every effort was made to provide identical conditions on both plots as required by the experiment. A study of the detailed results from this period (table 4) shows that plot 4 exceeded plot 3 in runoff by a very appreciable amount, and likewise in the total amount of eroded soil. These differences occurred not merely occasionally, but very frequently.

Detailed chemical and physical analyses of the soil profiles of these plots have been published (*18*). In order to present the differences in these analyses an abstract of them has been prepared (table 5).

Soil-Moisture Determinations, Control Plots, Experiment 2

In order to determine the soil moisture present in the treatments of experiment 1 a separate series of plots was laid out adjacent to the control plots. Soil samples for moisture determinations were taken at 0–6, 7–12, 13–24, and 25–36 inches at approximately monthly intervals throughout the growing season during the period 1932–42. A summary of these data is given in table 6. Because these plots were not replicated it is not possible to establish differences required for significance. However, on the basis of later studies on methods of sampling soil for moisture determination it appears that differences of about 0.5 percent would be required to be significant.

TABLE 4.—*Comparison of runoff and erosion from two plots having identical treatment, experiment 1, November 1931 to Dec. 31, 1932*

Runoff		Erosion		Runoff		Erosion	
Plot 3	Plot 4	Plot 3	Plot 4	Plot 3	Plot 4	Plot 3	Plot 4
Gallons	*Gallons*	*Pounds*	*Pounds*	*Gallons*	*Gallons*	*Pounds*	*Pounds*
327.07	323.24	8.42	9.30	185.26	255.32	107.96	153.41
228.05	274.70	2.59	2.82	120.55	155.52	32.43	62.74
21.42	57.10	5.90	16.60	73.92	100.52	23.86	30.71
33.81	69.04	11.55	15.29	258.61	241.12	26.09	31.02
95.24	114.55	86.28	84.15	10.44	26.55	4.17	4.53
138.07	169.25	152.57	188.97	25.63	41.56	3.24	3.33
65.44	91.07	66.80	64.34	2.70	5.93	.00	.00
297.33	305.68	312.40	316.25	.72	2.07	.00	.00
20.21	21.17	45.70	47.93	.00	1.50	.00	.00
29.71	54.26	21.13	20.75				
34.64	41.59	16.65	18.93	Total:			
43.97	61.27	28.33	31.03	2,024.19	2,421.10	958.46	1,111.18
Mean				96.39	115.29	45.63	52.91
Relative				100.00	120.00	100.00	116.00
Difference between means					18.90		6.70
Difference to be significant ($p=0.05$)					8.96		6.00
Difference to be highly significant ($p=0.01$)					12.29		8.20

TABLE 5.—*Comparisons of colloidal content, moisture equivalent, and dispersion ratio in plots 3 and 4 in continuous and rotated corn, respectively*

Horizon	Colloid by water vapor absorption		Moisture equivalent		Dispersion ratio	
	Plot 3	Plot 4	Plot 3	Plot 4	Plot 3	Plot 4
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	32.2	32.9	30.3	30.4	29.7	26.4
2	35.8	36.4	32.2	31.7	26.0	28.9
3	38.2	38.7	32.3	32.8	27.9	28.6
4	35.6	34.8	30.8	30.5	32.1	36.4

TABLE 6.—*Effect of different types of vegetation and length of slope on the average moisture content of Marshall silt loam soil, Clarinda, Iowa, 1932–42*

Plot number	Slope length	Treatment	Soil moisture (weighted averages)											
			1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	Average
			In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
0	....	Fallow				...	26.1	26.3	25.9	25.5	26.5	27.2	26.7	26.3
1	30.3	Continuous corn	26.8	26.1	19.1	24.1	22.2	21.4	22.0	22.9	24.2	24.0	26.1	23.5
2	145.2	do	25.9	26.3	20.9	25.7	23.1	22.1	24.5	22.8	25.5	25.6	26.2	24.4
3	72.6	do	26.4	26.7	19.5	24.0	22.0	23.1	23.2	22.6	24.0	24.3	25.8	24.0
4	72.6	Rotation corn	27.8	25.9	19.3	24.3	22.1	22.4	23.3	22.3	23.1	24.5	25.0	23.6
5	72.6	Rotation oats	21.5	25.7	19.5	26.3	22.2	20.5	20.5	20.9	22.6	23.6	24.9	22.6
6	72.6	Rotation clover	22.9	21.1	19.1	23.4	21.1	20.5	21.3	23.6	23.2	24.2	25.8	22.4
7	72.6	Continuous alfalfa	28.0	22.8	18.1	21.0	18.4	17.8	17.1	19.3	21.5	23.3	25.9	21.3
8	72.6	Continuous bluegrass	28.6	25.0	20.3	22.5	20.1	20.8	19.7	23.0	23.1	24.7	25.6	23.1
9	72.6	Continuous corn[1]	27.9	27.4	21.7	25.5	24.3	24.7	25.2	24.7	26.6	25.7	26.7	25.5

[1] Eroded.

Average yearly soil moisture under alfalfa, continuous corn, oats, and fallow is shown in figure 19. From these data it is apparent that the moisture content of the soil under alfalfa is consistently lower than for the other crops. The highest moisture content was under fallow.

This is to be expected since there was no vegetation growing on these plots and the only loss of moisture from the soil was through evaporation and percolation. The moisture content under continuous corn is not shown in this graph but from the detailed data (plots 3 and 4, table 6) it is evident that the values are essentially the same as for rotation corn. Runoff data from the control plots show that 1.7 inches more water per year entered the soil under rotation corn than under continuous corn. On the other hand, the amount of plant growth on the rotation plot has been considerably greater than that on the continuous corn plot (fig. 14); losses by transpiration, therefore, were higher from the rotation plot. The moisture content of the soil under the two treatments was practically the same. It is evident, therefore, that the larger transpiration loss from the corn on the rotation plots was about equal to the increased intake of water under rotation corn.

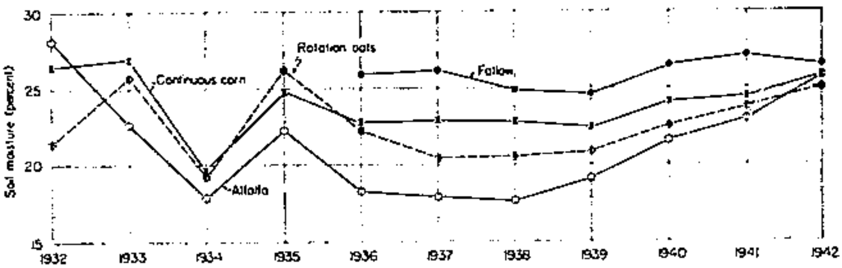

FIGURE 19.—Average soil moisture at 0- to 36-inch depth, under alfalfa and continuous corn on Marshall silt loam.

The monthly average moisture content of the soil at the 24- to 36-inch depth under alfalfa, continuous corn, continuous bluegrass, and rotation oats is shown in figure 20. It will be observed that the moisture content under alfalfa is consistently lower than for any of the other treatments. The moisture content under oats is somewhat lower than under continuous corn during the period April to August, but higher during the remainder of the season. Bluegrass during the hot period of July and August is practically dormant and the loss of moisture by transpiration is exceedingly low. Moisture content under continuous corn is high during April, May, and June, the period when there is very little growth of corn. This also represents the period of maximum rainfall. In July and August the rainfall drops off materially and the plants are making very rapid growth during this period. This causes rapid depletion of the moisture content. By September and October the growth of plants slows down materially. This fact accounts for the higher moisture content under corn during the late summer and early fall.

The moisture content under oats is considerably lower than under continuous corn during the months of May, June, and July, but in all cases is higher than under continuous alfalfa. Oats make their most rapid growth during the months of May and June. Even though precipitation is relatively high during this period, the extra loss of moisture through transpiration has reduced the moisture content of the soil. Oats are normally harvested the early part of July and the moisture requirements of the small clover plants growing in the oat stubble is not as great as for the oat crop. This and the fact that the clover provides protection to the surface and reduces the amount of runoff explains the higher moisture content evident on the oat stubble during September, October, and November.

The effect of length of slope on soil moisture is seen in the comparison of the results from plots 1, 2, and 3 (table 6). In 8 of the 11 years the moisture content of the soil increased with length of slope. The 11-year averages show the same trend, although the differences are small and may not be significant.

In the case of clover in rotation, the moisture content of the soil was less in 10 of the 11 years of the experiment than for soil under continuous corn. The moisture under the close-growing bluegrass crop likewise was lower in 7 of the 11 years than under continuous corn, which is in agreement with results reported for 1932–35 (*9, 26*). The oat plots likewise showed less moisture in 10 of the 11 years of the experiment.

The effects of continuous corn and continuous alfalfa on the moisture content at the 24- to 36-inch depth are shown graphically in figure 21. When the first samples were collected in 1932 the moisture content of the 24- to 36-inch depth was approximately at the field capacity. The water requirement of the crop during July and August is greater than that supplied by rainfall. The moisture content of the soil, therefore,

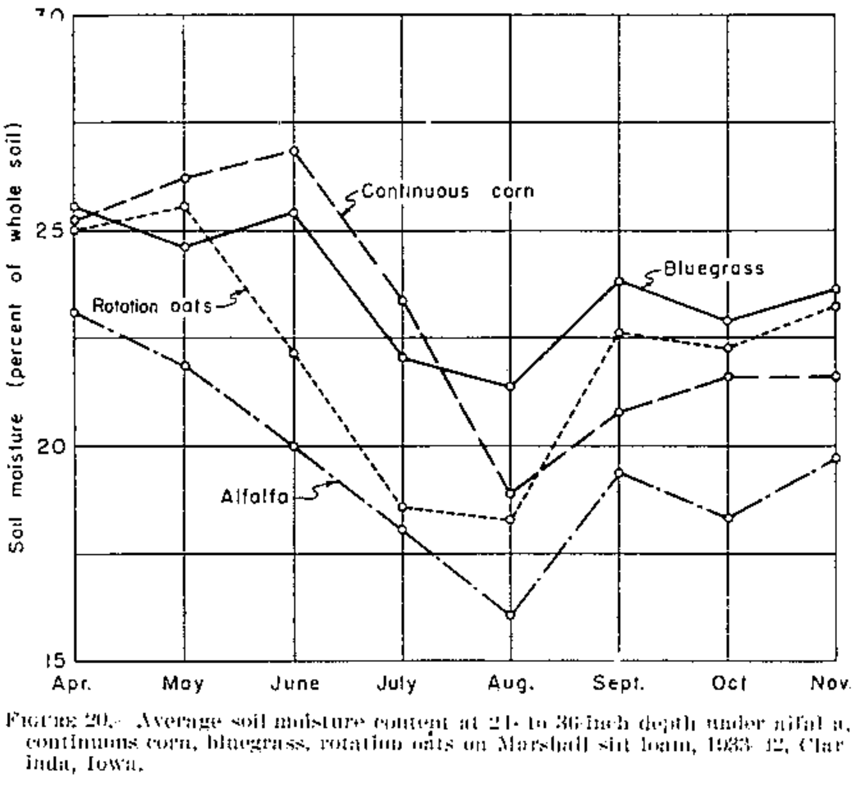

FIGURE 20.—Average soil moisture content at 24- to 36-inch depth under alfalfa, continuous corn, bluegrass, rotation oats on Marshall silt loam, 1933–42, Clarinda, Iowa.

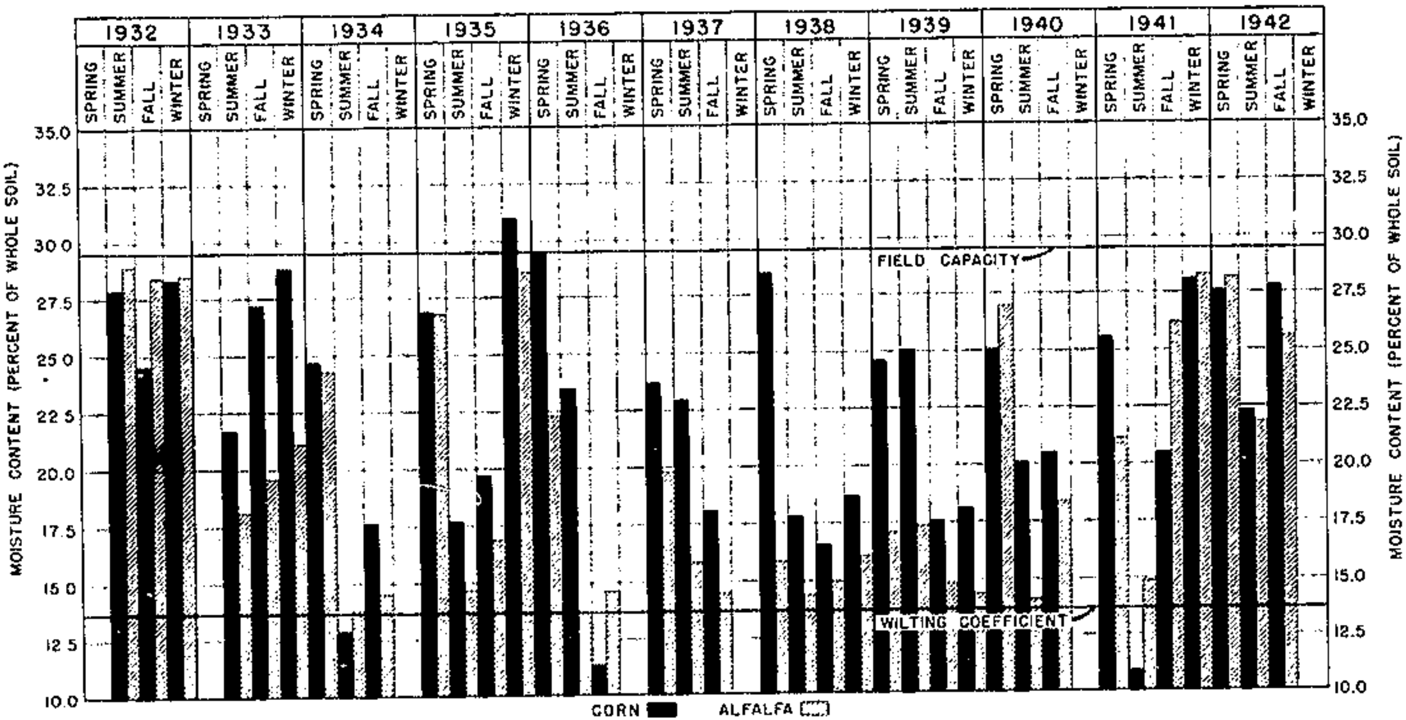

FIGURE 21.—Effects of continuous growing of corn and alfalfa on the moisture content of Marshall silt loam at the 24- to 36-inch depth.

was materially reduced during this period. In the fall and winter of 1933, 1934, and 1935 there was sufficient rain and snow to bring the moisture content of the soil back near the field capacity by spring. However, for the period 1936–39 the average annual precipitation was 3.9 inches below normal as shown in figure 5. As a result the moisture content of the soil did not reach the field capacity during the fall and winter months, particularly under alfalfa, which has a high water requirement. From July 1937 to April 4, 1939 the moisture content of the soil under alfalfa was only 4 percent above the wilting coefficient at the 24- to 36-inch depth. The data by depths showed that moisture had penetrated approximately 18 inches during the winter and spring and this, in addition to the moisture which was available at depths below 36 inches, was sufficient to produce 2.5 and 3.1 tons per acre of alfalfa in 1938 and 1939, respectively. Beginning in 1940 there was sufficient rainfall during the fall and winter months to bring the soil back again almost to the field capacity by the fall of 1941.

The effect of cropping system on the moisture content of the soil is a very important consideration on certain of the soils in the Missouri Valley loess region. The Marshall silt loam soils have approximately a 15-percent range in moisture content between the field capacity and the wilting coefficient, which during most years with normal rainfall provides sufficient moisture for plant growth. On the other hand, there are other soils in the region such as the lighter textured Knox soils that have only about 10 percent moisture that is available to the plant. In addition, many of the soils have steeper slopes than the Marshall soils and the structure of the surface soil is less favorable for water penetration; consequently there is a higher percentage of runoff. As a result, the moisture in the soil during many years is not adequate to produce maximum yields. This is particularly the case on fields that have been in alfalfa for a number of years.

Data obtained over a period of years at Lincoln, Nebr., (*12*) show that bromegrass or mixtures of alfalfa and brome do not deplete the moisture content as rapidly as straight stands of alfalfa. Furthermore, the effect of grass in improving the physical condition of the soil and in giving additional protection to the surface can be expected to increase the amount of water taken up by the soils. Therefore, the increasing interest in alfalfa-brome mixtures may be particularly helpful in the conservation of soil and water and in maintaining the yields of pasture and hay on the soils of this region.

The moisture content of the soil represents the balance between the losses of surface runoff and transpiration. Less runoff resulted, as shown previously, from the close-growing types of vegetation such as oats, clover, alfalfa, and bluegrass than from the row-spaced corn crop. However, it appears obvious that, in certain years at least, the transpiration losses from the close-growing crops exceeded the net savings in precipitation owing to reduced runoff from the same crops.

The results also show a slightly higher average percentage of moisture under the continuous corn growing on eroded soil than under the continuous corn growing on normal soil. This is probably because of the higher clay content in the profile of the highly eroded plot.

CROP YIELDS IN EXPERIMENTS 1 AND 2

The effects of cropping system and erosion on yields of corn are shown in table 7. The data given represent the average of experiment 1 and 2 since both sets of plots are identical except that they are 6 and 10.5 feet wide, respectively. The difference required for significance was determined by analysis of variance (*38*). It is to be seen from plots 1, 2, and 3, that length of slope has not produced a significant difference in yield of corn. The average yield of 6.6 bushels of corn per acre from continuous corn on desurfaced soil is significantly lower than yields of corn grown on normal soil. Furthermore, corn grown in a corn, oats, clover rotation yielded 14.4 bushels per acre more than continuous corn as an 11-year average. In 1932 there was not a significant difference in yield of corn on normal soil. In 1933, the first year of corn on clover sod, the yield was 67.8 bushels per acre in contrast to an average of 49.7 bushels per acre for the continuous corn. Regardless of treatment, corn in 1934 and 1936 was essentially a failure because of the severe drought. It was evident, however, that the larger corn plant on the rotation plots suffered more than continuous corn.

TABLE 7.—*Effect of cropping system, length of slope, and erosion on corn yield, average of experiment 1 and 2, Marshall silt loam*

Year	Yields of corn per acre [1]				
	Plot 1, 36.3 feet long, continuous corn	Plot 2, 145.2 feet long, continuous corn	Plot 3, 72.6 feet long, continuous corn	Plot 4, 5, 6, 72.6 feet long, rotation corn, oats, clover	Plot 9, 72.6 feet long, continuous corn [2]
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1932	23.5	24.2	26.4	22.9	5.1
1933	43.2	54.2	49.7	67.8	17.4
1934	2.8	2.6	2.1	------	.7
1935	37.5	37.6	36.3	37.9	5.9
1936	4.3	8.1	6.5	.5	.6
1937	21.7	18.1	27.8	36.1	7.1
1938	47.5	46.1	50.9	59.7	7.0
1939	39.6	41.7	40.8	62.8	11.3
1940	36.6	31.8	34.8	64.5	5.7
1941	10.0	14.4	17.4	61.9	3.4
1942	27.3	23.0	20.4	58.1	8.8
Mean annual	27.5	27.4	28.5	42.9	6.6
Means 1932-36	22.3	25.3	24.2	25.8	5.9
1937–42	27.5	27.4	28.5	42.9	6.6
1940–42	27.6	23.1	24.2	61.5	6.0

[1] Differences less than 6 bushels per acre are not considered significant.
[2] Desurfaced.

Frequent hot winds, damage from grasshoppers and chinch bugs, and low rainfall were responsible for the low and erratic corn yield obtained through 1936. Factors affecting corn yields were more favorable during the last 6 years of the experiment and the effect of cropping system and erosion on yields of corn is more evident as shown in the summary of yield from 1937–42 and 1940–42 at the bottom of table 7 and in figure 22. Fertility was so limited on the eroded soil that unfavorable climatic conditions had little effect upon yields of corn. Even with continuous corn on normal soil there was not a significant change in yield as affected by weather conditions.

On the other hand, the favorable effect of clover in the rotation on the yield of corn is particularly outstanding in years when moisture conditions are favorable, as shown by the 61.2 bushels average yield for 1940–42 in comparison with 25.0 bushels from continuous corn. The cropping system also influenced the amount of growth throughout the season as shown in figure 14.

Part of the low yields on the continuous corn plot during the last 2 or 3 years of the experiment may be explained by damage from Northern corn root worm. This has caused considerable damage in fields cropped to corn for 3 or more years in succession.

How much of the decrease in yield of continuous corn is directly due to erosion cannot be definitely determined from these data. However, in another experiment on terraced land where soil losses were negligible it was found that the yields from continuous corn and corn in a corn, corn, oats, clover rotation were practically the same as in this experiment. It appears, therefore, that under the conditions of the experiment other factors such as decreased organic matter, unfavorable soil structural conditions, and lack of available nitrogen

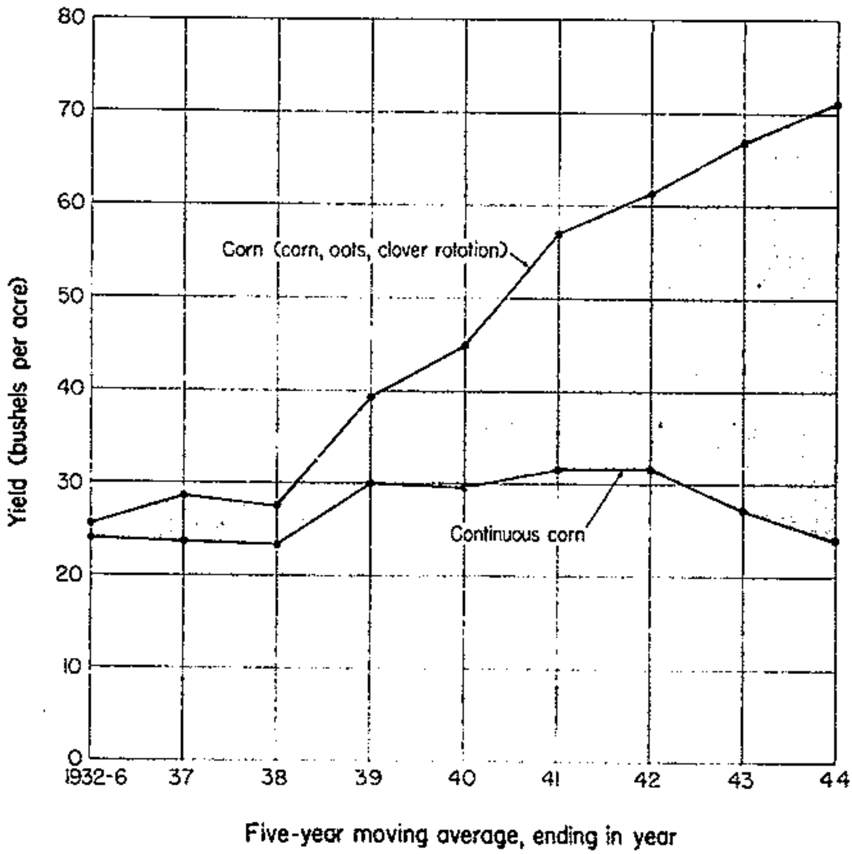

FIGURE 22.—Effect of crop rotation on yields of corn on Marshall silt loam.

in the soil were more important than erosion in reducing yields on the continuous corn plot.

Yields of oats have varied widely from year to year (table 8), directly or indirectly reflecting the effect of weather conditions on plant growth and development of rust in the earlier years of the experiment before rust-resistant varieties of oats were introduced.

TABLE 8.—*Acre yields of oats, clover, and alfalfa, average of experiment 1 and 2, 1933–42*

Year	Rotation oats	Rotation clover	Continuous alfalfa	Year	Rotation oats	Rotation clover	Continuous alfalfa
	Bushels	*Tons*	*Tons*		*Bushels*	*Tons*	*Tons*
1933	------	2.8	2.5	1939	20.3	(1)	3.1
1934	5.3	1.5	2.5	1940	34.1	1.2	3.9
1935	35.7	.8	3.4	1941	64.0	1.6	4.3
1936	12.3	2.0	3.6	1942	22.8	2.8	4.2
1937	47.6	(1)	3.1				
1938	26.4	(1)	2.5	Average	29.8	1.3	3.3

[1] Destroyed by grasshoppers and drought.

As shown in table 8, also, yields of red clover were extremely variable, depending on weather conditions. The extreme drought in 1934 was responsible for the low yield in 1935. Seedings in 1936, 1937, and 1938 failed because of unfavorable weather conditions and damage from grasshoppers and chinch bugs. On the other hand, the yields of alfalfa were good regardless of the season and it was not necessary to reestablish the seeding during the entire period. Ordinarily alfalfa becomes infested with wilt and fails within 3-4 years after it is seeded unless wilt-resistant strains are seeded. As a 10-year average, two cuttings of alfalfa each year gave a yield of 3.3 tons per acre which is 2.5 times greater than the 1.3 tons per acre average from red clover. The much larger yields of alfalfa, the lower seed cost which results from less frequent reestablishment, and reduced losses of runoff and erosion are all factors in favor of adopting rotation with more consecutive years of meadow. Bromegrass, which is well adapted to the Missouri Valley region, when used with alfalfa, has promising possibilities in providing more adequate protection to the soil surface from erosion, in furnishing pasture or hay, and in resisting unfavorable weather conditions that occur frequently in this region.

Effect of Cropping Systems on Organic Matter, Experiments 1 and 2

Carbon determinations on samples taken annually from the control plots (*11*) show that there has been a 16-percent decrease from the original carbon content in the case of continuous corn; whereas, a rotation of corn, oats, and clover has maintained the carbon content at the original level; furthermore, that continuous bluegrass has not increased the carbon content above the original level and is as effective as the rotation in maintaining the carbon content.

Data by Slater and Carleton (*36*) show that on the Marshall silt loam the eroded material contains a higher concentration of organic matter than the original soil. This is in agreement with data reported by several investigators and summarized by Neal (*28*), namely, that organic matter as well as other nutrient elements are higher in the eroded material than in the original soil.

Effect of Cropping Systems on Aggregation, Experiments 1 and 2

The effects of different crops grown from 1932–42 on aggregation of samples collected from the control plots in 1942 are shown in figure 23. These data represent the average of 2 sampling dates—June 1 and July 17. Aggregate distribution was determined by a method essentially as described by Yoder (*44*). Cropping to continuous corn has materially reduced the aggregates 0.25 mm. The clover, which is turned down before the corn in rotation of corn, oats, clover has increased the aggregates 2.7 percent in comparison with continuous corn. This, in addition to the smaller amount of plant

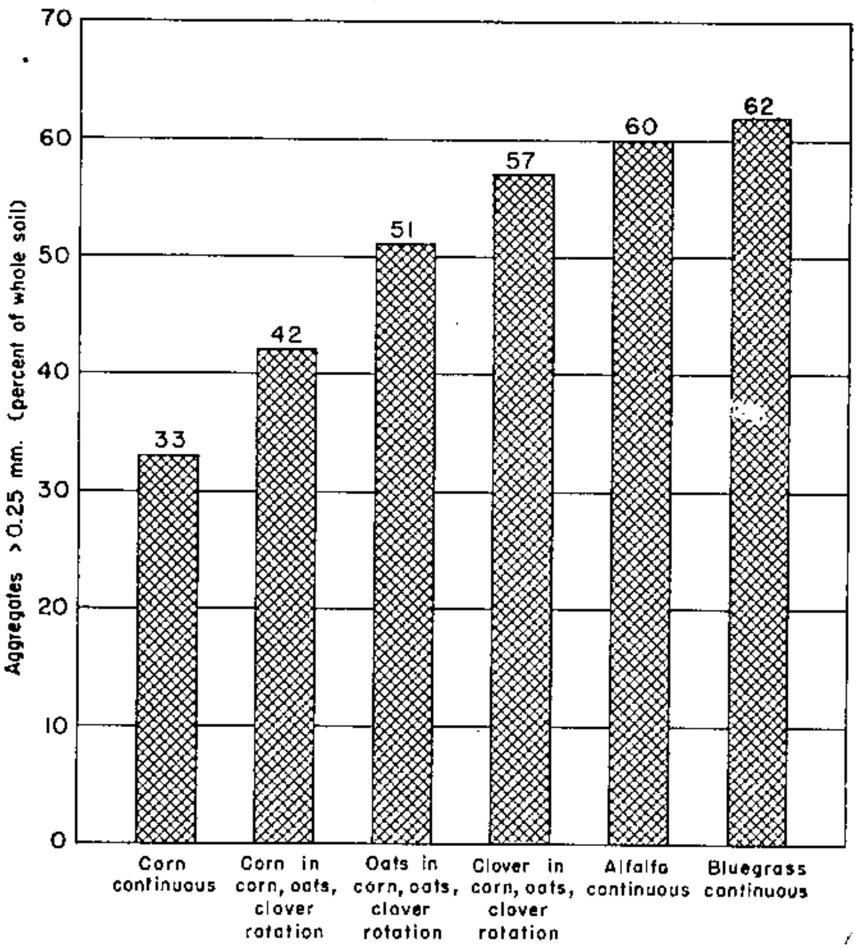

FIGURE 23.—Effect on soil aggregation of crops grown on Marshall silt loam for 11-year period, 1932–42.

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growth (fig. 16) available to protect the surface from the beating action of raindrops (*1*, *6*, *7*) when continuous corn is used, explains the higher soil and water losses under the system of cropping.

Oats and clover seeded in the oats have increased aggregation over that of the rotation-corn plot by 24 percent, but this value is 12 percent less than from rotation clover.

Alfalfa in comparison with clover has increased aggregation by 5 percent, whereas bluegrass gave an increase of 3 percent in aggregation in comparison with alfalfa.

The increased aggregation from close-growing vegetation emphasizes the importance of including meadows in the rotation in order to maintain a stable structure that will resist the action of tillage implements and the beating action of raindrops during the period when the land is in intertilled crops. Crops are known to differ materially in the type and amount of residue they leave in the soil (*8*, *43*). The chemical composition and amount of residue has also been shown to have an important influence on the amount and stability of the aggregates (*2*). Materials which decompose rapidly, such as legumes, bring about aggregation in a relatively short period of time—2 or 3 weeks under field conditions—but lose their effectiveness within 2 or 3 months. On the other hand, the more carbonaceous materials require a longer period of time to effect aggregation, but have a more lasting effect on soil structure.

If a grass, such as timothy or bromegrass, had been included with the legume in the meadow, a more stable structure would have been expected. It is evident, therefore, that cropping systems influence the structural condition of the soil which in turn determines to a considerable extent the amount of runoff and erosion that occur. Additional information is needed to show the effect of different crops and crop rotations on soil structure for different soil types and under different climatic conditions and the relation of these factors to the susceptibility of soils to erosion.

Lysimeter Measurements of Percolate, Runoff, and Erosion

Obviously it is important to know the relation between precipitation and various forms of loss of water from the soil. Information on the effects of various treatments on water intake, surface runoff, vapor losses, etc., provides the basis for the development of practical methods of water conservation. Soil conservation procedures generally accompany treatments that provide for water conservation.

Investigations were conducted over the period 1935–41 to determine the disposition of rainfall from undisturbed columns of soil 3 feet in diameter and 3 feet deep in Marshall and Shelby silt loam soils, with different cropping practices and organic matter treatments. Measurements were made of the loss of water as runoff, percolate, and vapor from special lysimeter units described by Musgrave (*22*, *25*). The detailed data are given in table 9 and a summary is presented graphically in figure 24.

In the fallow series on Marshall silt loam the application of manure, annually, made at the rate of 16 tons per acre, increased the percolate from 4.5 to 7.3 inches. At the same time the treatment reduced runoff from 8.5 to 7.0 inches. In the corresponding series in corn, the manure application increased the percolate from 1.6 to 3.8 inches, at the same time reducing runoff from 6.5 to 4.6 inches. In the corresponding series in Shelby silt loam, the application of manure increased percolate from 1.2 to 2.6 inches and reduced runoff from 8.4 to 6.7 inches.

These effects are striking, particularly in view of the fact that the application of the treatment was confined to the surface 7 inches of the soil profile, whereas the measurement of percolate shows very marked increase throughout the entire 3-foot profile. The Shelby silt loam, which has a rather impervious subsoil, was affected to an even greater degree than the Marshall silt loam.

Under the conditions of this experiment, runoff from the Marshall and Shelby soils was not significantly different. This probably is due to the relatively short length of slope, 3 feet, and the consequent short-time interval for runoff to occur. On longer slopes the more permeable Marshall soil would be expected to show a larger total infiltration and less runoff than the less permeable Shelby soil. That this is the case is shown by comparing the 27.1-percent runoff from continuous corn on Shelby silt loam at the Bethany, Mo., Soil Conservation Experiment Station (*37*) with the 18.7 percent from the Marshall soil as shown in figure 15.

Accompanying the reduction in runoff there has been even greater reduction in soil losses. On the fallow Marshall series the manure treatment reduced average annual erosion from 15.4 to 12.1 tons per acre. On the corn series of the Marshall silt loam the manure treatment reduced erosion from 9.9 to 6.5 tons per acre. Several interest-

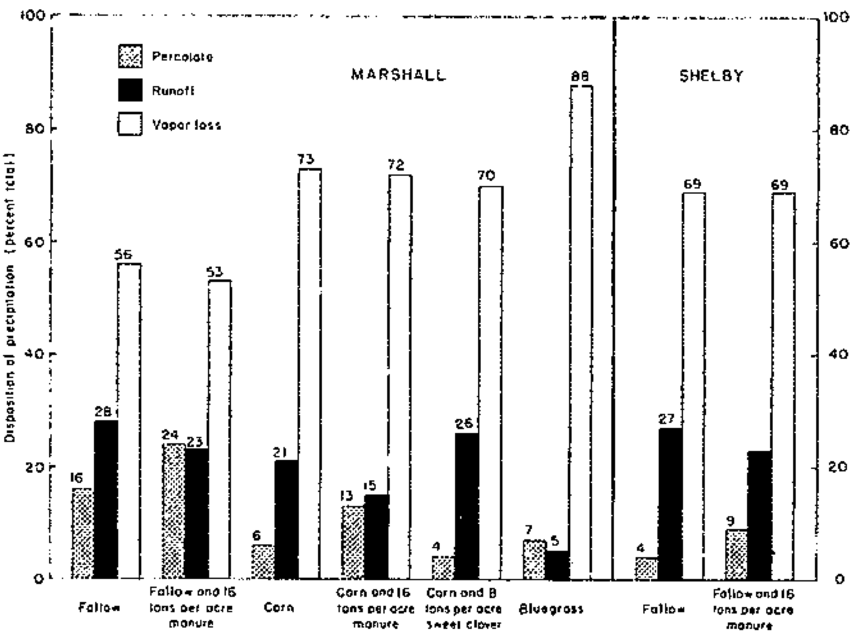

FIGURE 24.—Disposition of precipitation in lysimeters on Marshall and Shelby soils from 1934 to 1941.

ing facts are disclosed by these data. The reduction in runoff in the corn series is proportionately greater than in the fallow series. The reduction of erosion in the corn series is likewise proportionately greater than the reduction in the fallow series. This is in agreement with the results of the effect of organic matter on losses of soil and water as reported under experiment 3. While the runoff in the manured corn series was reduced to 66 percent of the check the erosion in the same series was reduced to less than 25 percent of the check. It is clear, therefore, that the manure treatment is producing several effects. It is: (1) Causing increased soil porosity, which is the result of a mechanical loosening effect of the organic matter and also through increased aggregation, of the surface soil; (2) producing a more vigorous plant with larger leaf surface, which in turn permits more effective interception of rainfall by the corn canopy and thus a better protection of the soil surface from the beating action of the raindrops: and (3) it is producing a plant with a more vigorous root system which apparently has a pronounced effect in binding the soil particles together and reducing the density of runoff.

A fairly close approximation of the effect of the treatment on the vapor losses from the soil may be arrived at by calculating the total losses in the form of percolate and runoff and subtracting the sum from the total precipitation. These results are shown in table 9. The total vapor losses from the Marshall fallow series was 16.7 inches for check and 15.5 inches for manure and represents evaporation from the surface of the soil. The vapor losses from the corn series were essentially the same for check and manure and represent the combined loss of evaporation from the soil and transpiration from the corn itself. It is of interest to note that the addition of manure did not increase the vapor losses in any case, but that the vapor losses from the corn series and bluegrass are considerably higher because of transpiration of the plants.

TABLE 9.—*Summary of water relations, lysimeter experiment 1–B, 1935–41*

[Average annual precipitation—29.75 inches]

Soil and treatment	Runoff [1]	Percolate [1]	Vapor loss	Potentially available water
	Inches	*Inches*	*Inches*	*Inches*
Marshall:				
Fallow, check	8.5	4.5	16.7	21.2
Fallow and 16 tons manure per acre	7.0	7.3	15.5	22.8
Corn, check	6.5	1.6	21.6	23.2
Corn and 16 tons manure per acre	4.6	3.8	21.3	25.1
Corn and 16 tons sweetclover per acre	7.6	1.4	20.7	22.1
Bluegrass, check	1.4	2.0	26.3	28.3
Shelby:				
Fallow, check	8.4	1.2	20.2	21.4
Fallow and 16 tons manure per acre	6.7	2.6	20.5	23.1

[1] Differences in inches of less than 1.1 and 1.2 for runoff and percolate, respectively, are not considered significant.

Regarding potentially available water as all water which enters the soil profile, it may be observed from the table that manure decreased runoff and thereby increased in both the fallow and the corn series the amount of water stored in the soil or lost as percolate or vapor.

It is also of interest to compare the vapor losses from the relatively impermeable Shelby soil with those from the more permeable Marshall silt loam. In both the check and manure treatments of the Shelby soil there have been increases in vapor losses of more than 21 and 30 percent, respectively, above that of the corresponding treatments in the Marshall series for the same period of time. A possible explanation of these greater losses in the relatively impermeable soil is that the general moisture level in this soil is nearer the surface. This is borne out by the greater total percolation in the Marshall than in the Shelby soil.

The limitation of the lysimeter as a means for studying the movement of moisture and nutrient material through soils has been recognized by different investigators (*13*). The question may be raised as to how moisture movement in short columns of soil compares with normal movement in the undisturbed profile. That the relation between moisture flow and negative pressure or tension in the lysimeter is not simple and is affected by relatively small changes in moisture is evident from studies on lysimeter installations on Marshall silt loam and Shelby silt loam at the Clarinda Experiment Station (*31, 34, 35*). Regardless of whether the results from lysimeters are directly comparable to field conditions, they offer the opportunity to study the relative effect of cropping practices and soil treatment on movement of moisture and nutrients through suspended undisturbed columns of soil.

Rainfall and runoff are seasonal; therefore, it is to be expected that percolate will vary not only with the rainfall but also with the manural treatment and the type and amount of plant growth. That this is the case is apparent from table 10. In general, June, May, and April are months of highest percolation. For example, 75.5 percent of the annual percolate from corn occurred in this period. An exception to this is bluegrass which lost 64.0 percent of the total yearly percolate in October, September, and November.

TABLE 10.—*Seasonal occurrence of percolate from Marshall silt and Shelby silt loam under different treatments, lysimeter experiment 1–B, 1935–41*

[Average annual precipitation—29.75 inches]

Month	Percolate							
	Marshall silt loam						Shelby silt loam	
	Fallow	Fallow manure	Continuous corn	Continuous corn manure	Continuous corn sweetclover	Bluegrass	Fallow	Fallow manure
	Percent[1]	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
January	1.5	1.3	---	0.2	---	---	3.6	1.9
February	6.5	3.6	0.1	1.2	---	0.3	1.2	.4
March	11.1	9.8	.5	2.5	---	.3	12.2	6.6
April	14.5	11.1	11.0	12.6	8.7	2.8	13.7	6.8
May	17.5	11.9	27.6	10.0	18.0	2.6	14.1	12.0
June	1.1	21.2	36.9	32.8	56.2	24.1	20.5	27.1
July	3.8	6.0	.9	1.6	.6	.5	3.4	5.7
August	1.2	4.4	1.6	1.3	1.1	.8	1.8	4.5
September	2.3	8.8	3.8	3.7	.6	12.6	2.7	9.6
October	6.5	5.5	3.3	11.9	.2	41.3	3.4	7.1
November	5.7	8.1	7.0	7.9	4.7	10.1	8.9	10.3
December	8.3	5.3	6.8	5.3	9.7	4.7	5.5	8.1
Amount of percolate	4.5	7.3	1.6	3.8	1.4	1.4	1.2	2.6

[1] Expressed as percent of average annual rainfall.

Nutrients in the Percolate

To study the effect of soil type, manural treatment, and cropping system on nutrient losses, percolate samples were collected and analyzed for nitrogen, calcium, and magnesium. The data for two different periods of time are shown in tables 11 and 12. In 1935, a year when rainfall was excessive, the losses of calcium and magnesium were considerably higher than in the drought year of 1936. The application of manure materially increased total calcium and magnesium lost in the percolate, whereas cropping, particularly to a close-growing crop, such as bluegrass, materially reduced the loss of calcium and magnesium. The losses from the Marshall soils were considerably higher than from comparable treatments on the Shelby soils. These differences may be explained in part by the larger amount of percolate as well as the difference in concentration of nutrient materials in the soil solution.

Table 11.—*Calcium and magnesium in percolate from lysimeters, 1935–36*

[Precipitation: 1935, 32.35 inches; 1936, 22.02 inches]

Soil, crop, and treatments	1935		1936	
	Ca per acre	Mg per acre	Ca per acre	Mg per acre
Marshall silt loam:	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Fallow	175.5	42.5	39.8	12.1
Fallow plus 16 tons per acre of manure	394.0	105.1	112.3	30.4
Corn	173.7	37.7	4.5	1.3
Corn plus 16 tons per acre of manure	211.9	48.9	51.0	12.2
Bluegrass			6.8	1.2
Corn plus 16 tons per acre of sweetclover			20.5	4.7
Shelby silt loam:				
Fallow			16.7	7.8
Fallow plus 16 tons per acre of manure			35.6	11.7

Table 12.—*Nitrogen, calcium, and magnesium in percolate from lysimeter on Marshall and Shelby silt loam with different crops and residues, May to September, 1941* [1]

[Total rainfall May to September, 1941, 25.15 inches]

Soil, crop, treatment	N as NO_3 per acre	Ca per acre	Mg per acre
Marshall silt loam:	*Pounds*	*Pounds*	*Pounds*
Fallow	31.7	32.2	11.4
Fallow plus 16 tons per acre of manure	90.1	110.2	31.6
Corn	2.5	64.3	19.2
Corn plus 16 tons per acre of manure	34.3	31.4	28.7
Bluegrass	2.0	149.1	41.6
Corn plus 16 tons per acre of sweetclover	246.6	321.5	90.1
Shelby silt loam:			
Fallow	19.6	53.2	13.2
Fallow plus 16 tons per acre of manure	78.1	103.9	41.7

[1] Data represent the average for triplicate lysimeters.

Table 12 shows that continued application of relatively large quantities of organic matter over a period of time materially increased the loss of nitrogen, calcium, and magnesium in the percolate. The extreme differences in organic matter losses may be observed by comparing the 2 pounds per acre loss of nitrogen from Marshall soil in bluegrass with the 246.6 pounds per acre loss from corn to which an application of 16 tons per acre of sweetclover had been applied annually. Further evidence that relatively large losses of the excess nutrient materials may occur from permeable soil such as Marshall is seen by comparing the 246.6 pounds per acre nitrogen loss under corn when sweetclover is the source of manure, with 34.3 pounds per acre loss from barnyard manure. The sweetclover decomposes much more rapidly than the more carbonaceous barnyard manure. There is also a greater excess of nitrogen in the soil solution to be lost in the percolate unless there is sufficient plant growth to utilize it as it becomes available.

Organic Matter in Relation to Erosion Control, Experiment 3

The concurrent and residual effect of organic matter on runoff, erosion, crop yields, and carbon content of desurfaced Marshall silt loam have been reported by Neal (*30*). Changes in moisture content as affected by treatment have been reported previously (*33*). In general the data show that soil and water losses have been materially reduced by the annual application of 8 and 16 tons per acre of barnyard manure or a leguminous green manure. The second 8-ton increment was somewhat less effective in reducing the loss of soil and water than the first 8 tons. Soil and water losses were significantly less from continuous corn than from fallow, indicating that even an intertilled crop such as corn intercepts considerable water and gives a limited protection to the soil surface. Organic matter was more effective in reducing losses under corn than under fallow. During a 3-year period, immediately after the application of organic matter had been discontinued, the fallow plots showed little evidence of reduction in runoff as a residual effect of the previous treatments. On the other hand, under continuous corn there was a distinct residual effect of treatment, probably due largely to the differences in the vigor and amount of vegetative growth. Organic-matter treatments materially increased corn yields during the years when it was applied. Also their effect was to maintain yields at practically the same level during a 3-year period immediately after treatments were discontinued. The addition of as much as 64 tons of organic material per acre during a 3-year period gave only a very slight increase in the carbon content of the surface soil. This emphasizes the extreme difficulty of replenishing the organic matter content of cultivated soils.

Effect of Length of Slope and Direction of Row, Experiment 4

Length of Slope.—It has become increasingly apparent that the relative runoff that occurs from slopes of different lengths is directly related to the factors of rainfall intensity and infiltration rate.

In the comparison of length of slope in experiment 1, there was some doubt as to whether sufficient differences in length had been provided in the original plans. If relative runoff is determined by the relationship of infiltration rate to rainfall intensity, then it is obvious that a proper comparison of slope length must contain such differences in comparison as to allow appreciable time for infiltration to occur on the various lengths under study. Experiment 4 provides slopes of 157.5, 315, and 630 feet in length.

Long slopes are more of an erosion hazard than short slopes as shown in figures 25 and 26. The data in figure 25 represent the results obtained from the control plots series, plot 1, 2, and 3, which were cropped continuously to corn planted and cultivated uphill and downhill. Figure 26 shows data from experiment 4 located about 100 yards from experiment 1. The plots of experiment 4 were also cropped continuously to corn, but were loose-ground listed in rows uphill and downhill. Treatment of experiment 4 also varied from experiment 1 in that a cover crop of rye and vetch was seeded annually in the standing corn about August 15. This difference in management, as well as some variation that may be expected in the soil at different locations, probably explains the difference in absolute values for soil and water losses from the two experiments. In other words, part of the differences in soil losses between surface-planted and listed corn may be explained by the fact that runoff water from listed corn is confined to the bottom of the lister furrow, whereas water from surface-planted corn comes from the entire surface area. The loss of the loose soil from the bottom of a lister furrow may be excessive during the early part of the storm after the loose soil is removed. However, the undisturbed and compact soil at the bottom of the lister furrow may be more resistant to erosion than is the entire loose surface area of surface-planted corn.

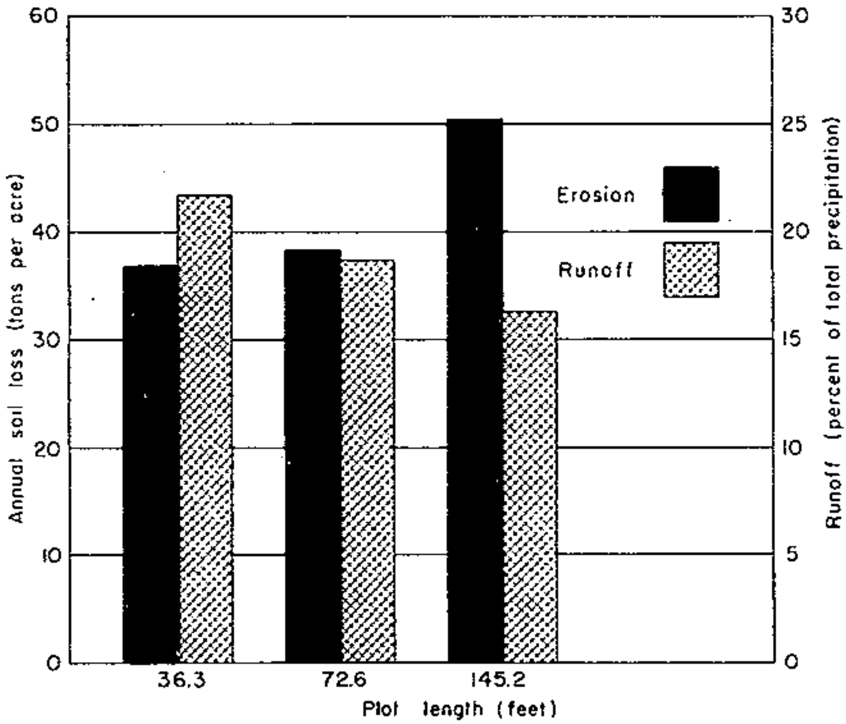

FIGURE 25.—Effect of length of slope on runoff and erosion on Marshall silt loam, experiment 1.

Although the absolute values for length of slope vary between experiment 1 and 4, the average of the yearly soil-loss ratios obtained by doubling the length of slope in experiment 1 and 4 are not materially different, as shown in table 13. It is to be seen that there is considerable variation in the ratios from year to year. This is to be expected since the intensity, amount, and distribution of rainfall influence the soil and water losses, depending on the length of slope (*19*, *20*). The smaller and less intense rains produce more runoff and soil loss from short plots than from longer plots. This is due to the fact that the shorter distance of overland flow does not allow so much time for water to soak into the soil as a longer distance. On the other hand, hard-driving rains cause proportionally more loss from long slopes than from short slopes. This increased loss is caused by the greater con-

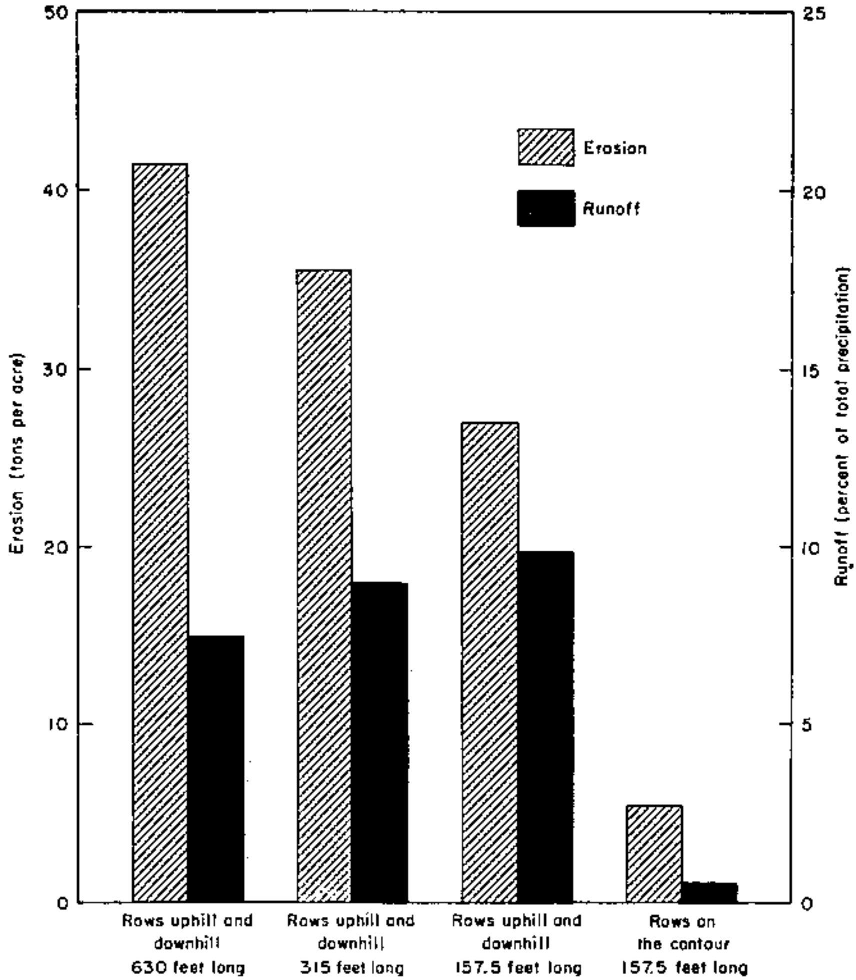

FIGURE 26.—Effect of length of slope on runoff and erosion on Marshall silt loam, experiment 4.

centration of water flowing over the surface and the larger volume of water flowing over the lower parts of the slope. However, if average values for the entire period are considered, it is evident that for slopes longer than 72.6 feet the ratio obtained by doubling the length of slope is relatively constant. The average ratios between the 72.6 and 36.3 feet plots is somewhat smaller than the ratios for the longer slopes. Since the 36.3-foot length of slope is not important from the standpoint of designing practical erosion control measures, it was omitted to obtain the average ratio 2.63 for slopes greater than 72.6 feet. In other words, if all the ratios are averaged, they show that doubling the length of slope increased the soil loss 2.63 times. This is in general agreement with data by other investigators (*5, 6, 14, 27, 45, 46*).

TABLE 13.—*Annual soil loss ratios produced by doubling length (in feet) of plots, Marshall silt loam, 1933–42* [1]

Year	Soil-loss ratio for lengthened plots			
	From 36.3 to 72.6	From 72.6 to 145.2	From 157.5 to 315.0	From 315.0 to 630.0
1933	1.30	3.20	3.57	3.45
1934	1.93	2.02	2.33	3.71
1935	2.19	2.44	2.40	2.01
1936	3.06	1.94	3.37	3.51
1937	1.86	2.72	2.36	2.31
1938	1.50	2.99	1.61	1.13
1939	2.06	2.00	3.16	2.04
1940	2.56	2.12		
1941	2.09	3.21		
1942	1.73	2.54		
Average 1933–39	1.98	2.61	2.68	2.50
Average 1933–42	2.03	2.62		

[1] Values for 36.3-, 72.6-, and 145.2-foot length plots from control plots experiment 1, corn planted in rows uphill and downhill. Values from 157.5-, 315-, and 630-foot length plots from experiment 4, corn listed uphill and downhill. Average ratio for all lengths, 2.46. Average ratio omitting $\frac{72.6}{36.3}$, 2.63. Since 72.6-foot length is about the average terrace spacing for Marshall soils and it is not practicable to consider control measures for slopes as short as 36.3 feet, the value 2.63 has been used in calculations relating soil losses to length of slope for the Marshall soils.

Since the ratios obtained from doubling the length of slope were similar in both experiments, a uniform ratio of 2.63 was assumed throughout the length of slope studied. The values for experiment 4 were, therefore, adjusted to the same management condition as in experiment 1. Similar calculations were also made for runoff. These data are shown in table 14. The limitation of such calculations should be recognized, but, it is believed that the results are in general agreement with what would be expected under field conditions.

Length of slope in relation to runoff.—It was found that soil loss increased with length of slope. From figure 25 and 26 it is evident that the percentage runoff decreases with increase in length of slope. Doubling the length of slope increased the percentage runoff 0.73 times (table 15). In other words, adding an extra increment of slope gave the runoff water from the first increment an opportunity to be absorbed by the second increment of slope; consequently, a higher percentage of the total rainfall penetrated the soil. The percentage decrease in total runoff, however, should not be confused with the fact that there was actually more water flowing over the lower increment of slope. For example, 18.7 percent of the total rainfall was lost as runoff from a 72.6-foot length of slope on plot 3, experiment 1. The first 72.6-foot length of the 145.2-foot length of slope would also produce the same amount of runoff, 18.7 percent. This amount plus the runoff from the bottom 72.6 feet of the slope would materially increase the amount and velocity of water flowing over the lower part of the slope. This explains the larger amount of soil that is lost from the longer slope.

Recent data by Krusekopf (*14*) indicate that the relation between length of slope and soil and water losses is not the same from continuous corn as from a rotation of corn, wheat, and clover. He observed that the relationship between length of slope and soil and water losses from continuous corn is of the same order as found by other investigators. He found, however, that length of slope was not a factor in increasing the loss of soil and water when the plots were cropped to a rotation of corn, wheat, and clover.

TABLE 14.—*Effect of length of slope on soil and water losses, Marshall silt loam, experiments 1 and 4, 1933–42*

Experiment	Slope length	Soil loss per acre		Runoff	
		1933–39	1933–42	1933–39	1933–42
	Feet	*Tons*	*Tons*	*Percent*	*Percent*
1	36.3	29.7	30.9	17.4	21.2
1	72.6	30.5	38.3	14.5	18.2
1	145.2	37.8	50.4	13.2	16.1
4	157.5	29.2	[1] 51.8	10.4	[1] 16.0
4	315.0	36.0	[1] 68.5	9.4	[1] 13.9
4	630.0	41.8	[1] 90.5	7.8	[1] 12.1

[1] Calculations made on basis of values for 145.2-foot plot, 1933–42, using factors 2.63 and 1.73 for increased soil and water loss, respectively, when length of slope is doubled.

TABLE 15.—*Annual runoff ratios produced by doubling length of plots, Marshall silt loam, 1933–42* [1]

Year	Runoff ratio			
	From 36.3 to 72.6	From 72.6 to 145.2	From 157.5 to 315.0	From 315.0 to 630.0
1933	1.34	1.59	1.53	2.01
1934	1.67	2.01	1.68	1.28
1935	1.57	1.84	1.46	1.30
1936	1.95	1.63	1.50	1.52
1937	1.46	1.77	2.05	1.45
1938	1.90	1.74	1.51	1.66
1939	1.70	2.02	1.70	2.01
1940	2.08	1.75		
1941	1.90	1.70		
1942	1.22	1.57		
Average 1933–39	1.66	1.81	1.52	1.60
Average 1933–42	1.69	1.79		

[1] Average ratio for all lengths equals 1.73. Since ratio is essentially the same for all plot lengths the average of all values was used.

It is logical to expect that length of slope will be less of a factor affecting soil and water losses when a rotation is used. Obviously, the small grain and clover grown in the rotation are less of an erosion hazard than continuous corn. Likewise, the losses of soil and water from rotation corn are less because of the improved physical condition of the soil following the clover sod. However, if length of slope is not a factor when a rotation of corn, wheat, and clover is followed, other control measures which reduce length of slope, such as terracing, contouring, and strip cropping, would not be needed regardless of length of slope. Practical experience would indicate that this is not the case. Further studies carried on over a long period of time to average out climatic variations are needed to answer this problem definitely.

Steepness of slope in relation to soil and water losses.—Although studies were not conducted to determine the effect of increasing the degree of slope on the loss of soil and water from the Marshall silt loam, investigations at other locations that included widely different soils and slopes show that runoff and erosion increase as the slope of the land increases. For example, data on Shelby loam soil at the Bethany Soil Conservation Experiment Station show soil loss from an 8-percent slope to be 2.6 times as great as that from a 4-percent slope. Furthermore, loss from a 12-percent slope was 4.7 times that from a 4-percent slope.

INFILTRATION

Infiltration, or the rate at which precipitation penetrates into the soil profile, is influenced by a number of factors and may be measured in a number of ways. One of the most satisfactory undoubtedly is to compare the rate of rainfall and the rate of runoff. Another method is to apply water directly to the soil at known rates and for specific conditions of structure, slope, soil-moisture content, and vegetative cover. It is also possible to get relative differences in infiltration by measuring percolate from lysimeters as described previously. However, it should be remembered that the actual amount of percolate is materially influenced by the moisture content of the soil and vapor loss by evaporation and transpiration.

On the Marshall soil at the Clarinda Soil Conservation Experiment Station and on other soils and under other cultural conditions, studies were conducted to determine the infiltration rate by direct application of water to the soil at known rates as described in detail elsewhere (*21*, *23*). It is recognized that this procedure fails to simulate the dispersing action of raindrops. It is also recognized that such raindrop action is of extreme importance on soils which, because of inherent characteristics or past management, run together badly and form a crust at the surface that materially limits the rate at which water penetrates the soil. Nevertheless, this procedure makes possible the comparison of infiltration rates of different soils under specific conditions. It is helpful also in evaluation of the effect of different factors affecting runoff and erosion. The infiltration of Marshall silt loam has been found to be approximately from 7 to 10 times more rapid than that of Shelby silt loam. If, as an example, we should take these two soils and apply to them the same treatment for the surface impoundage of water, we could provide a degree of protection on permeable Marshall silt loam to exceed the greatest rainfall that has been reported by the weather bureau in this section. In fact, as will be shown subsequently, listing on the contour and level terraces has provided essentially complete control of runoff and erosion on the Marshall silt loam even though cropped continuously to corn. On the other hand, the same treatment on the Shelby silt loam would fail to provide protection by as much as 2 surface inches per hour in a long-continued rain.

One of the most potent factors affecting the infiltration rate of a soil profile is the amount, size, and distribution of its soil pores. For example, it has been found in comparing three profiles, one of which is cultivated 6 inches deep, one 4 inches deep, and the other left uncultivated, that the infiltration is greatest on the deeper cultivated profile and least on the uncultivated or check treatment. The infiltration rates for these three conditions on Marshall silt loam are 1.20, 1.00, and 0.77 inches per hour, respectively, as based on a 3½-hour run. The average percentages of porosity were 57.4, 55.8, and 52.8, respectively, for the entire profile. The details of this study have been presented separately (*23*).

It has also been found that the addition of organic material in the form of green manure, stable manure, etc., considerably increases the infiltration rate. This may be explained partly by the protection afforded the surface by organic material, the direct loosening effect of the organic material, and the increased aggregation it affords. In this case the effects of the treatment are prolonged over several months. On cultivated soil, however, the effect of the treatments is transitory, lasting in the case of the Marshall silt loam only for about one-half hour following the application of water, and in the case of the Shelby silt loam about 1½ hours following the application of water.

The infiltration capacity of the soil is affected by the presence of soil moisture at the beginning of the application of water to the extent to which the water itself occupies pore space within the profile. Thus, in soil in which 2.2 inches of water was contained within the profile, the intake of water was reduced by 2.5 inches. In Marshall silt loam, at least, soil moisture appears to be a more potent agent in the form of actual space occupancy as indicated above, rather than in any possible effect it may have on the swelling of soil colloids.

Type and amount of vegetation definitely affect the infiltration rate. Probably the most important effect of vegetation is to protect the surface soil from the beating action of raindrops. It also materially reduces the rate of surface runoff, thus allowing more time for infiltration. Vegetation also tends to reduce the concentration of surface water into rivulets, thus presenting a greater surface for infiltration. Likewise, the improved physical condition of the soil that results from root action and the presence of organic matter added by the roots is also important, particularly in the case of grasses which have a fine network of roots.

Soil Moisture on Terraced Areas

A rather intensive study has been made to determine the effect of terracing and contour listing on moisture distribution on Marshall silt loam. The detailed results of this study have been reported previously (*3, 29*). In general, the data show that the moisture content was 4.6 percent higher under the channel of two level terraces than under the ridges, and 2.7 percent higher than under the middles. The middles were 1.9 percent higher than the ridges. Similar results were obtained for graded terraces.

Under the conditions of these experiments there was little or no evidence that water held in the channel of level terraces moved far enough laterally to affect the moisture content of the profile samples taken on the terrace ridge, a distance of approximately 10 feet from where the samples were taken in the terrace channel. These areas were listed on the contour and runoff from the interterraced spaces to the channel was considerably less than would have been the case if the corn had been surface planted. The typical Marshall silt loam soil has a high permeability; therefore the greatest movement of water is downward and there is little tendency for the water to move laterally. It was observed, however, that as the impermeable glacial till was closer to the surface at lower levels on the slope the moisture moved downward through the permeable loessial mantle until it reached the impermeable glacial till and then moved along this layer, increasing the moisture content of subsoil samples. In places where the glacial till comes close to the surface the entire soil mass becomes saturated and seepy spots develop on the hillside which are of considerable inconvenience to farming operations at certain seasons of the year.

Effect of Contour Listing on Runoff and Erosion, Experiment 4

The effect of contour listing on loss of soil and water is shown in figure 27. It is evident from the table that an average annual soil loss of 27.2 tons per acre was reduced to 5.2 tons per acre by listing on the contour. Likewise, runoff from contour listing was about one-fifth that from rows that run uphill and downhill. This means a saving of about 2.5 inches of rainfall each year by contouring. In years when moisture is limited, as is frequently the case in the Missouri Valley region, the extra moisture may be the difference between a reasonably good crop or a crop failure. Total soil loss for the 7-year period was 36.6 tons per acre from the plot with the rows listed on the contour and 190.4 from the plot with rows listed uphill and downhill.

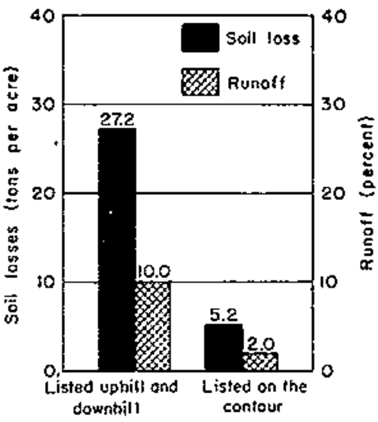

Figure 27.—Effect of contour listing on soil and water losses on Marshall silt loam, 1933–39.

One rain on May 6, 1937, was responsible for 32.2 of the 36.6 total tons of soil lost from the contoured plot. This rain came after the land had been plowed and worked down level and before the corn had been listed. There was little or no capacity to impound water and the soil was loose and susceptible to erosion; consequently runoff and erosion were excessive.

During the 7-year period 13 storms, 7 of which were from melting snow, produced runoff from the contoured plots, whereas 48 storms produced runoff from the plot with rows uphill and downhill. Apparently more snow was held on the contoured plots than on the plot with rows uphill and downhill. The soil was still frozen when the snow melted; hence most of the water was lost as runoff.

It is to be seen from these data that the listing practice, which provides a deep furrow in which the corn is planted, furnishes considerable capacity for the surface impounding of water provided the rows are on the contour. During subsequent cultivation of the corn the furrows are filled in and in the final cultivation are ridged, the amount depending upon the type and angle of shovels or sweeps and upon the speed with which the cultivator is operated. As commonly practiced the ridging is sufficient to impound one or more inches of water on slopes up to 9 percent.

It should be recognized that under field conditions there will be more variation from the true contour than on the plots in this experiment because of irregularity in the slope. Slopes in many cases will also be longer than under the conditions of this experiment. The soil and water losses, therefore, may be somewhat larger than found in these studies. However, with reasonable care in laying out the contour lines to prevent depressed areas in some places and excessive variations from the contour in other places, contouring, especially contour listing, used with grassed waterways is a very effective means of reducing losses of soil and water when the slopes are not too long. Where excessive water has to be handled, as on long slopes, contouring alone is not adequate. In these cases, strip cropping, terraces, or other conservation measures are needed to divert the excessive water from the field at a slow enough rate to prevent cutting.

Furrow openers provide another method of surface impounding that aids in reducing losses of water and soil. Disks attached to the planter open a furrow considerably smaller than that left by the loose- or hard-ground lister but still large enough to impound considerable water unless the slope is too steep.

Another method of changing the surface configuration to impound water and help hold snow during the winter months is the disk hiller. The inside shovels or sweeps are replaced by disks at the last cultivation. These disks are set to throw soil into the row and under average conditions produce a ridge that will impound 1½ to 2 inches of water if the rows are on the contour (fig. 28). One objection to the disk hiller from the practical standpoint is that the field is left unusually rough and more time is required to work the ridges down when the seedbed is being prepared for oats the following spring. However, if the first disking parallels the rows, most of the ridge will be destroyed and subsequent diskings at angles to the ridges are effective in smoothing the surface and thoroughly incorporating the stalks and other residue with the soil, leaving a very satisfactory seedbed. Using the cultivator on the tractor when disking has also been found effective in breaking down the ridges and in reducing the number of times required to go over the ground to prepare a satisfactory seedbed.

The effectiveness of contouring is determined by the impounding basin left by the tillage implement, slope of the land, amount and intensity of rainfall, and the infiltration capacity of the soil. It is obvious

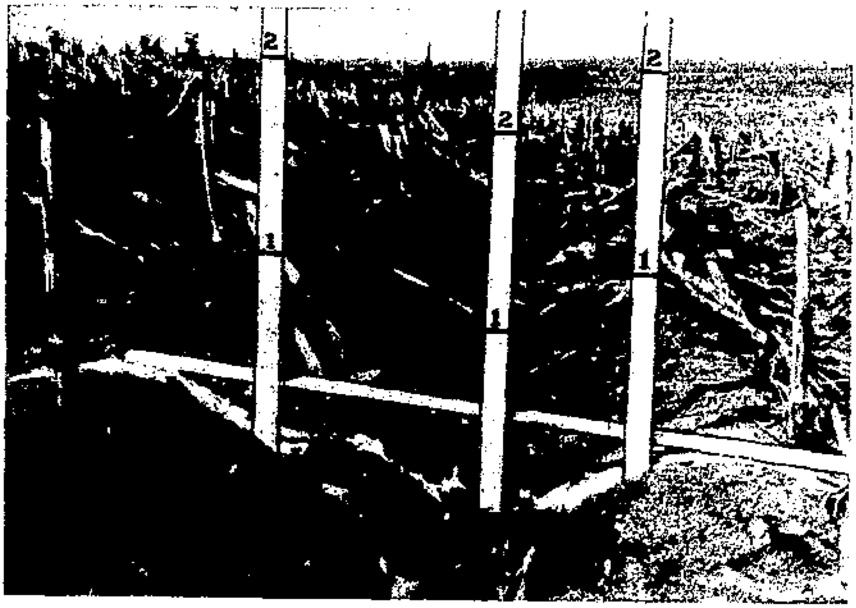

FIGURE 28.—Cross section of corn row on 9-percent slope of Marshall silt loam. The disk hillers left ridge and furrows with capacity to impound 2¼ inches of water.

that the lister furrow, which is much larger than the basin left by the furrow opener, is much more effective in impounding water; furthermore, that the small depression left by the planter marks when the corn is surface planted will afford a minimum capacity to impound water. Certain soils and climatic conditions are not suitable for listing, but wherever adapted listing affords a very effective means for impounding water. The Marshall and closely associated soils of the Missouri Valley loess region are adapted to listing. Further study is needed to determine the possible use of the lister on other soils.

Slope of Land as it Affects Contouring and Surface Impoundage.—Slope of the land is another important factor influencing the effectiveness of contouring. As a slope increases the effectiveness of any impounding basin decreases. This is shown in figure 29. It is to be seen from *b* that at about a 24-percent slope a furrow of the size normally made with the lister ceases to be effective in impounding water. The smaller furrow opener, such as might be represented by *c*, is not effective on slopes much above 20 percent. Planter marks with surface planting, disk and cultivator marks, and cornstalks at right angles to the slope are all helpful in impounding water and decreasing the velocity on gentle slopes. Their capacity, however, decreases rapidly with increasing degree of slope and is lost on steeper slopes.

Methods of impounding water are also more effective on soils with high infiltration rates. For example, assume that there are 2 inches of rain in one hour, which is about a 15- to 20-year frequency in the Missouri Valley region, on a soil that has an infiltration rate of 0.75 inches per hour and that lister furrows are used which will impound

1.25 inches of water. Under these conditions there would be no loss of water as runoff since the infiltration rate and the impounding capacity equal the total rainfall. On the other hand, consider a less permeable soil with the infiltration rate of 0.1 inch per hour. Then, the lister furrows and the amount that entered the soil would amount to only 1.35 inches and the remaining 0.65 inches would be lost as runoff. Actually, a soil with an infiltration rate of 0.1 inch per hour would hold water in the furrow and drown out the crop; therefore, a smaller furrow or surface planting would be necessary and this would further reduce the capacity to impound water.

Contour farming has also been found very effective in increasing yields. Studies conducted from 1942 through 1944 in cooperation with 237 farmers at different locations in Iowa show that on the average contouring increased the yields of corn 6.2 bushels per acre and soybeans 2.2 bushels per acre. The lower yields on the uphill and downhill

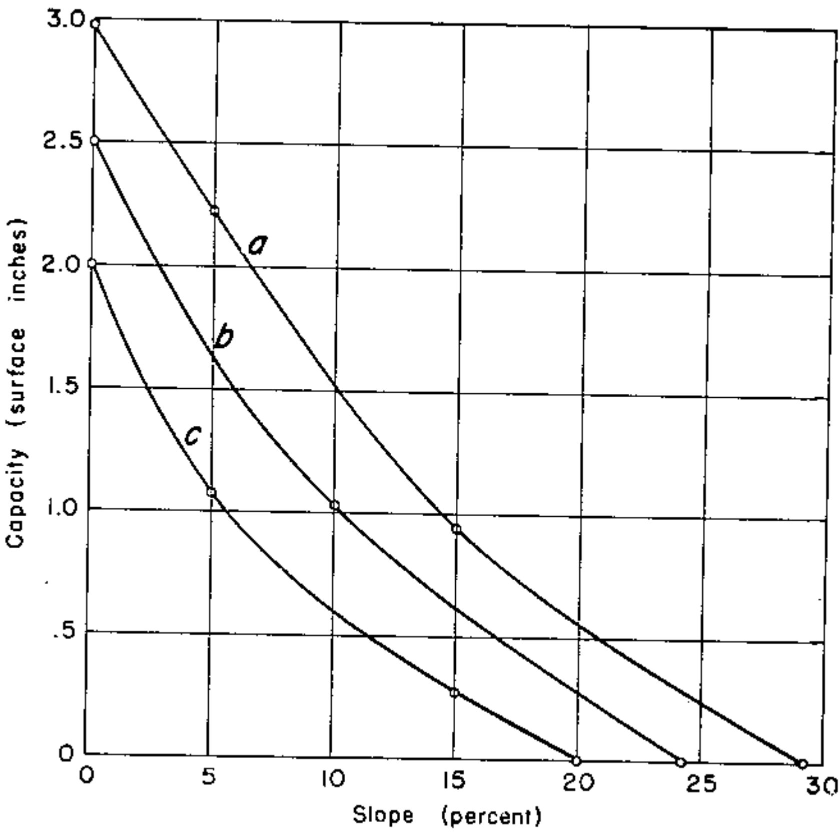

FIGURE 29.—Relation of degree of slope to theoretical capacities for impounding surface water. Theoretically, furrow represented by *a* retains 3.0 surface inches of water at 0-percent slope and loses its capacity at 28-percent slope; *b* retains 2.5 surface inches at 0-percent, and loses its capacity at 24-percent slope; *c* retains 2.0 surface inches at 0-percent slope and loses its capacity as 20-percent slope.

area may be explained by reduced stands caused by washing out of the plants and by damage to roots that are exposed and destroyed by the sun or by subsequent cultivations.

Another advantage in favor of contouring is that extra moisture is held, as has been shown previously. During periods when rainfall is limited this may decidedly increase the yield on the contoured areas. There also is a saving of about 10 percent in power and fuel when all farming operations are carried out on the contour.

In addition to the short-time effects, contouring, by saving the soil and soil fertility, can be expected over a period of time to have even larger effects on yields than were found during the short-time studies referred to.

STRIP CROPPING

The practice of strip cropping is a method of controlling runoff and erosion. It increases canopy interception, infiltration, and surface impoundage, and provides the lowest density of runoff. It consists of growing crops in strips across the slope, the width of the strip representing slope lengths which give the least runoff for the soil, slope, and common rainfall intensities of the locality. The ideal treatment will produce these several control measures during the season of the year when maximum rains commonly occur. The basic design of the strip-cropping procedure will vary widely for different soils, slopes, and prevailing agricultural practices. In essence, it is an adaptation of local agricultural practices in that it affords some measure of protection and conservation. For economic reasons it commonly centers around the cash crop or crops of the area.

For example, in the Missouri Valley loess region the maximum rains occur from May to September, inclusive, corn is the common cash crop, and a landslope of 8 percent is common. A 4-year rotation of corn, corn, oats, and clover is commonly used. The basis of the control treatment, therefore, may be this rotation to which a winter cover crop such as rye, or rye and winter vetch is added. Under these conditions protection is particularly needed during the corn years of the rotation from May to September, inclusive.

By placing corn in listed rows on the contour, 1.5 surface inches of water may be impounded on the field. This together with infiltration gives protection against all rains up to frequency of once in 15 or 20 years. By seeding down all drainageways and putting the listed rows on approximate contours so that the water of heavy rains flows naturally to these protected outlets, a series of "safety valves" may be added to the system without appreciable loss of capacity. Through the addition of organic matter (as provided both by the clover and the winter cover crop) still further protection is provided by reason of increased infiltration. To add to the convenience of operation and also to give a certain degree of protection to the field from the time of plowing the clover sod to the listing of corn, strips of close-growing vegetation such as alfalfa, oats, and clover may be used. Such strips serve primarily as correction strips for contoured rows and eliminate short corn rows from the field.

In contrast to conditions such as those indicated above, entirely different measures may be called for on soils of low-infiltration capacity. Under conditions where frequent runoff is likely, dependence must be placed primarily on methods of reducing the density of runoff. Short slopes as well as close vegetation are the most effective means of reducing the density of runoff. Under these conditions relatively narrow strips including as much close vegetation as feasible (corn, oats, clover, or corn, oats, wheat, clover, and timothy) are to be recommended. The same is true of relatively steep slopes on which appreciable surface impounding is impracticable.

The effectiveness of strip cropping in reducing soil and water losses has not been studied on Marshall soils. Several farmers during the drought period 1934–36 tried it on their farms. The results were rather discouraging because of excessive damage to the corn crops from hot winds, grasshoppers, and chinch bugs, which are frequent hazards in this region. As a result, the use of strip cropping is not extensive in the region. In recent years when weather conditions have been more favorable, it seems likely there would have been no detrimental effects from strip cropping. Nevertheless, the number of years when it would be hazardous make it seem inadvisable to recommend strip cropping in this region. Other conservation measures such as contour listing and level terraces are well adapted to serve the same purposes.

COVER CROPS

From the data in figures 19 and 20, it is evident that appreciable losses of soil and water occur in late summer and fall following the last cultivation of corn, and again in the spring before the land is prepared and seeded to oats. A close-growing crop, seeded at the last cultivation of corn or at a date when moisture conditions are favorable for germination, will be helpful in reducing the loss of soil and water. Such a crop will also provide green material to turn under in the spring as a readily available source of nitrates. Seedings of rye and vetch as a cover crop were made on a field basis during the earlier years of the study. In general seedings were successful about 80 percent of the time. Satisfactory stands were not obtained in some years because of moisture deficiency during July and August or injury from insects such as grasshoppers and chinch bugs. Beginning in 1941 seedings of rye and vetch, vetch, sweetclover, sudan grass, oats, alfalfa, orchard grass, and wheat were made at 2-week intervals beginning July 1 and extending through November 15. A 1-horse drill was used for making the seedings in all cases. Rye or vetch or a mixture of rye and vetch have been more successful than any other crops under all conditions studied (fig. 30). Seedings between July 1 and August 15 have been successful about half the time. July and August are normally months of limited rainfall in southwestern Iowa and seedings of cover crops during this period were successful only if the moisture was adequate. Sometimes the seedings also failed, even when moisture was adequate, because of damage from chinch bugs and grasshoppers. In general, however, seedings made on or after August 15 have been successful. In most years, late August and early September seedings produced the maximum amount of growth in the fall and spring. September seedings were also satisfactory, particularly of the small grains and vetch. On the other hand, seedings made later than October 15 have not generally made enough growth to protect the soil from washing or to supply material to be turned down and benefit the succeeding crop.

that is removed by the cover crop. For example, the moisture content of Marshall silt loam on May 4, 1943 with no cover crop was 21.01 percent. However, a rye and vetch cover crop reduced the moisture content of the soil to 16.1 percent. The rye and vetch cover crop was seeded in standing corn on August 14, 1942. In 1943, there was sufficient rain in late May and June to replenish the moisture removed by the cover crop and the yields were not reduced, but in years of very light rainfall considerable damage could be expected.

In general, seedings of a cover crop in a cropping system with only 1 year of corn in the rotation will not be helpful unless oats or some other crop is used that will winterkill or unless the land is plowed for oats, a practice that is not common in the Corn Belt. Plants that are not killed during the winter interfere with preparation of the seedbed for oats in the spring, continue to grow in the oats, and in general cannot be recommended. However, rotations in which corn follows corn at least once or twice in the rotation are suitable for use of cover crops. The facts developed in these limited studies on cover crops warrant further investigations to determine the most satisfactory of these crops to use and the date and method of seeding for different soil and climatic conditions.

TERRACES IN EROSION CONTROL

A number of groups of terraces were built shortly after the establishment of the experimental farm to provide information on the design features of terraces on Marshall and associated soils. A range of terrace grades, lengths, and spacings were provided but because of the large areas required for studies of this kind there was practically no replication of designs. However, because of the 8- or 9-year period over which the observations were spread and the large number of different kinds of storms affecting the various areas it has been possible to evaluate the results in practically all cases.

The area devoted to these studies was farmed in a rotation of corn, corn, oats, and clover, beginning with oats in 1933. Terraced areas were plowed with the 2-way plow which permits placement of the dead furrows and back furrows in any position desired by the operator. By back furrowing on the terrace ridges and placing the dead furrows in terrace channels the terrace cross section was maintained without recourse to any other implement. Farming was carried on by the ordinary farm machines common to the area, using the methods described by Cutter and Norton (*4*). Measurement of soil and water losses at the ends of terraces was done with Parshall flumes as described by Parshall (*32*), combined with Ramser silt samplers.

Terrace-Grade Study

Three groups of three terraces each were provided for a study of terrace grades within a range of terrace lengths. By reference to tables 16 and 17 the year-by-year losses of soil and water may be found. These data are summarized and presented in graphic form in figure 31.

As might be expected it is apparent that, with other design features held constant, the terraces with the steeper grades will lose the greater

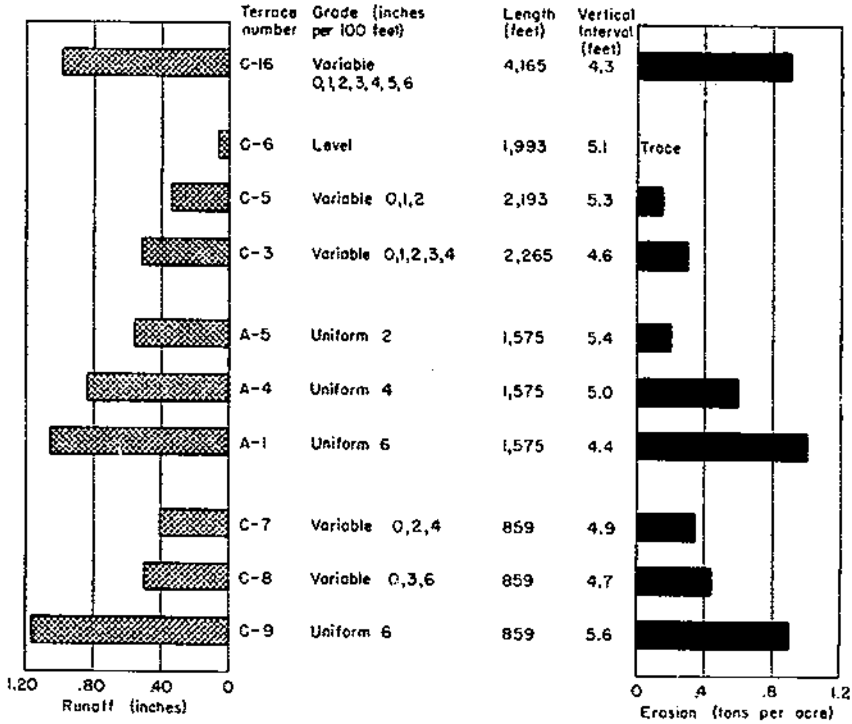

FIGURE 31.—Average annual soil and water losses from different terrace grades, 1933–40.

quantities of soil and water. Considering the variations in length between the four groups for which data are presented, it seems that as the terrace lengths increase the soil and water losses tend to become less. At least this is true within the usually accepted range of terrace lengths. However, when the excessively long terrace number C–16 is considered it will be seen that losses of both soil and water per unit of area are comparatively greater than those from terraces more nearly conforming to standard design.

Some of the conclusions which may be drawn from this study are:

1. On Marshall silt loam soil one need not hesitate to use a long terrace if it is needed. The losses of soil and water are not likely to be excessive.

2. If a suitable outlet is not available, it is permissable to use level terraces with closed ends provided the terrace is confined to Marshall silt loam with topsoil at least 6 to 9 inches deep (see data for Terrace C–6). Observations of level terraces with closed ends revealed that it was necessary to be in the field during the heaviest downpours to find any water impounded behind them. On the other hand, water impounded behind terraces on Shelby soils for months at a time and level terraces on such soils should be avoided.

3. If suitable outlets are available, it is probably desirable to give terraces in this region a moderate grade because in any case the soil and water losses will be small. Somewhat less care is required in farming and maintaining graded terraces than level ones. Soil and water losses may be held to a minimum by using variable-graded rather than uniform-graded terraces although it requires a little more care to lay out a variable graded terrace accurately.

TABLE 16.—*Runoff through terrace channels of different lengths and grades*

Year	C-6	C-5	C-3	A-5	A-4	A-1	C-7	C-8	C-9	C-16
	1,993-foot length; level	2,193-foot length; 0-, 1-, 2-inch grade	2,265-foot length; 0-, 1-, 2-, 3-, 4-inch grade	1,575-foot length; 2-inch grade	1,575-foot length; 4-inch grade	1,575-foot length; 6-inch grade	850-foot length; 0-, 2-, 4-inch grade	850-foot length; 0-, 3-, 6-inch grade	850-foot length; 6-inch grade	4,165-foot length; 0-, 1-, 2-, 3-, 4-, 5-, 6-inch grade
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1933	0.01	0.02	0.06	0.05	0.06	0.47	0.15	0.11	0.05	0.36
1934	.01	.01	.01	.01	.01	.63	.01	.04	.01	.02
1935	.01	.02	.06	.02	.04	.52	.04	.12	.04	.08
1936	[1]	.02	.04	.01	.03	.05	.03	.11	.02	.09
1937	.05	.88	1.28	.75	1.43	2.26	1.39	1.58	3.26	1.24
1938	[1]	[1]	[1]	.01	.01	.01	.01	.04	.08	.02
1939	.48	1.27	2.16	1.22	2.77	3.93	.72	1.09	3.44	3.28
1940	.03	.58	.66	2.31	2.36	1.25	.93	.92	2.47	2.66
Total	.59	2.80	4.27	4.38	6.71	8.52	3.28	4.01	9.37	7.73
Annual average	.07	.35	.53	.55	.84	1.06	.41	.50	1.17	.97

[1] Trace.

TABLE 17.—*Soil loss per acre at ends of terraces*

Year	C-6	C-5	C-3	A-5	A-4	A-1	C-7	C-8	C-9	C-16
	1,993-foot length; level	2,193-foot length; 0-, 1-, 2-inch grade	2,265-foot length; 0-, 1-, 2-, 3-, 4-inch grade	1,575-foot length; 2-inch grade	1,575-foot length; 4-inch grade	1,575-foot length; 6-inch grade	850-foot length; 0-, 2-, 4-inch grade	850-foot length; 0-, 3-, 6-inch grade	850-foot length; 6-inch grade	4,165-foot length; 0-, 1-, 2-, 3-, 4-, 5-, 6-inch grade
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
1933	0.01	[1]	0.04	0.01	0.02	0.38	0.02	0.06	0.01	0.24
1934	[1]	[1]	[1]	[1]	.01	.01	[1]	.01	[1]	[1]
1935	[1]	[1]	.02	[1]	.04	.48	.01	.04	.01	.03
1936	[1]	[1]	.01	[1]	.08	.03	.01	.03	.01	.09
1937	.02	.97	1.73	.98	2.94	4.49	2.13	2.80	6.04	2.53
1938	[1]	[1]	[1]	[1]	[1]	[1]	.01	[1]	.02	.02
1939	.04	.05	.14	.33	1.02	2.08	.10	.22	.39	1.11
1940	.02	.20	.36	.46	.72	.48	.54	.33	.70	2.89
Total	.09	1.22	2.30	1.78	4.83	7.95	2.82	3.49	7.18	6.91
Annual average	.01	.15	.29	.22	.60	.99	.35	.44	.90	.86

[1] Trace.

Terrace-Spacing Study

Two groups of terraces with vertical intervals of 4, 5, and 6 feet were used for this study. The data for individual years are presented in tabular form in tables 18 and 19 and are summarized in figure 32.

Table 18.—*Runoff through terrace channels*

Year	C-2 2,265-foot length; 4-foot vertical interval	C-3 2,265-foot length; 5-foot vertical interval	C-4 2,265-foot length; 6-foot vertical interval	A-3 1,575-foot length; 4-foot vertical interval	A-4 1,575-foot length; 5-foot vertical interval	A-2 1,575-foot length; 6-foot vertical interval
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1933	0.05	0.06	0.04	0.11	0.06	0.10
1934	.01	.01	.01	.04	.01	.02
1935	.04	.06	.01	.01	.04	.10
1936	.02	.04	.02	.04	.03	.02
1937	.84	1.28	.86	1.05	1.43	1.81
1938	(1)	(1)	(1)	(1)	.01	(1)
1939	2.15	2.16	1.40	1.65	2.77	4.10
1940	1.27	.66	.83	.82	2.36	1.37
Total	4.38	4.27	3.17	3.72	6.71	7.61
Annual average	.55	.53	.40	.47	.84	.95

[1] Trace.

Table 19.—*Soil loss per acre at ends of terraces*

Year	C-2 2,265-foot length; 4-foot vertical interval	C-3 2,265-foot length; 5-foot vertical interval	C-4 2,265-foot length; 6-foot vertical interval	A-3 1,575-foot length; 4-foot vertical interval	A-4 1,575-foot length; 5-foot vertical interval	A-2 1,575-foot length; 6-foot vertical interval
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
1933	0.02	0.04	0.01	0.05	0.02	0.06
1934	(1)	(1)	(1)	.02	.01	(1)
1935	.01	.02	(1)	(1)	.04	.14
1936	(1)	.01	.01	.02	.08	.01
1937	1.15	1.73	1.47	1.24	2.94	3.06
1938	(1)	(1)	(1)	(1)	(1)	(1)
1939	.08	.14	.11	.62	1.02	1.17
1940	.40	.30	.66	1.58	.72	.54
Total	1.66	2.30	2.26	3.43	4.83	4.98
Annual average	.21	.29	.28	.43	.60	.62

[1] Trace.

Within the range of spacings available for this study no definite trends can be shown. There seems to be some indication that greater soil and water losses accompany the wider spacings but this is not consistent. All losses are small and one may conclude that terraces spaced considerably wider apart would have given adequate protection against any storms that occurred within the period 1933–40. After conclusion of the initial period of investigations several terraces were removed to provide vertical intervals as wide as 9 feet. No measuring equipment has been placed on these terraces but no difficulty has been observed which would indicate that this spacing is too wide.

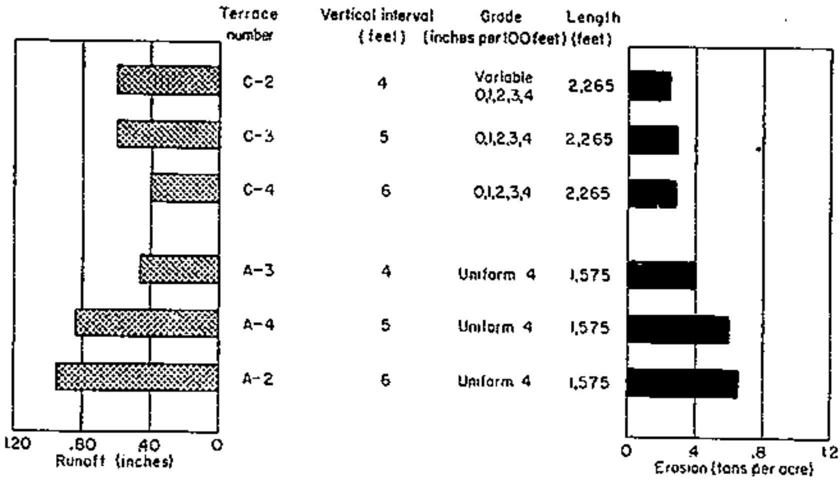

FIGURE 32.—Average annual runoff and soil losses from terraces with different vertical intervals, 1933–40.

CROPS ON TERRACED LAND

In 1933 a series of five terraces of identical design were set aside for a test of the effects of crops on soil and water losses from terraced land. From that year through 1944 the middle terrace of the group was kept in continuous corn. The other four terraces were farmed in a rotation of corn, corn, oats, and clover so that one terrace was in each crop each year. Measuring equipment for determination of soil and water losses was maintained throughout the 8-year period 1934–41. The data from this study are shown for each year in tables 20 and 21 and are summarized graphically in figure 33.

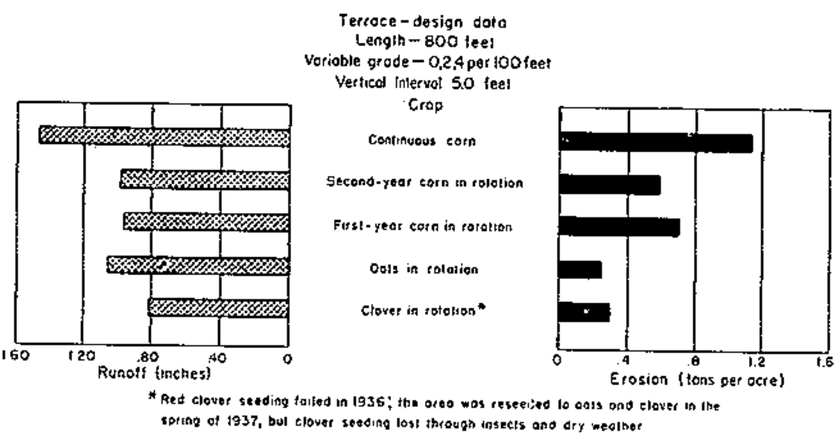

FIGURE 33.—Effect of crops on average annual runoff and soil losses as measured at ends of terraces, 1934–41.

TABLE 20.—*Effect of crop on runoff through terrace channels*

Year	Continuous corn; 800-foot length; 0-, 2-, 4-inch grade	1st-year corn; 800-foot length; 0-, 2-, 4-inch grade	2d-year corn; 800-foot length; 0-, 2-, 4-inch grade	Oats; 800-foot length; 0-, 2-, 4-inch grade	Clover; 800-foot length; 0-, 2-, 4-inch grade
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
1934	0.15	0.21	0.13	0.23	0.03
1935	.88	.14	.30	.76	.88
1936	.23	.06	.02	.67	.11
1937	1.26	1.22	.58	1.00	[1] 1.86
1938	.01	.01	.01	(²)	(²)
1939	3.37	2.40	3.24	2.60	1.31
1940	2.42	1.24	1.32	1.31	.23
1941	3.22	2.42	2.21	1.69	2.07
Total	11.54	7.78	7.81	8.32	[1] 6.49
Annual average	1.44	.97	.98	1.04	.81

[1] Red clover seeding failed in 1936. The area was reseeded to oats and clover in spring of 1937, but clover seeding was again lost due to insects and dry weather.
[2] Trace.

TABLE 21.—*Effect of crop on soil loss per acre at the ends of terraces*

Year	Continuous corn; 800-foot length; 0-, 2-, 4-inch grade	1st-year corn; 800-foot length; 0-, 2-, 4-inch grade	2d-year corn, 800-foot length; 0-, 2-, 4-inch grade	Oats; 800-foot length; 0,- 2-, 4-inch grade	Clover; 800-foot length; 0-, 2-, 4-inch grade
	Tons	*Tons*	*Tons*	*Tons*	*Tons*
1934	0.39	0.27	0.24	0.12	0.01
1935	1.08	.16	.20	.13	.10
1936	.15	.02	.01	.53	.04
1937	1.81	1.17	.38	.73	[1] 1.08
1938	(²)	0	(²)	(²)	(²)
1939	.80	.20	.64	.34	.20
1940	1.20	.52	.52	.13	.02
1941	3.66	3.39	3.03	.03	.02
Total	9.09	5.82	5.11	2.01	2.16
Annual average	1.14	.73	.64	.25	.27

[1] Red clover seeding failed in 1936. The area was reseeded to oats and clover in the spring of 1937, but clover seeding was again lost due to insects and dry weather.
[2] Trace.

The continuous corn lost considerably more soil and water each year than any of the other crops. Very small average differences were found between first-year and second-year corn in the rotation. Oats lost a little more water but considerably less soil than corn. The corn fields, being listed on the contour, afforded more surface retention of precipitation than the areas in oats which were not appreciably ridged during farming operations.

The red clover would have provided more protection against runoff and soil loss had it not been for the two consecutive failures of the clover seeding in 1936 and 1937. The land was exposed to considerable weathering during the attempts to reestablish the clover crop.

The yields of corn furnish material for an interesting study. These data are presented for each of the 12 years of record in table 22 and as a 4-year moving median in figure 34. In the graph, note that the yield of first-year corn always maintained an upward trend while that for second-year corn and continuous corn suffered several reverses.

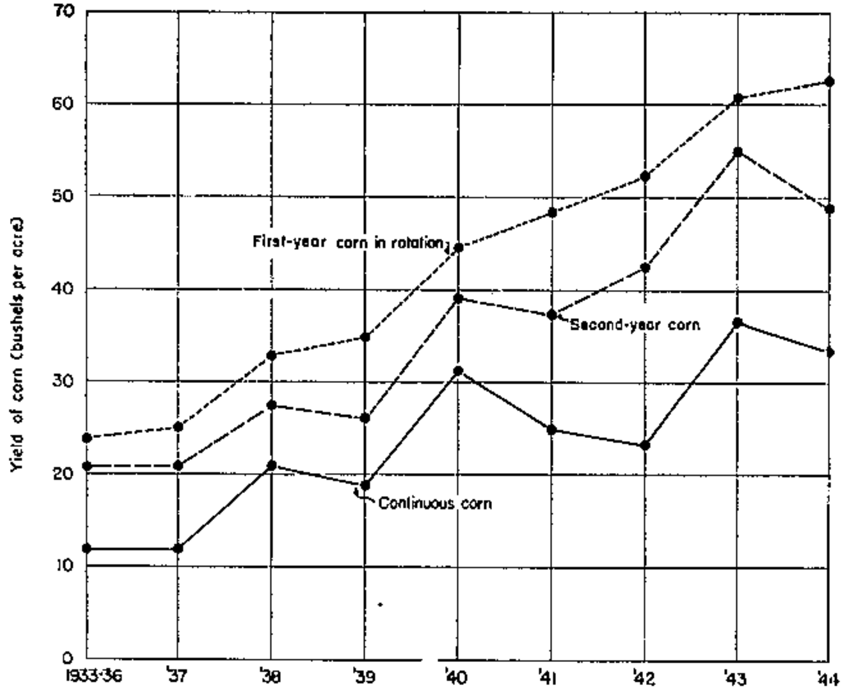

FIGURE 34.—A 4-year comparison of corn grown continuously and in rotation.

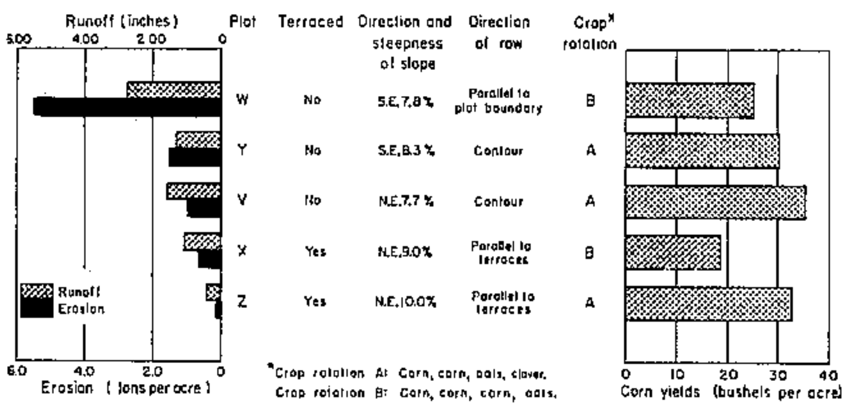

FIGURE 35.—Average annual runoff and soil losses and corn yields from small watersheds.

SMALL WATERSHEDS

Soil and water losses and corn yields have been compared for an 8-year period 1934–41 on five small watersheds. The various natural and induced factors which characterize these watersheds complicate the interpretation of the results but several well established trends may be identified. Graphic presentation of soil and water losses and yields is made in figure 35. The runoff and erosion observed each year are shown in tables 23 and 24. Table 25 shows soil and topographic information which is useful in interpreting soil and water losses and yields.

TABLE 22.—*Yield of corn on terraced land*

Year	Continuous corn; 800-foot length; 0-, 2-, 4-inch grade	1st-year corn; 800-foot length; 0-, 2-, 4-inch grade	2d-year corn; 800-foot length; 0-, 2-, 4-inch grade
	Bushels	*Bushels*	*Bushels*
1933	41.0	40.0	43.6
1934	2.9	7.4	2.4
1935	20.8	41.7	28.5
1936	1.8	3.4	13.0
1937	41.1	44.2	52.5
1938	20.9	24.9	26.3
1939	16.3	44.6	25.3
1940	43.8	53.5	60.6
1941	28.6	51.7	48.6
1942	18.9	67.6	35.7
1943	43.4	85.3	62.2
1944	39.1	58.3	40.8
Total	318.6	522.6	448.4
Annual average	26.5	43.6	37.4

TABLE 23.—*Effect of crop rotations,[1] terracing, and direction of slope on runoff from small watersheds, 1934–41*

Year	Plot W Unterraced, rotation B, SE slope	Plot Y Unterraced, rotation A, SE slope	Plot V Unterraced, rotation A, NE slope	Plot X Terraced, rotation B, NE slope	Plot Z Terraced, rotation A, NE slope
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
1934	0.49	0.12	0.04	0.52	0.02
1935	1.20	.19	.32	.74	.07
1936	.22	.11	.14	(2)	(2)
1937	.78	1.64	1.60	.63	.69
1938	.22	.02	.04	0	(2)
1939	5.09	2.40	3.32	1.93	.84
1940	4.80	1.40	2.25	2.08	.67
1941	8.60	4.22	4.76	3.00	1.37
Total	21.40	10.10	12.47	8.90	3.46
Annual average	2.67	1.26	1.56	1.11	.43

[1] Rotation A—Corn, corn, oats, clover; beginning with clover in 1934. Rotation B—Corn, corn, corn, oats; beginning with oats in 1934.
[2] Trace.

The unterraced plots showed considerably greater average losses than the corresponding terraced area. The plots carrying a 4-year rotation including a legume lost far less soil and water than the corresponding plots where no legume was included in the rotation.

TABLE 24.—*Effect of crop rotations,*[1] *terracing, and direction of slope on soil loss per acre from small watersheds, 1934–41*

Year	Plot W Unterraced, rotation B, SE slope	Plot Y Unterraced, rotation A, SE slope	Plot V Unterraced, rotation A, NE slope	Plot X Terraced, rotation B, NE slope	Plot Z Terraced, rotation A, NE slope
	Tons	*Tons*	*Tons*	*Tons*	*Tons*
1934	0.38	0.42	(2)	0.78	0.01
1935	3.42	.07	.08	.79	.03
1936	.28	.07	.09	(2)	(2)
1937	4.35	4.82	2.80	.77	.46
1938	.17	(2)	.01	0	(2)
1939	7.99	2.39	1.64	.42	.23
1940	13.86	2.56	2.33	1.22	.09
1941	13.73	1.58	.48	1.62	.03
Total	44.18	11.91	7.52	5.60	.85
Annual average	5.52	1.49	.94	.72	.11

[1] Rotation A—Corn, corn, oats, clover; beginning with clover in 1934. Rotation B—Corn, corn, corn, oats; beginning with oats in 1934.
[2] Trace.

TABLE 25.—*Distribution of soil series among small watersheds*

Plot	Marshall soils	Shelby soils	Wabash-Judson Genesee complex
	Percent	*Percent*	*Percent*
X	74.0	17.0	9.0
W	82.4	8.1	9.5
Z	74.5	9.2	16.3
Y	71.7		28.3
V	90.3		9.7

Only one direct comparison of the effect of aspect of slope on soil and water losses could be made; that between Plot V and Plot Y. During the summer months Plot Y with its southeast exposure seems to become drier in the surface layers than Plot V with its northeastern exposure. This allows greater capacity for absorption of water during summer storms with consequent smaller annual water loss. On the other hand, Plot Y is often subjected to alternate freezing and thawing in the spring and finally all frost leaves it earlier than Plot V. Hence Plot Y is exposed to more storms without the protection of freezing weather and greater soil loss results.

Because of the soil and topographic variations between the watersheds they were not equally productive at the outset of the experimental period. For purposes of yield comparison, let us think of the years 1932–33 as a preliminary period during which rotations were being established. The corn crop of 1932 was considered about an average crop in southwestern Iowa. Yields obtained that year, as recorded in the first line of table 27, reflected the natural productivity of the individual watersheds prior to treatment. That is, these yields bear a reasonable relationship to the productivity one might expect from areas with soils distributed proportionately as in table 26. The Marshall soils are the most productive; Shelby, relatively unproductive; while the soils of the Wabash-Judson-Genesee complex, with good potential fertility, are subject to seepiness which may reduce their productivity. Specifically, Plot X has a steeper slope than Plot W and also has nearly twice as much of the relatively unproductive Shelby soil within its borders so the comparatively low initial yield of Plot X is as would be expected. Likewise Plot Z, the steepest in the group, and having a rather low percentage of the productive Marshall soil, should be expected to yield less than Plot Y, which is not so steep. Again, Plots Y and Z should be expected to yield considerably less than Plot V which has a larger proportion of Marshall soil and a flatter slope than any other plot in the group.

Within the years 1935–41, inclusive, after the rotations had been established, plots W and X produced six corn crops; the other plots produced only four. Table 26 shows total corn yields for that period. From this it may be seen that Plot Z, with its good rotation, yielded more corn per acre in 4 years than Plot X, with no legumes in the rotation, produced in 6 years. In the unterraced group, plots V and Y made a creditable showing, on the same basis, against Plot W. The value of the better rotation may also be seen in the average yields for the 4 years—1935, 1936, 1939, and 1940—when all plots were in corn.

TABLE 26.—*Effect of crop rotations,[1] terracing, and direction of slope on yield of corn per acre from small watersheds*

Year	Plot W Unterraced, rotation B, SE slope	Plot X Terraced, rotation B, NE slope	Plot V Unterraced, rotation A, NE slope	Plot Y Unterraced, rotation A, SE slope	Plot Z Terraced, rotation A, NE slope
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Preliminary:					
1932	52.8	36.2	53.0	41.6	25.7
1933	34.1	28.3	(2)	(2)	(2)
Period of active experimentation:					
1934	(2)	(2)	(2)	(2)	(2)
1935	20.0	15.9	39.6	31.4	28.2
1936	4.3	2.8	14.9	12.9	13.6
1937	31.8	29.5	(2)	(2)	(2)
1938	(2)	(2)	(2)	(2)	(2)
1939	29.2	18.5	34.3	25.5	36.
1940	42.1	37.4	54.8	50.8	51.6
1941	23.5	18.6	(2)	(2)	(2)
Total yield 1935–41	150.[illegible]	122.7	143.6	120.6	130.1
4-year average yield 1935, 1936, 1939, and 1940	23.9	18.6	35.9	30.2	32.5
Yield increase (+) or decrease (−) 1932–40	−10.1	+1.2	+1.8	+9.2	+25.9

[1] Rotation A: Corn, corn, oats, clover; beginning with second-year corn in 1932. Rotation B: Corn, corn, corn, oats; beginning with second-year corn in 1932.

[2] Some crop other than corn was grown that year.

Eight years after the experimental watersheds were established, or in 1940, another year of about normal corn yields was experienced. Actually the average corn yield per acre for Iowa in 1940 was about 11 percent greater than in 1932; for Page County the increase was about 6 percent, and the average yield per acre of all plots in this experiment was about 13 percent greater than at the start of the study. By 1940 the crop rotations which had been practiced on these small watersheds had passed through two complete cycles. By comparison, then, of corn yields from these watersheds for 1940 with those of 1932, we may gain some idea of the trends in soil improvement which may have taken place as a result of the treatments. The differences in yields between these two years is presented in the last line of table 26. Here we see that Plot W, which originally yielded well, but which carried a severe rotation and was unterraced, actually yielded less at the end of the experimental period than at the beginning. Plot X, with the same severe rotation but with terraces, showed a very slight increased yield for 1940 as compared with 1932. Plots V and Y, the results from which may be considered together for purposes of this comparison, showed increases roughly like those for Page County, Iowa. On the other hand, Plot Z, which had been terraced at the beginning of the experiment and carried the improved rotation, doubled its yield within the 8-year period. Through the combination of terracing and a good rotation, the annual soil loss from this area was reduced to a negligible quantity. It is obvious that a further benefit had accrued to this plot through the combination of the two good practices—the retention, for use of plants, of the nutrients added through commercial fertilizers and through the growth of a legume.

Detailed analyses with hydrographs of many individual storms occurring on these watersheds were presented by Schoenleber.[5]

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[5] Schoenleber, L. H. COMPILATION OF RAINFALL AND RUNOFF FROM THE WATERSHEDS OF THE MISSOURI VALLEY LOESS REGION CONSERVATION EXPERIMENT STATION, CLARINDA, IOWA, 1934–38, Hydrologic Studies, SCS–TP–31, 1940. [Mimeographed]

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APPENDIX

In order to avoid an excess of tabular material throughout the text, summary tables giving yearly records of rainfall, runoff, and soil loss at the Clarinda Station have been placed in the Appendix as tables 27 to 48.

The data presented in these tables will be of practical value and interest to technicians who wish to follow the details of this 12-year record of research at the station.

TABLE 27.—*Individual runoff records of control plots 1–9, experiment 1, Nov. 1, 1931 to Dec. 31, 1932*

[Average slope, 9 percent]

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
1931	*Inches*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Nov. 23	2.62	19.05	75.18	43.83	43.31	50.55	46.87	44.21	44.21	49.91
1932										
Feb. 17 to Apr. 1	.77	20.19	53.68	30.56	36.81	32.44	26.89	32.48	22.26	30.20
Apr. 6	.84	2.89	9.70	2.87	7.66	2.40	5.41	5.92	7.00	3.40
Apr. 21	.55	2.83	10.55	4.53	9.25	4.41	8.14	8.61	9.91	5.57
May 7	1.54	4.25	25.01	12.76	15.35	31.51	37.52	30.52	36.85	2.89
Total	[1] 6.32	49.21	174.12	94.55	112.38	121.31	124.83	130.74	120.23	91.97
June 2 (a. m.)	1.18	7.05	26.99	18.50	22.55	14.15	12.26	10.13	15.70	8.23
June 2 (p. m.)	.33	3.34	20.02	8.77	12.20	5.80	5.64	4.70	8.50	7.04
June 10	2.06	11.19	73.54	39.84	40.96	33.40	31.46	48.08	44.81	4.74
June 14	.27	1.07	4.57	2.71	2.84	2.67	2.80	2.68	4.87	....
June 26	.74	2.44	10.06	3.98	7.27	....	.97	6.43	5.01	....
July 31	.76	2.45	2.17	4.64	5.57	1.47	3.10	1.39	2.04	2.85
Aug. 6	.74	4.11	4.78	5.80	8.21	....	....	....	....	3.65
Aug. 12	1.95	11.60	48.89	25.23	34.21	3.96	2.50	1.33	6.00	28.2[illegible]
Aug. 15	.93	5.60	35.63	16.15	20.84	1.79	.63	1.30	3.23	12.27
Aug. 17	.67	4.35	24.30	9.91	14.68	1.17	.26	1.91	2.24	10.30
Aug. 31	2.29	12.37	61.00	34.65	32.31	1.40	2.97	2.99	3.13	25.61
Sept. 12	.47	2.21	5.76	2.60	3.56	....	....	....	....	2.80
Sept. 21	.71	3.69	6.50	3.85	5.57	.16	.97	.90	.93	6.04
Oct. 22	.92	.43	....	.36	.79	....	.55	.12	.11	1.43
Dec. 22	.41	.05	....	.10	.28	.05	.60	5.48	.78	....
Dec. 24	.43	....	....	....	.21	1.06	8.15	12.17	6.57	....
Total	[2] 14.69	71.98	324.27	176.68	212.06	67.71	72.50	106.61	107.04	113.29

[1] Nov. 1, 1931-June 1, 1932, total precipitation 14.76 inches.
[2] June 1, 1932-Dec. 31, 1932, total precipitation 21.70 inches.

TABLE 28.—*Individual erosion records of control plots 1–9, experiment 1, Nov. 1, 1931, to Dec. 31, 1932*

[Average slope, 9 percent]

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
1931	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Nov. 23	2.62	5.45	11.38	8.42	9.30	9.70	8.74	9.92	11.77	67.73
1932										
Feb. 17–Apr. 1	.77	2.23	3.30	2.59	2.82	3.31	3.42	1.76	2.58	5.66
Apr. 6	.84	7.87	13.89	5.90	16.66	3.96	9.51	6.30	8.80	19.01
Apr. 24	.55	10.54	16.59	11.55	15.29	13.32	19.08	22.07	27.82	41.02
May 7	1.54	49.24	129.38	86.28	84.15	119.70	102.23	112.67	110.30	35.31
Total	[1] 6.32	75.33	174.54	114.74	128.22	149.99	142.98	152.72	161.27	168.73
June 2 (a. m.)	1.18	80.27	172.54	152.57	188.07	10.22	4.52	7.34	4.51	61.04
June 2 (p. m.)	.33	33.47	117.36	66.80	64.34	4.43	3.30	2.20	2.44	56.49
June 10	2.06	80.80	780.81	312.40	316.25	9.66	5.77	8.37	12.43	18.90
June 14	.27	18.12	77.49	45.79	47.93	.07	.07	.08	.21	-------
June 26	.74	12.84	37.55	21.13	20.75	-------	-------	3.41	3.27	-------
July 31	.76	5.47	13.48	16.65	18.93	2.65	2.33	1.51	1.00	17.50
Aug. 6	.74	22.52	14.13	28.33	31.03	-------	-------	-------	-------	35.96
Aug. 12	1.95	82.11	229.84	107.96	153.41	-------	-------	-------	-------	183.88
Aug. 15	.93	36.29	110.11	32.43	62.74	-------	-------	-------	-------	93.47
Aug. 17	.67	19.41	70.39	23.86	39.71	-------	-------	-------	-------	76.93
Aug. 31	2.29	26.02	90.74	26.09	31.02	.09	-------	-------	-------	154.45
Sept. 12	.47	7.10	10.21	4.17	4.53	-------	-------	-------	-------	28.86
Sept. 21	.71	3.94	7.89	3.24	3.33	-------	.01	.02	.01	56.50
Oct. 22	.92	-------	-------	-------	-------	-------	-------	-------	-------	-------
Dec. 22	.44	-------	-------	-------	-------	-------	-------	-------	-------	-------
Dec. 24	.43	-------	-------	-------	-------	-------	-------	-------	-------	-------
Total	[2] 14.89	428.00	1,738.54	841.42	982.04	27.12	16.00	22.93	23.87	785.98

[1] Nov. 1, 1931-June 1, 1932, total precipitation 14.76 inches.
[2] June 1, 1932-Dec. 31, 1932, total precipitation 21.70 inches.

TABLE 29.—*Individual runoff records of control plots 1–9, experiment 1, Jan. 1, 1933 to Dec. 31, 1934*

[Average slope, 9 percent]

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
1933	*Inches*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Mar. 30	1.00									3.04
Mar. 31	.52	1.57	1.70	1.22	1.93					3.34
May 12	.82	2.26	1.50	1.10	5.04		1.20			3.61
May 22	.29	1.45			4.88					1.43
June 27	2.88	7.93	18.44	8.50	6.50	2.43	13.51	2.93	3.31	17.38
June 29	1.10	13.31	48.99	23.44	8.74		26.07			23.95
July 8	.54									3.77
Aug. 21	3.70	2.18	2.65	3.18	11.67	1.50	2.91	3.52	3.53	58.02
Sept. 12	1.02									4.27
Sept. 16	.35									3.94
Sept. 25	1.76	2.20	5.12	3.90			5.00			30.53
Total	[1] 14.98	30.90	78.40	41.34	38.76	3.93	48.69	6.45	6.84	154.18
1934										
Mar. 5	([2])	.31	.74	.25	1.09	.98		4.52	2.88	.40
Apr. 4	.44									1.83
May 9	.50						6.00			
May 12	1.30	12.91	53.36	26.56		21.40	27.36			22.40
Aug. 31	1.15	1.39		4.20	4.46	21.57	14.16			
Sept. 3	1.22	1.69		2.27		3.47	3.14			
Sept. 15	.54	4.12	16.09	5.81	4.00	13.50	6.00			8.19
Sept. 20	1.73	12.81	40.74	17.88	3.64	24.79	17.31			25.88
Oct. 19	2.37	18.45	65.09	29.92	5.93	32.32	11.90		3.85	38.67
Oct. 20	.37	2.10	7.70	3.91		3.09				4.01
Nov. 3	1.39	4.55	14.02	7.77		3.79				7.77
Nov. 22	.47	1.89	4.80	1.55						2.47
Total	[3] 11.78	60.22	202.60	100.42	20.02	125.15	85.84	4.52	6.73	111.50
Total, excluding Mar. 5	11.78	59.91	201.86	100.17	18.93	124.17	85.84	0	3.85	111.31

[1] Jan. 1–Dec. 31, 1933, total precipitation 20.37 inches.
[2] Melted snow, winter accumulation.
[3] Jan. 1–Dec. 31, 1934, total precipitation 21.77 inches.

TABLE 30.—*Individual erosion records of control plots 1–9, experiment 1, Jan. 1, 1933 to Dec. 31, 1934*

[Average slope, 9 percent]

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
1933	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Mar. 30	1.00									31.96
Mar. 31	.52		8.73	2.66	2.59					14.60
May 12	.82	7.14	6.45	2.59	11.25		2.47			10.55
May 22	.29	2.59			7.60					4.86
June 27	2.88	9.77	27.24	10.17	.36	0.15	30.11	0.20	0.27	132.01
June 29	1.10	17.50	135.21	31.01	.49		38.02			242.07
July 8	.64									29.62
Aug. 21	3.70	3.57	6.88	3.47	2.62	1.11	3.15	.70	1.45	120.25
Sept. 12	1.92									7.16
Sept. 16	.35									7.85
Sept. 25	1.76	2.10	3.27	1.09			3.64			217.71
Total	[1] 14.98	42.67	185.78	52.19	24.01	1.26	77.30	.90	1.72	834.63
1934										
Mar. 5	(2)	1.40	2.60	2.11	1.35	.89		.96	1.26	3.94
Apr. 4	.44									9.48
May 9	.50						17.42			
May 12	1.30	99.12	442.48	187.52		100.99	83.38			94.92
Aug. 31	1.15	9.76		29.32	.17	99.28	13.76			
Sept. 3	1.22	2.27		4.78		8.30	.54			
Sept. 15	.84	14.04	62.52	23.60	.06	44.20	3.39			48.84
Sept. 26	1.73	17.03	52.35	31.67	.06	64.00	4.41			88.76
Oct. 19	2.37	51.00	191.91	95.58	.15	89.52	3.75		.10	160.26
Oct. 20	.37	5.36	20.69	9.27		5.98				13.77
Nov. 3	1.30	4.18	15.72	7.31		4.18				19.46
Nov. 22	.47	.37	3.41	.55						2.08
Total	[4] 11.78	204.53	791.68	391.71	1.79	417.24	120.65	.96	1.36	441.51
Total, excluding Mar. 5	11.78	203.13	789.08	389.60	.44	416.35	120.65	0	.10	437.57

[1] Jan. 1–Dec. 31, 1933, total precipitation 26.37 inches.
[2] Melted snow, winter accumulation.
[4] Jan. 1–Dec. 31, 1934, total precipitation 21.77 inches.

TABLE 31.—*Individual runoff records of control plots 1–9, experiment 1, Jan. 1–Dec. 31, 1935*

[Average slope, 9 percent]

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
	Inches	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Jan. 19	0.53	5.66	8.41	12.03	13.86	3.61	3.26	13.41	11.82	6.15
May 14	1.35					2.58				
May 21	2.22				3.40	1.85				4.93
May 23	.73	1.63	6.46	3.94	.73	1.09	1.54	1.28		3.63
May 28	1.55	5.57	17.58	10.33	5.31	5.70	2.74			4.03
June 1	1.57	12.47	47.41	24.21	16.39	4.03	2. 4			18.07
June 3	.97	6.52	25.83	13.70	7.23					10.01
June 4	.47	2.66	10.49	5.02	3.46	1.07	.73	.94	2.35	3.16
June 6	.66		10.92							
June 10	.30	1.16	3.15	1.33		1.73				
June 21	.70	5.36	15.38	8.26	6.67	1.52				6.76
June 26	.61	7.01	26.54	12.75	9.47	1.29				11.66
Sept. 2	1.84	4.14			3.00		2.28			
Sept. 16	.42	1.31	2.11	2.11					3.36	2.97
Sept. 26	1.98	4.77		3.64	3.22			2.17		11.41
Oct. 17	1.28	2.89		2.42						4.94
Oct. 31	1.10	7.40	32.01	9.40	3.57					17.75
Nov. 4	.91	2.66	5.50	2.16						3.34
Total	[1] 10.28	71.21	201.73	111.30	76.31	25.07	12.89	17.80	17.53	108.81

[1] Jan. 1–Dec. 31, 1935, total precipitation 32.31 inches.

TABLE 32.—*Individual erosion records of control plots 1–9, experiment 1, Jan. 1 to Dec. 31, 1935*

[Average slope, 9 percent]

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Jan. 19	0.53	7.88	14.30	14.18	0.28	0.24	0.10	0.23	0.20	0.35
May 14	1.35					.05				
May 21	2.22				.06	7.30				4.85
May 23	.73	1.78	11.01	7.62	.01	.03	.06	.04		8.76
May 28	1.55	23.52	139.09	01.28	11.80	3.51	1.87			15.91
June 1	1.57	68.23	397.85	177.32	73.93	.13	.03			108.23
June 3	.07	14.79	99.52	38.02	10.70					43.20
June 4	.47	21.27	134.31	57.10	22.20	.04	.01	.04	.07	24.48
June 6	.60		101.48							
June 10	.30	4.10	53.39	8.99		.01				
June 24	.70	40.40	230.07	94.61	04.76	.02				52.02
June 20	.61	83.00	402.29	191.77	82.35	.01				139.53
Sept. 2	1.94	11.97			.21		.09			
Sept. 10	.42	4.30	35.31	17.31					.13	10.05
Sept. 20	1.08	7.46		5.77	9.35			.16		30.36
Oct. 17	1.28	2.38		1.50						14.42
Oct. 31	1.10	9.85	46.09	9.17	5.16					71.90
Nov. 4	.91	3.54	7.37	2.61						9.12
Total	[1] 19.28	314.05	1,679.01	687.31	310.98	11.43	2.22	.46	.40	545.04

[1] Jan. 1–Dec. 31, 1935, total precipitation 32.31 inches.

TABLE 33.—*Mean heights of corn on control plots, with standard deviation, experiment 1, 1932–35*

Date	Continuous corn				Rotation corn				Continuous corn, desurfaced			
	Row 1		Row 2		Row 1		Row 2		Row 1		Row 2	
	Mean height	Standard deviation	Mean height	Standard deviation	Mean height	Standard deviation	Mean height	Standard deviation	Mean height	Standard deviation	Mean height	Standard deviation
	Centimeters		*Centimeters*		*Centimeters*		*Centimeters*		*Centimeters*		*Centimeters*	
June 22, 1932	91.7	9.4	92.1	7.7	87.6	10.7	91.8	14.9	50.4	6.3	49.5	6.0
July 2, 1932	130.1	11.7	133.2	9.9	128.6	5.6	138.3	6.9	73.7	10.7	67.7	14.5
July 12, 1932	153.5	7.9	156.1	8.0	153.0	16.3	156.1	16.6	92.5	14.5	87.7	12.9
June 6, 1933	42.1	3.2	38.7	4.2	49.4	5.3	48.4	5.6	28.6	3.8	29.7	3.0
June 16, 1933	81.3	5.0	74.7	7.3	88.0	5.9	86.4	6.2	46.6	9.2	43.9	6.1
June 26, 1933	125.7	7.1	114.1	11.1	129.6	10.0	122.7	9.1	74.8	16.8	72.5	9.4
July 6, 1933	179.5	13.0	161.2	13.0	186.2	13.6	179.6	14.5	105.8	21.5	100.9	11.7
June 9, 1934	46.8	7.6	45.5	4.6	40.8	5.6	36.9	6.6	32.2	3.5	32.9	4.1
June 19, 1934	90.9	16.3	89.8	7.1	81.3	8.5	71.7	9.9	64.4	7.4	65.3	8.8
June 29, 1934	135.0	22.6	134.7	9.3	116.1	9.8	104.7	13.7	102.5	9.6	104.8	9.1
July 9, 1934	154.3	23.5	149.3	9.7	128.4	9.3	110.3	14.8	116.0	12.4	120.5	12.0
July 19, 1934	165.6	23.9	164.7	14.3	130.1	12.3	110.4	11.6	134.6	11.0	135.8	14.8
June 19, 1935	35.6	2.8	34.6	3.1	43.6	4.9	43.0	6.8	28.8	3.9	29.5	3.1
June 29, 1935	68.2	5.3	65.6	7.3	90.0	6.9	86.5	10.6	51.0	6.6	51.6	5.8
July 9, 1935	128.0	6.1	125.3	6.9	154.7	7.9	150.1	12.1	92.4	8.4	91.4	8.1
July 19, 1935	173.9	8.5	172.2	9.2	198.3	9.2	191.1	10.2	125.5	11.4	127.4	10.6
July 29, 1935	219.0	11.4	216.0	12.7	236.9	11.5	223.5	16.1	146.2	13.6	151.2	13.4

TABLE 34.—*Crop yields per acre*[1] *on soil-moisture plots in field E, experiment 2*

Plot No.	Treatment	1932		1933		1934		1935	
		Grain	Hay or stover[2]	Grain	Hay or stover	Grain	Hay or stover	Grain	Hay or stover
		Bushels	*Tons*	*Bushels*	*Tons*	*Bushels*	*Tons*	*Bushels*	*Tons*
1	Continuous corn	25.71	----------	29.29	(2)	3.06	1.16	35.10	1.70
2	do	23.84	----------	49.57	(2)	3.57	1.00	39.59	1.65
3	do	22.23	----------	47.36	(2)	2.73	.96	34.69	1.79
4	Rotation[3]	22.77	----------	(2)	0.58	(2)	1.55	32.24	1.43
5	do.[3]	(2)	----------	(2)	2.47	(2)	.50	38.04	2.73
6	do.[3]	(2)	----------	62.50	(2)	5.19	.37	(2)	.61
7	Alfalfa	(2)	----------	(2)	1.82	(2)	2.41	(2)	3.21
8	Bluegrass	(2)	----------	(2)	(2)	(2)	(2)	(2)	1.20
9	Continuous corn, eroded	6.43	----------	17.43	(2)	.85	.49	7.35	1.11

[1] Calculated on basis of 70 pounds per bushel air-dry corn, except 1934 which was calculated on basis of 84 pounds per bushel air-dry snapped corn, and 32 pounds of oats per bushel; hay and stover yields calculated on basis of oven-dry (105° C.) material.

[2] No crop harvested or yield not determined.

[3] Corn, oats, clover on plots 4, 5, and 6 respectively in 1932; plots 6, 4, and 5 in 1933; plots 5, 6, and 4 in 1934; and plots 4, 5, and 6 in 1935.

TABLE 35.—*Runoff records of control plots 1 to 9, experiment 1, 1936*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4[1]	Plot 5[1]	Plot 6[1]	Plot 7	Plot 8	Plot 9
	Inches	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
Feb. 27	(2)	14.21	70.87	49.64	57.62	20.16	11.49	19.08	5.69	49.40
Mar. 2	(2)	24.33	50.82	19.37	17.77					9.79
Apr. 28	1.12	2.35	4.15	3.83	5.18		2.80			2.85
May 1	.79	8.27	20.61	10.78	12.69		10.55			14.90
May 11	2.14	10.72	35.20	13.53	10.83		7.43			15.13
June 6	1.63	6.14	19.03	11.18			7.67			0.06
June 9	.59	2.38	8.04	4.34			2.02			2.71
June 30	.54			1.66						.92
Sept. 5	2.29	10.00	25.86	21.63	0.58	1.06	17.19	1.85		18.61
Sept. 13	.82	5.41	14.89	11.54	4.07		9.44			13.59
Sept. 28	1.57	1.41	3.08	4.63						6.15
Oct. 5	1.04	3.55	9.60	8.81	2.57		2.62			11.26
Nov. 2	.30	.88	1.83	1.64						1.04
Dec. 30	.86	10.89	42.55	22.17	15.07		18.82			18.42
Total	[3] 13.69	100.54	316.13	195.75	135.37	21.22	90.03	20.93	5.69	170.83

[1] In 1936, plot 4 in oats, plot 5 in clover, and plot 6 in corn.
[2] Runoff caused by melting snow.
[3] 1936 total precipitation 23.15 inches.

TABLE 36.—*Erosion records of control plots 1 to 9, experiment 1, 1936*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4[1]	Plot 5[1]	Plot 6[1]	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Feb. 27	(2)	0.00	0.44	0.93	1.08				0.05	0.62
Mar. 2	(2)	2.39	28.84	24.13	25.42					4.88
Apr. 28	1.12	7.96	18.63	17.72	24.56		5.06			6.65
May 1	.79	30.05	178.83	119.67	55.50		34.65			60.62
May 11	2.14	51.11	283.76	131.56	37.91		28.61			100.77
June 6	1.63	20.07	121.71	77.05			197.02			23.03
June 9	.59	10.62	73.55	31.09			8.10			8.43
June 30	.54			.45						.12
Sept. 5	2.29	18.04	64.30	62.86	5.85	0.01	02.70	0.12		03.63
Sept. 13	.82	10.00	26.35	24.64	5.06		22.86			49.18
Sept. 28	1.57	.06	.06	3.06						5.00
Oct. 5	1.04	6.67	43.67	32.64	4.30		20.08			62.07
Nov. 2	.30	5.80	9.02	5.56						14.59
Dec. 30	.86	141.07	957.22	399.36	171.88		299.47			302.94
Total	[3] 13.69	304.83	1,806.38	930.72	331.56	.01	679.45	.12	.05	722.53

[1] In 1936, plot 4 in oats, plot 5 in clover, and plot 6 in corn.
[2] Erosion caused by melting snow.
[3] 1936 total precipitation, 23.15 inches.

TABLE 37.—*Runoff records of control plots 1 to 9, experiment 1, 1937*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Feb. 13	(2)	7.38	18.80	14.33	7.44	6.38	11.28	10.44	3.07	16.48
Feb. 15	(2)	7.91	18.20	18.03	9.81	6.67	11.45	12.65	3.15	30.42
Feb. 19	(2)	9.19	20.06	15.87	11.18	10.28	13.80	25.30	5.55	19.15
Mar. 3	(2)	24.19	12.67	5.25	3.20	2.87	6.03	22.52	10.94	10.75
Mar. 4	(2)	3.14						2.01		6.43
Apr. 21	1.09	4.82	10.71	8.63	8.40		7.73			6.94
Apr. 24	.46	2.43	9.24	5.11	4.58		4.10			4.16
May 5	.23	1.90	6.37	4.58	2.40		3.30	1.88		2.23
May 7	1.43	21.41	81.25	40.09	49.50	20.15	40.18			42.65
May 21	1.23	9.74	39.31	19.07	27.82	15.67	22.37			17.08
May 20	.37	2.43	8.30	3.90	6.18	2.88	3.69			2.90
May 31	.31	1.96	7.01	3.40		2.81				2.89
June 13	1.37	10.06	39.40	22.26	16.14	11.49	9.33	1.72		22.06
June 16	1.08	8.99	32.18	15.97	11.80	10.86	7.23			17.46
July 14	.67				7.13		6.84			4.20
July 19	1.69	11.08	22.46	11.06	1.26	10.99	13.58	1.72		20.41
July 30	1.48	11.94	31.23	15.23	7.40	11.57	17.76			25.42
Aug. 20	1.00						5.16			21.23
Total	[3] 12.41	140.07	363.25	204.67	173.22	124.00	101.83	78.33	22.71	277.86

[1] In 1937, plot 4 in clover, plot 5 in corn, and plot 6 in oats.
[2] Runoff caused by melting snow.
[3] 1937 total precipitation, 26.43 inches.

TABLE 38.—*Erosion records of control plots 1 to 9, experiment 1, 1937*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Feb. 13	(2)	3.83	0.23	2.23	1.71	0.12	1.53	0.07	0.02	4.69
Feb. 15	(2)	.12		66.88	.00		.01	.02		87.03
Feb. 19	(2)	0.22	.75	3.75	.13	.03	.03	.24	.01	.28
Mar. 3	(2)	83.10	9.05	.13	.02	.01	.03	.04		.08
Mar. 4	(2)	.08						.02		.09
Apr. 21	1.09	43.61	370.23	105.57	51.58		56.19			80.23
Apr. 24	.46	28.36	240.11	102.00	50.95		55.26			30.80
May 5	.23	12.20	81.14	37.07	.18		12.22			16.32
May 7	1.43	296.99	2,117.31	676.92	554.81	129.29	630.80			62.64
May 21	1.23	91.08	507.80	213.32	134.50	68.77	100.07			137.88
May 26	.37	13.95	64.21	25.63	8.69	5.76	5.36			20.00
May 31	.31	18.82	101.53	30.81		10.73				26.10
June 13	1.37	108.43	535.38	225.22	6.77	47.76	.13	.05		189.40
June 16	1.08	79.17	324.30	129.98	2.30	40.88	4.87			175.03
July 14	.67				.04		.28			8.04
July 19	1.69	82.18	139.30	43.14	.03	50.63	.96	.06		148.89
July 30	1.48	31.11	60.54	13.24	.02	14.09	14.93			150.02
Aug. 20	1.00						3.19			67.27
Total	[3] 12.41	902.34	4,657.88	1,673.80	822.11	367.07	891.80	.50	.03	1,214.09

[1] In 1937, plot 4 in clover, plot 5 in corn, and plot 6 in oats.
[2] Erosion caused by melting snow.
[3] 1937 total precipitation, 26.43 inches.

TABLE 39.—*Runoff records of control plots 1 to 9, experiment 1, 1938*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Apr. 6	0.94	2.69	8.74	4.33	--------	3.77	4.96	--------	--------	6.97
Apr. 16	1.06	7.02	23.85	12.27	--------	6.78	10.32	--------	--------	12.83
May 4	1.96	.94	3.63	2.20	--------	14.82	10.06	--------	--------	5.41
May 7	.72	.96	2.53	2.74	--------	8.06	9.36	--------	--------	.09
May 17	.51	--------	--------	--------	--------	1.55	1.88	--------	--------	--------
June 1	.64	2.89	5.70	5.10	--------	3.52	3.58	--------	--------	1.75
Aug. 21	2.28	16.48	53.31	30.17	23.78	19.08	16.84	--------	--------	34.59
Aug. 28	1.18	3.41	12.99	6.85	6.05	--------	--------	--------	--------	8.42
Sept. 6	.56	.87	2.69	1.94	.78	--------	--------	--------	--------	2.65
Sept. 11	1.31	--------	--------	--------	--------	--------	--------	--------	--------	2.00
Sept. 13	1.09	8.79	31.27	17.46	10.85	--------	2.45	--------	--------	18.65
Sept. 14	.40	4.57	15.07	7.73	5.52	--------	2.15	--------	--------	9.73
Nov. 3	2.06	9.10	28.72	18.63	7.63	--------	--------	--------	--------	20.88
Total	[2] 14.71	57.72	169.16	109.48	54.61	58.18	69.60	--------	--------	124.85

[1] In 1938, plot 4 in corn, plot 5 in oats, and plot 6 in clover.
[2] 1938 total precipitation, 26.23 inches.

TABLE 40.—*Erosion records of control plots 1 to 9, experiment 1, 1938*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Apr. 6	0.94	0.64	28.27	5.76	--------	11.60	10.86	--------	--------	25.41
Apr. 16	1.06	47.24	360.00	117.42	--------	32.71	73.04	--------	--------	83.41
May 4	1.96	3.54	17.32	12.13	--------	64.00	76.10	--------	--------	42.66
May 7	.72	.62	3.10	3.93	--------	15.33	28.50	--------	--------	2.68
May 17	.51	--------	--------	--------	--------	3.44	9.37	--------	--------	--------
June 1	.64	7.18	16.18	24.07	--------	3.62	10.59	--------	--------	8.38
Aug. 21	2.28	77.22	233.82	80.99	78.68	.12	.10	--------	--------	272.98
Aug. 28	1.18	16.15	63.79	25.62	11.57	--------	--------	--------	--------	85.60
Sept. 6	.56	1.68	6.40	1.45	2.63	--------	--------	--------	--------	6.05
Sept. 11	1.31	--------	--------	--------	--------	--------	--------	--------	--------	13.48
Sept. 13	1.09	28.50	108.38	20.54	22.47	--------	.03	--------	--------	100.40
Sept. 14	.40	13.99	56.28	8.59	6.05	--------	9.27	--------	--------	44.79
Nov. 3	2.06	12.67	38.64	13.41	3.36	--------	--------	--------	--------	27.04
Total	[2] 14.71	209.43	941.18	314.41	120.76	130.82	217.86	--------	--------	713.98

[1] In 1938, plot 4 in corn, plot 5 in oats, and plot 6 in clover.
[2] 1938 total precipitation, 26.23 inches.

TABLE 41.—*Runoff records of control plots 1 to 9, experiment 1, 1939*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Mar. 4	(2)					1.93	6.17	12.80	6.58	
Mar. 9	(2)	9.16	2.70	2.53		4.55	20.02	28.28	15.21	12.26
Mar. 11	1.02	21.06	72.75	35.34	20.13	5.40	7.93	19.23	15.56	39.07
June 9	2.18	25.24	104.97	63.00	17.22		41.22			48.22
June 10	.85	9.31	33.10	17.36	6.50		16.13			10.76
June 13	.70	5.62	17.30	10.24	5.42		8.30			8.57
June 19	1.19		2.25	2.67						
June 21	1.40	10.33	45.16	20.46	17.20		14.02			23.10
June 22	.55	4.40	19.10	8.94	3.84		6.37			10.59
July 4	1.20	7.64	26.26	14.54	11.68		3.67			18.19
July 5	.36	2.26	8.93	4.30	2.48		1.75			5.86
July 25	.91	5.71	19.52	6.73			6.20			14.11
July 28	.56	5.28	19.33	9.52			6.67			12.42
Aug. 8	1.23	1.68	4.02	1.07						1.27
Oct. 9	1.25	2.54	4.68	1.77						1.42
Total	[3] 14.39	111.13	381.09	180.43	93.47	11.88	139.44	60.40	37.35	211.84

[1] In 1939, plot 4 in oats, plot 5 in clover, and plot 6 in corn.
[2] Runoff caused by melting snow.
[3] 1939 total precipitation 24.76 inches.

TABLE 42.—*Erosion records of control plots 1 to 9, experiment 1, 1939*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Mar. 4	(2)							0.08		
Mar. 9	(2)	0.06		0.03		0.03	0.12	.18	0.09	1.07
Mar. 11	1.92	56.08	313.15	100.33	78.54	1.18	1.44	.12		80.37
June 9	2.18	20.27	154.95	54.20	3.88		20.15			53.31
June 10	.85	5.04	17.92	6.96	.37		4.55			7.48
June 13	.70	2.15	9.31	4.77	.47		2.84			5.35
June 19	1.19		1.42	2.87						
June 21	1.40	4.54	30.45	10.60	.43		3.18			15.75
June 22	.55	2.13	10.59	3.82	.10		.76			5.40
July 4	1.20	5.84	41.61	18.53	.58		1.40			21.17
July 5	.36	2.89	11.32	3.53	.20		1.14			4.63
July 25	.91	2.41	12.43	2.58			1.36			8.81
July 28	.56	3.30	17.63	7.70			3.10			20.87
Aug. 8	1.23	.05	.00	.04						.08
Oct. 9	1.25	1.57	2.41	1.20						2.71
Total	[3] 14.39	106.33	632.15	217.27	84.60	1.21	40.04	.38	.09	227.00

[1] In 1939, plot 4 in oats, plot 5 in clover, and plot 6 in corn.
[2] Erosion caused by melting snow.
[3] 1939 total precipitation, 24.76 inches.

TABLE 43.—*Runoff records of control plots 1 to 9, experiment 1, 1940*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Mar. 1	(2)	1.20	5.85	5.34	4.74	2.37	2.65	1.37	1.90	
Mar. 2	0.96	1.36	1.56	2.17	2.19	1.38	1.75	1.43	1.64	2.44
Mar. 29	.09									.66
Apr. 26	.99	.81	.78	.79						1.98
Apr. 29	.96	2.90	9.49	6.02			1.33			6.00
June 4	.92	1.14	4.18	2.52			1.46			
June 27	.51	1.06	3.78	3.68	.51	.91	.76			1.52
July 11	1.61	7.06	18.38	17.07	3.02	4.86	14.52	.51	.78	14.34
July 15	.66	1.03	2.99	2.76		.64	2.35			2.64
July 27	1.68	10.73	30.24	17.96		16.38	5.90			20.90
July 28	2.62	24.01	101.29	58.56	8.24	54.87	47.50	4.40		69.21
July 31	.45	2.78	10.10	5.79		5.12	1.49			5.73
Aug. 8	.68	2.92	10.19	5.21		4.48				5.83
Aug. 11	1.17	10.80	40.81	22.74		16.87	8.75			20.46
Aug. 12	.29	1.22	3.87	2.31		1.35				2.31
Aug. 13	.50	3.83	14.98	7.75		6.41	2.79			7.55
Aug. 24	.53	5.29	18.10	9.38		8.19				7.90
Aug. 26	1.95	16.73	60.67	32.60		30.03	0.55			27.85
Aug. 27	1.50	14.77	56.65	29.85		24.86				27.78
Nov. 11	.82	1.80	7.23	1.30		1.40	9.01		.80	3.41
Total	[3] 18.80	112.34	408.14	233.89	18.70	180.12	109.90	7.71	5.12	220.41

[1] In 1940, plot 4 in clover, plot 5 in corn, and plot 6 in oats.
[2] Runoff caused by melting snow.
[3] 1940 total precipitation, 30.81 inches.

TABLE 44.—*Erosion records of control plots 1–9, experiment 1, 1940*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Mar. 1	(2)	6.71	1.14	2.02	0.09	0.15	0.08	0.05	0.02	
Mar. 2	0.96					.03	.78	.17	.07	0.02
Mar. 29	.09									6.08
Apr. 26	.99	.54	1.84	.44						2.40
Apr. 29	.96	5.16	34.28	17.80			.47			56.44
June 4	.92	2.90	36.41	17.16			2.28			
June 27	.51	9.75	18.22	15.10	.62	1.61	.59			3.94
July 11	1.61	25.50	154.52	146.44	.91	8.17	11.39	.01		114.10
July 15	.66	4.06	23.44	15.31		.91	2.27			17.51
July 27	1.68	45.43	341.34	109.40		103.77	3.36			483.30
July 28	2.62	95.00	591.96	203.81	1.08	102.86	15.20	.11		316.74
July 31	.45	9.71	57.36	17.46		25.79	2.50			39.05
Aug. 8	.68	8.09	23.42	12.53		14.51				39.20
Aug. 11	1.17	27.79	82.06	31.20		87.50	2.75			68.66
Aug. 12	.29	1.14	6.71	1.31		3.95				5.98
Aug. 13	.50	5.45	35.33	14.08		12.28	.23			23.88
Aug. 24	.53	9.23	45.28	8.19		19.10				78.59
Aug. 26	1.95	44.55	211.13	81.05		111.44	.00			189.55
Aug. 27	1.50	30.19	98.52	48.78		61.13				74.34
Nov. 11	.82	.43	1.82	1.30		.86	.34			4.30
Total	[3] 18.89	332.53	1,764.78	833.06	2.70	644.06	43.14	.34	.09	1,524.86

[1] In 1940, plot 4 in clover, plot 5 in corn, and plot 6 in oats.
[2] Erosion caused by melting snow.
[3] 1940 total precipitation, 30.81 inches.

TABLE 45.—*Runoff records of control plots 1 to 9, experiment 1, 1941*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
Apr. 18	1.62	15.38	67.97	31.28		27.34	1.63		0.72	32.44
May 7	.26					2.40				
May 20	.68	1.35				8.30				
May 22	.39	1.75	4.47	3.33		5.27				1.58
May 22	.30	1.73	5.47	3.30		3.82				2.32
May 27	.37					1.38				
June 3	.49	7.02	26.86	13.91	7.78	15.13			2.26	0.84
June 10	3.76	19.44	158.51	95.47	79.02	58.63	2.03	10.90	3.13	80.87
June 11	.56	6.33	24.88	12.48	8.98	3.79				11.26
July 1	1.25	1.61	4.91	3.63		1.38				4.94
Sept. 3	1.31	8.48	17.26	13.40	8.22	1.28				17.60
Sept. 8	1.86	15.00	43.37	24.00	17.90	5.02			.83	28.80
Sept. 13	.38	1.01	1.83	1.50						1.70
Sept. 15	4.40	58.33	163.42	94.14	78.50	24.18		.60	3.11	94.40
Sept. 16	.20	1.08	6.04	3.50	2.38					4.05
Sept. 30	1.12	6.30	7.59	4.61	.84					11.42
Oct. 6	2.00	27.67	86.13	46.76	18.12	3.83				53.00
Oct. 7	1.96	31.40	102.10	58.47	31.48	15.60	3.97			57.58
Oct. 9	.45	.80	1.40	1.26	.96					1.53
Oct. 20	.93	1.65	3.41	3.81						2.21
Oct. 22	2.16	25.25	97.12	47.94	32.65	7.36				47.28
Oct. 27	.50	.77	2.01	1.98						1.56
Nov. 1	2.35	10.70	35.48	16.61	15.57					21.17
Nov. 3	([2])	3.16	17.02	8.25	5.42					7.37
Nov. 5	.21	1.60	6.65	2.77	1.25					3.03
Nov. 23	1.81	4.84	8.46	5.15	5.68					3.60
Total	[3] 31.32	251.82	893.46	500.73	316.74	184.86	7.63	11.50	10.05	490.28

[1] In 1941, plot 4 in corn, plot 5 in oats, and plot 6 in clover.
[2] Runoff caused by melting snow.
[3] 1941 total precipitation, 44.55 inches.

TABLE 46.—*Erosion records of control plots 1 to 9, experiment 1, 1941*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4 [1]	Plot 5 [1]	Plot 6 [1]	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Apr. 18	1.62	292.87	1,281.07	412.46		176.06	0.18			330.51
May 7	.26					7.19				
May 20	.68	3.24				35.13				
May 22	.39	3.34	33.90	10.54		9.48				2.16
May 29	.30	7.47	75.27	24.43		11.83				15.13
May 27	.37					2.46				
June 3	.49	25.37	247.23	88.12	16.00	23.83				25.88
June 10	3.76	121.41	3,185.78	738.02	277.02	22.09	.03	0.07		919.60
June 11	.56	19.49	149.52	56.40	72.10	2.42				51.61
July 1	1.25	5.60	17.32	9.67		.03				11.00
Sept. 3	1.31	21.10	89.35	38.10	28.43	.33				88.65
Sept. 8	1.86	68.86	221.77	115.11	66.05	.91				188.20
Sept. 13	.38	2.77	10.51	1.87						2.91
Sept. 15	4.40	157.23	356.89	186.13	125.20	7.43		.22		670.88
Sept. 16	.20	9.06	8.17	4.89	3.23					7.16
Sept. 30	1.12	1.18	.66	1.20	.46					8.00
Oct. 6	2.00	44.65	62.00	45.66	28.89	1.13				32.50
Oct. 7	1.96	90.45	172.99	116.22	90.45	2.26	3.82			135.03
Oct. 9	.45	.57	.57	.51	1.00					2.60
Oct. 20	.93	.57	2.02	2.01						2.16
Oct. 22	2.16	51.95	312.42	91.29	60.44	2.17				103.26
Oct. 27	.50	.40	1.34	.58						1.54
Nov. 1	2.35	2.43	31.45	6.47	19.23					13.62
Nov. 3	([2])	.36	.11							.28
Nov. 5	.21	.24	3.10	.96						1.55
Nov. 23	1.81	1.40	2.40	1.52	3.20					.60
Total	[3] 31.32	932.01	6,266.02	1,952.01	792.87	304.75	4.03	.29		2,604.97

[1] In 1941, plot 4 in corn, plot 5 in oats, and plot 6 in clover.
[2] Erosion caused by melting snow.
[3] 1941 total precipitation, 44.65 inches.

TABLE 47.—*Runoff records of control plots 1 to 9, experiment 1, 1942*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4[1]	Plot 5[1]	Plot 6[1]	Plot 7	Plot 8	Plot 9
	Inches	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
Jan. 28	(2)	1.37		1.57	0.48	1.44	1.07	1.26	1.41	1.34
Mar. 7	(2)	51.08	76.68	40.65	30.40	13.44	0.85	3.94	3.61	31.02
Mar. 16	.86	4.55	5.05	3.21	4.16	.50			.76	8.72
Mar. 19	.48	.92		1.31	.03					.44
May 11	1.29	2.91	3.87	4.06	6.47					
May 22	1.25	1.90	.93	1.58	8.80					
June 20	2.95	39.64	102.10	58.19	29.83	19.61	53.12	2.86	3.10	52.18
June 25	1.56	6.37	20.28	11.99	9.19	3.90	7.19			10.23
Aug. 6	.82	3.03	3.69	3.69			3.09			5.80
Aug. 27	1.08	7.11	11.48	11.66	1.41		12.24		1.00	13.50
Sept. 2-3	3.46	43.89	82.14	53.24	8.78	2.00	41.66		2.35	52.96
Sept. 15	.90	1.42	3.40	2.56			1.16			4.73
Oct. 3-4	.93	1.55	1.17	1.77						
Dec. 21-22	.21	2.20	1.09	3.34	.90		2.01			
Dec. 26-27	.88	9.74	17.85	12.26	15.62	11.84	10.25	12.38		2.90
Total	[3] 16.67	177.68	330.53	217.08	110.06	52.73	142.24	20.44	12.23	184.81

[1] In 1942, plot 4 in oats, plot 5 in clover, and plot 6 in corn.
[2] Runoff caused by melting snow.
[3] 1942 total precipitation, 30.68 inches.

TABLE 48.—*Erosion records of control plots 1 to 9, experiment 1, 1942*

Date	Effective precipitation	Plot 1	Plot 2	Plot 3	Plot 4[1]	Plot 5[1]	Plot 6[1]	Plot 7	Plot 8	Plot 9
	Inches	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Jan. 28	(2)	0.03		0.02	0.07	0.04	0.03	0.07	0.03	0.08
Mar. 7	(2)	.06	1.44	.58	.57	.17	1.85	.47	.38	2.99
Mar. 16	0.86	3.56	14.89	1.25	.42	.02			.01	7.68
Mar. 19	.48	.22		.03	.01					.08
May 11	1.29	9.42	8.51	7.38	5.87					
May 22	1.25	.96	.47	1.01	11.68					
June 20	2.95	219.90	1,061.01	413.50	47.36	27.92	28.53	.04		380.98
June 25	1.56	11.63	145.69	48.54	.17	.10	10.38			29.82
Aug. 6	.82	4.53	18.24	10.58			10.60			33.70
Aug. 27	1.08	11.19	23.84	20.06	.37		45.77		.30	73.31
Sept. 2-3	3.46	78.17	245.00	81.04	.82	.08	112.61		.16	190.20
Sept. 15	.90	1.04	7.07	4.32			4.44			9.13
Oct. 3-4	.93	.51	1.59	.47						
Dec. 21-22	.21	.16	.06	.04	.03		.03			
Dec. 26-27	.88	6.58	8.19	5.39	.20	.22	2.78	.54		4.76
Total	[3] 16.67	348.86	1,536.00	603.21	67.06	28.55	217.00	1.12	.88	732.73

[1] In 1942, plot 4 in oats, plot 5 in clover, and plot 6 in corn.
[2] Erosion caused by melting snow.
[3] 1942 total precipitation, 30.68 inches.

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