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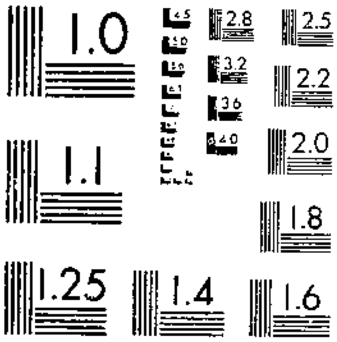

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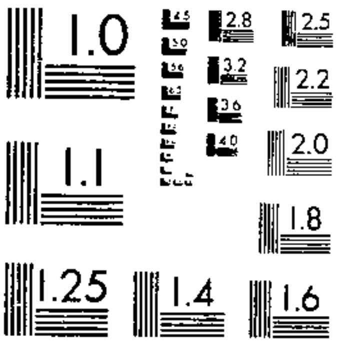

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UNITED STATES DEPARTMENT OF AGRICULTURE WASHINGTON, D. C.

Investigations in Erosion Control and Reclamation of Eroded Shelby and Related Soils at the Conservation Experiment Station, Bethany, Mo., 1930–42.[1]

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

CONTENTS

SUMMARY OF RESULTS AND THEIR APPLICATION TO LAND USE PLANNING

More than a decade of investigations of the basic factors affecting runoff and soil losses at the Bethany Station have established certain principles that are fundamental to sound land use planning. The problem area of the Shelby loam and associated soils includes wide variations in weather conditions, topography, erosion, and cropping practices which occur in many combinations for the individual fields and farms of the area. The investigational program of the station has necessarily been concerned not with all possible combinations of these variables, but with the more generally occurring combinations with as

[1] Submitted for publication June 1944.

[2] Former members of the Station staff who contributed to the planning and development of the research program are R. E. Uhland, C. K. Shedd, A. T. Holman, and C. M. Woodruff.

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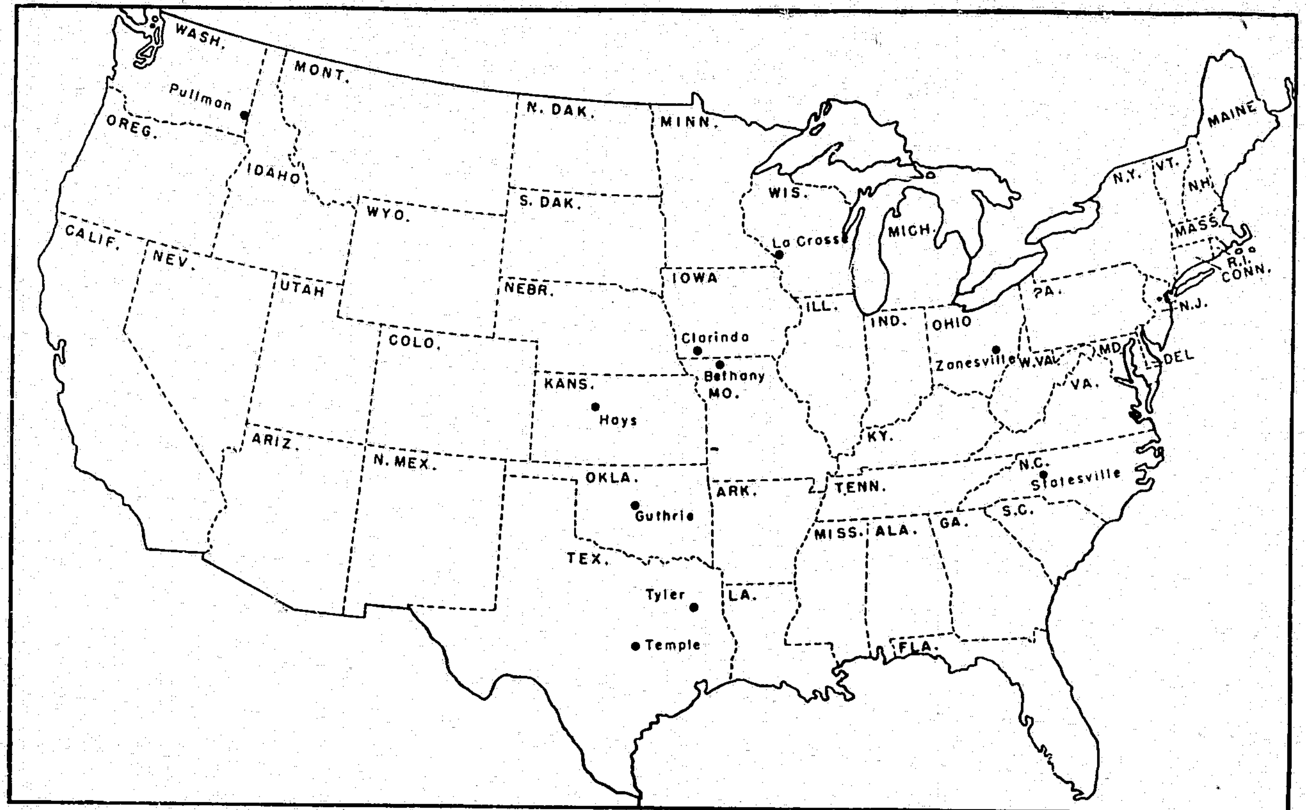

Map of United States showing location of 10 soil conservation experiment stations

ERRATA

United States Department of Agriculture Technical Bulletin No. 883, Investigations in Erosion Control and Reclamation of Eroded Shelby and Related Soils at the Conservation Experiment Station, Bethany, Mo., 1930–42

Page 15, paragraph 6, "the central portion of the Big Creek watershed just north of Bethany, Mo.," should be "the experiment station farm, west of Bethany, Mo."

Page 16, legend of figure 3 should be "An aerial view of the Bethany Experiment Station farm."

Page 20, eleventh line from bottom, "figure 5 (p. 25)" should be "figure 1 (p. 12)."

Page 27, last line should be "these plots are designated as plot series 1, plots 1 to 10, inclusive."

Page 32, line 6, "Figure 8" should be "Figure 28 (p. 81)."

Page 42, table 14, figure for amount of run-off from treated plot in meadow should be 0.88 inch, not 0.088 inch.

Page 43, last paragraph, third sentence should be replaced by "Reduction in water loss was 66 percent for meadow, 62 percent for oats, and 34 percent for corn"; in line next to last on page, "50 percent" should be "52 percent."

Page 53, line 4, "yields" should be followed by "than."

Pages 53 and 57, legends of figures 15 and 18 should be interchanged.

Page 59, first sentence, "water-" should be "watershed."

Page 64, line 2, "figure 21" should be "figure 20."

Page 84, figure 29, in horizontal scales the phrases "13 percent slope" and "7-percent slope" should be interchanged.

Page 93, line 8, sentence now beginning with "During the three years" should be "After 1931 both areas were in corn on the contour during three different years"; in sentence immediately preceding table 35, the words "original and" should be deleted.

Page 112 belongs in the section under the heading Vegetation in Drainageways, on page 115; it should follow the second paragraph under that heading.

Page 113, the third and fourth paragraphs should follow the third paragraph on page 112.

Page 125, line 17, "3/4 inches" should be "3 to 4 inches."

Page 128, third line from bottom, "0.65" should be "0.065."

Page 130, line 7, "0.034" should be "0.0034."

Page 130, transpose last 10 lines on page 134 and first 9 lines on page 135 to bottom of page 130.

Pages 162 and 163, tables 58 and 59, plot numbers in subheadings should be deleted, as all data in each case are for three plots.

Pages 174 and 175, in box heads of tables 76 and 77 "Min." should in each case be "inch per hour" or "inches per hour"; in box heads of table 77 "Rate" should in each case be "Amount."

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many of the variables as possible held constant during a particular study. The results of these investigations can be interpreted into precise recommendations that are closely applicable to conditions represented by the station fields and plots and will serve as fundamental principles for general application under conditions which may differ materially from those on the station farm.

It is apparent from the studies on the causes of erosion that climate, vegetation, degree and length of slope, the soil and its physical condition, moisture content, and level of productivity, are basic factors determining the potential erodibility of the land.

Conservation practices must be procedures which reduce the potential erodibility of the soil. This is accomplished by conditioning of the soil, by shortening the length of slope, by reducing the volume of runoff, and by providing vegetation to diminish the force with which rainfall reaches the soil surface or flows over it during heavy rainstorm periods.

The reconnaissance erosion survey of 1934 indicated that on the Shelby and related soils, erosion, had proceeded to a point where plowing resulted in mixing the subsoil with the surface layer over one-half of the area. That this has been reflected in decreased productivity of the soils cannot be denied. Studies on the station and surrounding farms show that yields of corn decreased 3 to 5 bushels per acre for each inch of surface soil lost for soil depths of less than one foot. At the station farm the yields of oats and second-year meadow grown on subsoil have been about one-fourth, while the yields of corn and first-year meadow have been about one-half those of the same crops grown on surface soil.

The deteriorated soils of the area are generally the result of continuous cropping to corn or corn with occasional small grain. Control plots on which corn grew annually for 10 years lost 3½ inches of topsoil during the period, while those in a 3-year rotation of corn-wheat-meadow lost less than ¾ inch during the same period. Runoff losses from the rotation have averaged about 60 percent of those from the continuous corn during the same period. The plots on which these crops were grown were only 72.6 feet long, or about the horizontal spacing for terraces on a similar slope.

Insignificant erosion was measured from bluegrass and alfalfa. The use of lime and fertilizer resulted in high alfalfa yield and increased the yield of wheat 65 percent and the yield of meadow 33 percent.

These and other studies on the station definitely show that the continuous growing of corn or other row crops is not justified in the area, even when supported by such conservation practices as terracing with contouring and the addition of manure and other soil amendments.

As rainfall is a phenomenon over which man has no control, he must become acquainted with its characteristics from the study of meteorological records. The range of fluctuation and critical periods of the heaviest and most intense rainfall for various seasons of the year are used in designing cropping systems and conservation practices to give adequate protection to the soil.

Meteorological records for the 10-year period showed an average annual precipitation of 29.5 inches with the highest intensities occurring in June, July, and August, when 60 percent of the total rain fell at a rate equal to or greater than a quarter of an inch per hour. The percent of rainfall occurring at rates equal to or greater than 4 inches per hour was almost constant from April through September. The 11 most intense storms during 10 years of study accounted for 11 percent of the rainfall, 23 percent of the runoff, and 36 percent of the soil loss from the continuous corn plot.

Additions of organic matter in the form of barnyard manure or crop residues, have been found to lessen erosion on the Shelby soils. When incorporated with the soil they favorably modify or condition its physical structure and raise its fertility level, resulting in increased absorption of rainfall, an accompanying reduction of soil loss, and an increase in crop yield.

The use of lime and fertilizer has resulted in increased density of stand, increased yield, and reduced soil and water loss, not only from small grain, but from the meadow that follows. Winter-killing of wheat has been materially lessened by these amendments.

Shelby subsoil aggregates were found to be larger than those in the surface soil and more resistant to erosion when in a fallow condition. Runoff and erosion were, however, less from the surface soil under conditions of cropping, due to the more abundant vegetation supported by the higher fertility level of the surface soil.

In comparing fall- versus spring-plowing, it was found that an improved soil structure and better distribution of labor resulted from the fall plowing. This improvement of soil structure greatly facilitated the management of eroded subsoil areas. Fall plowing resulted in less winter and early spring erosion, but greater soil losses in late spring. Fall plowing is recommended only for terraced or strip-cropped land to be plowed out of sod.

Organic matter and nitrogen decreased with loss of surface soil. Calcium and magnesium, however, were found to be more plentiful in the subsoil than in the surface soil. The organic matter and nitrogen of a plot in a 3-year rotation of corn-wheat-meadow when limed and fertilized with 20 percent superphosphate increased slightly with time, whereas without the soil treatment the organic matter and nitrogen declined.

The benefits of crop rotations are mainly derived through the effects of the meadow crop, making it important that meadow be secured each time without seeding failure. Competition between small grain and young meadow for moisture has been a factor in the establishment of new meadows. The use of phosphate fertilizer and lime has proved a valuable aid in securing a vigorous stand of grasses and legumes. While their costs have been repaid in increased yields of the small grain crops, their use in establishing meadow crops and thus insuring the unbroken continuity of rotations is of primary importance. The importance of these treatments increases rapidly with increased erosion, and they become mandatory on the more severely eroded lands.

With other variables constant, soil and water losses are proportional to the amount and type of vegetative cover present at the time of the rain. Small grain crops offer more protection than cultivated row crops, but not as much as dense grass or meadow crops; neither do they offer adequate protection without other supporting conservation practices. Wheat permits significant soil and water loss during October and November, while oats permits significant soil loss during the spring months.

The most important consideration in the growing of cultivated row crops such as corn and soybeans is that they be employed in a cropping system directly following at least one year of grass and legume meadow. These row crops provide minimum protection to the soil during the critical rainfall periods occurring in the spring, early summer, and fall. The conditioning of the soil by preceding sod crops will carry over into the following year to give appreciable protection to the soil. During June, corn following corn lost 3½ times as much soil as corn following meadow. Soybeans drilled in 8-inch rows lost only half as much soil as when planted in 42-inch rows, thus illustrating the decrease in erosion accompanying increased density of plant cover.

Legumes grown without grasses have been observed to leave the soil in a loosened condition. Plowing under of legumes as green manure has depressed crop growth and yield when moisture was deficient. Alfalfa stands were maintained for a 12-year period by periodic liming and phosphating. This crop was unsuitable for use in waterways or other locations, such as terrace channels of too small gradient, where a condition of poor drainage was present. Weak points from an erosion control standpoint, in the growing of alfalfa, occur at the time of seeding and again when the crop is plowed for subsequent cropping. The growing of timothy or brome grass with alfalfa was a desirable practice from both an erosion and a production standpoint. Small grain-Korean lespedeza cropping has produced large tonnage yields on both surface and subsoil. This type of cropping is increasing rapidly on the Shelby soil of Missouri. It has been superior to a corn-wheat-meadow rotation from an erosion standpoint.

Well managed bluegrass pastures have provided adequate protection from all rainstorms experienced during the period of study. Intensive grazing of the bluegrass has resulted, however, in increased runoff, gully formation, and rapid advancement of gully headers. Intensive grazing has also reduced the palatable species of grasses, increased the unpalatable, and yielded little or no gain in weight of the grazing stock.

The topography of the soils area is such that most slopes have a combined degree and length which demands modifying measures. As the degree of slope cannot be lessened practicably, conservation practices must be devised to shorten the length of slope, reduce the quantity of storm runoff or give mechanical protection to the soil surface from the water that flows from the field. Soil loss from plots was found to be proportional to the 1.6 power of the length and to the 1.4 power of the percent slope.

TERRACING

Terracing has proved to be the most effective supporting conservation practice on the station. Terraces or diversion dykes are the only means for actually reducing the length of slope factor. When combined with soil conserving crop rotations, soil amendments, and contour tillage, a maximum of soil and water will be retained on the field for crop production.

Annual runoff from terraced areas has been about three-fourths of that from unterraced land. Average maximum rates of runoff from terraced watersheds were less than half of those from unterraced watersheds during seven major storms. Soil loss at the outlet of a terraced watershed during the 8-year period 1935–42 was about 2 percent of that from a similar watershed without supporting conservation practices.

Terraces do not obviate the necessity for soil treatments and for crop rotations in keeping with the capabilities of the land. The use of terraces is limited, not by physical limitations of construction, but by the economics of construction, maintenance, and the practical operation of farm machinery after construction.

In the Shelby soil area, well defined drainageways are usually present at a distance of 300 to 400 feet from the crest of the hill. Their points of origin generally mark the dividing line above which terraces are easily constructed and operated, and suggest the practical limit of their application to a land area. The construction of terraces below this point is accompanied by increased cost, and, on the more steep and irregular areas, the terrace lines tend to become one short curve after another. Thus, 3 to 6 terraces is usually the practical number for the majority of fields. Contour tillage of 100- to 200-foot widths strips below the last terrace would, in general, mark the limit of cultivation feasibility, or if the slope is somewhat longer, the additional support of strip cropping may be economically introduced for complete utilization of the area while providing adequate protection of the land from erosion.

The ease and practicability of farming terraced fields decreases with increases in the degree of steepness and the irrgularity of the slope. From an economic standpoint the greatest returns per dollar spent for terracing comes from that expended on the upper reaches of the fields. An upper slope limit of practical terrace operation in this area appears to be not much greater than 10 percent. This does not infer the use of less effective supporting practices on steeper slopes, but the elimination of cultivated crops, an increase in the number of years of meadow, or preferably the return of the land to permanent hay or pasture.

Terraces with wide gentle side slopes are the easiest to farm. Construction of terraces of standard sizes, grades, etc., without regard to length or hydraulic traffic to be expected is not in accord with good judgment. Short terraces draining a convex section at the upper part of the slope can have smaller ridges and channel capacity than those farther down the slope where the length is greater and additional volmes of water must be conveyed from the field.

Terrace spacing is not a rigid design factor on land of uniform slope. Wide horizontal spacings on the flatter and uniform slopes are not only more economical and workable, but are satisfactory for erosion control. With increased irregularity of land slope, the spacing factor becomes more exacting, due to possible concentrations of runoff and accompanying silt deposits in the channels. Spacing that is too close, however, will increase the density of runoff. Sixty feet appears to be the minimum practicable spacing. Spacing experiments indicate that a 5-foot vertical interval should be recommended for a 7-percent slope, and an 8-foot interval for a 13-percent slope. Appreciable deviation from these recommendations can only be made with safety on land of uniform slope, the amount of deviation decreasing as the irregularity of slope increases.

Flat grades on shallow surface soil are undesirable due to ponding in the channels, and subsequent crop damage and delayed farming operations. As the Shelby loam experiments have shown, grades of less than 2 inches per 100 feet of length were not practicable, and grades of 6 inches per 100 feet of length marked the safe upper limit. Grades of 8 inches per 100 feet, while not allowing scour, were conducive to damaging silt deposits in sodded outlet channels. The most desirable grade for the normal or long terrace appears to be a variable grade ranging from 2 to 6 inches per 100 feet.

Terraces one-half mile in length have functioned satisfactorily, although greater height and channel capacities are naturally required than for terraces one-quarter mile long. This latter length appears the more desirable.

Contour tillage is always desirable and necessary on terraced fields for operations involving the movement of soil. One-way plowing, wherein the furrow slice was turned up hill when breaking sod for corn in a 3-year rotation of corn-oats-meadow, eliminated the necessity for terrace maintenance. Experiments have shown that corn rows should not cross terrace channels or ridges, even at slight angles. Point rows have been placed in the terrace channels or below the ridge at the base of the terrace. While either location has certain advantages, the latter has appeared to be the most practicable on the average slope on the Shelby soil.

Soil losses as measured at the ends of terrace channels were about 2 tons per acre per year for a rotation of corn, soybeans, wheat and meadow as compared with half this amount for a 3-year rotation of corn-oats-meadow. However, the soil losses measured at the end of the terrace channel represented only a part of the soil that moved down the terrace interval and accumulated on the front slope of the terrace ridge.

Bluegrass has proved to be the most effective grass for outlet control. The most practicable way to secure satisfactory outlets from seeding has been to establish them before the terraces were constructed, or to divert the runoff until after the seedings have become established.

Rotational-type strip cropping, wherein a sequence of crops is grown on a slope at a given time, has, when wisely applied, proved effective in reducing soil erosion. Measurements showed that it reduced soil loss to slightly less than one-half that from similar contour-farmed areas although runoff was not affected. Rotational strip cropping has proved effective on convex land areas when the slope length did not greatly exceed 300 feet, but the practice did not lend itself to livestock types of farming. Insect damage has almost precluded the growing of corn and small-grain crops on adjacent strips. Permanent buffer-type strip cropping with varying degrees of support by terraces and diversion dikes has eliminated many of the difficulties inherent in rotational strip cropping.

The fundamental factors favorable to successful strip cropping are: a soil fertility level capable of supporting dense growths of vegetation; convex slope aspect; well-grassed waterways at all water concentration points; and the location of the strip-cropped area on slopes of limited length. Long slopes on the station have had water removed from the upper reaches by terraces or diversion dikes to provide this latter condition for strip cropping.

Contour tillage has been the cheapest and most easily applied supporting conservation practice on the station. In general, it has given adequate protection when used as the sole supporting practice for the normal, and below normal, rainstorms. For the more intense storms the relative amount of protection it has afforded, in comparison to noncontoured areas, has decreased with increases in the severity of the storms. Its average effect has been to reduce water loss by one-fifth and soil loss by one-half.

The Shelby subsoil, while higher in lime and magnesium than surface soil, is low in organic matter, nitrogen, and phosphate. Thus any cropping on severely eroded areas must be accompanied by the use of organic matter in the form of manure, crop residues, or green manure crops, in addition to the use of lime and phosphate fertilizer. Lime and fertilizer has increased the yield of oats fourfold and first-year meadow twofold. Any plowing should preferably be done in the fall to improve the soil structure by freezing during the winter. The cropping, to be economically sound, should be confined to small grain and grass and legume meadow without cultivated crops which have the higher production costs. This will often require a transition to a livestock system of farming with harvesting largely by livestock grazing. Since eroded fields must be plowed and soil treatments renewed at intervals, the use of terraces is recommended to safeguard the progress already made.

The development of satisfactory outlets and permanent drainage channels is essential to the successful operation of terraces and other protective measures such as strip cropping and contour farming. For the successful and permanent operation of these devices it has been found that the drainage systems of the fields must be protected by the establishment of a perennial vegetation. The relative effectiveness of various methods and different materials has been investigated and the results recorded.

Grass cannot be expected to grow and produce an erosion-resistant lining in a channel without the proper cross-section, seedbed preparation, and most important of all, a high level of soil fertility. Experiments have shown that grass-seeding mixtures should be selected according to the waterway characteristics of moisture, soil fertility, and volume of runoff to be carried. Highly satisfactory methods of drainageway preparation for successful seedings have been developed. They are of course more easily established while the drainage area is planted to erosion-resistant crops or while the runoff is temporarily diverted to other channels.

Grassed waterways and terrace outlet channels can be established more practicably without wire or brush checks, spreader boards or sod strips, than with them. Devices of this type require not only costly maintenance, but leave the channel a series of steps which are the continuing cause of the maintenance.

Bluegrass sod has been tested as complete sodding, sod flumes, sod-hump dams, check or barriers, and sod-bag checks. Of these, complete sodding was the most successful but also the most costly. Sod check barriers or sod bags were of doubtful value and cannot be recommended. Sod-hump dams have been more successful than the other forms of checks when properly located.

Successful erosion control has been secured from plantings of black locust in well-drained hillside gullies with drainage areas of less than one-half acre, but where the drainage areas were appreciably larger such plantings have not given satisfactory control.

Mechanical structures of concrete or earth are generally necessary at the junctions of outlets and field drainageways with ravines or main drainage channels. Earth dams which provide a stock water supply are ideal gully-control methods for fields to be grazed by cattle.

Temporary devices such as brush and wire dams, creosoted spreader boards, and asphalt-sand structures have proved unsatisfactory since water cannot be lowered over such barriers without constant and costly maintenance operations. Furthermore, these structures when placed in terrace outlets or waterways have proved to be a hindrance to the establishment of grassed channels.

Rock-masonry dams have performed satisfactorily and are applicable to locations where it is necessary to maintain a permanent drop of 3 to 5 feet in water disposal systems draining approximately 20 to 30 acres. Unformed concrete spillways and dams, when properly constructed, have given good control and in the long run are very economical when considered from the viewpoints of both maintenance and construction. Prefabricated metal flumes are easily installed and have given good performance in lowering runoff from farm ponds. A drop-inlet dam, if wisely placed, may be made to protect several overfalls entering a large gully and consequently be more economical than several smaller structures. Considering maintenance, life expectancy, and performance, drop inlet dams, detention reservoirs, and unformed concrete flumes have been the least expensive of the gully control structures investigated.

Eight small watersheds varying in size from 2 to 8 acres have been devoted to a study of the effect of land use and conservation practices on runoff and erosion. Of the four cultivated watersheds under study, the soil loss from the contoured field was 11 percent; from the strip cropped watershed 7 percent; and from the terraced land 2 percent of that from the watershed in a rotation without supporting conservation practices. The measured runoff from the contoured watershed was 84 percent; from the strip-cropped area 68 percent; and from the terraced land 70 percent of that from the rotation-cropped watershed without supporting practices. For both the cultivated and the pasture watershed the 30-minute rainfall intensity was more closely correlated with the maximum rate of runoff than either the 5- or 15-minute intensities. Antecedent rainfall had an appreciably greater influence on the maximum rate of runoff from the cultivated field than from the pasture watershed. For the nine major storms the undisturbed blue grass pasture had the highest average retention rate index and the cultivated watershed without supporting practices the lowest rate.

RAINFALL-SIMULATOR STUDIES

Infiltration rates were determined from rainfall-simulator data for dry and saturated bluegrass sod, bluegrass rough spaded, bluegrass sod smooth cultivated after spading, and for a smooth cultivated cornfield soil. The minimum rates of infiltration for bluegrass sod was approximately 0.10 inch per hour or about double that from the smooth cultivated cornfield soil. Increasing the supply rate increased surface detention and equilibrium rate of runoff but decreased the time required to reach equilibrium. Surface detention was found to be related to both rate of supply and rate of runoff. Velocity of overland flow at the plot outlets for an equilibrium runoff rate of 3 inches per hour was only 0.13 foot per second for bluegrass, as compared with 1.03 feet for the smooth cultivated cornfield soil.

These conclusions and applications of results for the station are based upon scientific measurements as well as practical operation of the practices on field-size areas. They represent an accumulation of facts secured during the 12-year life of the station. The findings of the station have served as the basis for the establishment of erosion control measures and practices on not only the Big Creek and other Missouri projects, but also have been useful in the formulation of conservation programs on demonstration projects throughout the country.

The experiment station site has proved invaluable in acquainting interested visitor groups with the need for erosion control, the fundamental principles involved, and the application of the various control methods to practical farm use. Over 8,000 people have viewed the work of the station since it was established. Thirty-seven States of the Union and 10 foreign countries have been represented among the visitors. Five thousand visitors have registered from 67 Missouri counties. Iowa has led the States outside of Missouri with 1,400 visitors.

INTRODUCTION

This publication deals with the development and results of investigations pertaining to the basic factors affecting soil and water loss, and methods for the conservation of soil and water, carried on at the Soil Conservation Experiment Station, Bethany, Mo., during the period 1930–42.

Dr. H. H. Bennett in his book "Soil Conservation" (*4*)[3] states that "probably the first survey of a large area in America which pointed specifically and quantitatively to the wholesale ravages of unrestrained soil erosion" was the soil survey of Fairchild County, S. C., in the year 1911.

The fact that serious erosion was occurring on farm lands in other sections of the country was soon recognized by agricultural leaders. M. F. Miller organized at the Missouri Agricultural Experiment Station, in 1917, the first plot study of the effect of crops and crop rotations on runoff and erosion. Also, in 1917 the United States Department of Agriculture published a bulletin on erosion control by terracing (*22*). In 1923 the Missouri Agricultural Experiment Station reported on their plot work (*9*). In 1924 the Bureau of Public Roads began soil erosion experiments at the Raleigh, N. C., Agricultural Experiment Station. In 1926 the substation of the Texas Agricultural Experiment Station at Spur, began work on conservation of runoff and soil. In 1928 the Department of Agriculture published "Soil Erosion a National Menace" (*5*).

Nation-wide interest in soil and water conservation developed rapidly and resulted in the passing by Congress of the Buchanan Amendment and subsequent establishment of the 10 original Soil Erosion Stations during the period 1929–33 (see map on p. 2). The Bethany Station was the fifth of the group to be put into operation. Plans for the station, selection of land and personnel, and preparation of soil and topographic map were made during 1929 and early 1930. Leasing of the station and possession of the land was of

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[3] Italic numbers in parentheses refer to Literature Cited, p. 143.

March 1, 1930. The original plan specified that the station would operate for 10 years. Securing soil and water loss data was discontinued on most of the original studies on December 31, 1940, but in a few instances the studies [4] were continued through the 1942 season in order to round out the rotational period.

The work at the station has been cooperative between the United States Department of Agriculture, the Missouri Agricultural Experiment Station, and the Bethany Chamber of Commerce.[5] Originally, the Department of Agriculture was represented by the Bureau of Chemistry and Soils and the Bureau of Public Roads (later the Bureau of Agricultural Engineering), but in 1935 all work of the Department was transferred to the Soil Conservation Service.

THE PROBLEM AREA

Nature of the Area

The Bethany station, about 25 miles south of the Missouri-Iowa State line, is representative of the problem area of Shelby and related soils which occur largely in north central Missouri and south central Iowa, and to a less extent in southeastern Nebraska and northeastern Kansas. The area consists of approximately 15,730 square miles, distributed as follows: 7,260 square miles in Missouri, 4,760 square miles in Iowa, 220 square miles in Nebraska, and 3,490 square miles in Kansas. Secondary areas of closely associated soil and similar natural characteristics occur in southeastern Nebraska, central and northeastern Iowa, and northern Illinois. Figure 1 is a map of the primary areas in Missouri, Iowa, Nebraska, and Kansas. The map shows the extent of erosion of the area as determined by the reconnaissance erosion surveys made in the different States in 1933–34.

The soil of the problem area is developed largely from till from the Kansan glaciation, which was deposited in the form of terminal moraines. In some sections the till is deposited directly on residual limestone; in others it apparently covers large areas of soil of an earlier period. Where the till has been deposited over unconsolidated material, few, if any, fragments of limestone occur, but large quantities of gravel and granite are not uncommon. The deposits of till vary from a trace to a depth of 100 feet or more. Along the main streams and on the more level ridges there are considerable deposits of windblown material of varying depths. Pockets of sand, hillsides of gravel, and scattered rocks and boulders cause various soil, slope, and vegetative conditions.

The soils in general are those of the northern prairies, with a trace of the grayish-brown podzols. Three soil types, Shelby loam, Grundy silt loam, and Lindley loam make up the greater part of the uplands of the region. Of these the Shelby and Grundy soils are representative of the great soil group of Prairie soils of the northern prairie region, and the Lindley of the Gray-Brown Podzolic group. The Shelby loam is the most extensive on the experiment station plots.

[4] Woodruff, C. M., and Smith, D. D. Progress report of the problem area of Shelby loam and related soils. Soil and Water Conservation Experiment Station, Bethany, Mo. 1938. [Processed.]

[5] The Bethany Chamber of Commerce was represented by its president, J. E. Noll, who worked untiringly with the station and Service personnel, not only in local affairs of the station, but for national furtherance of soil conservation.

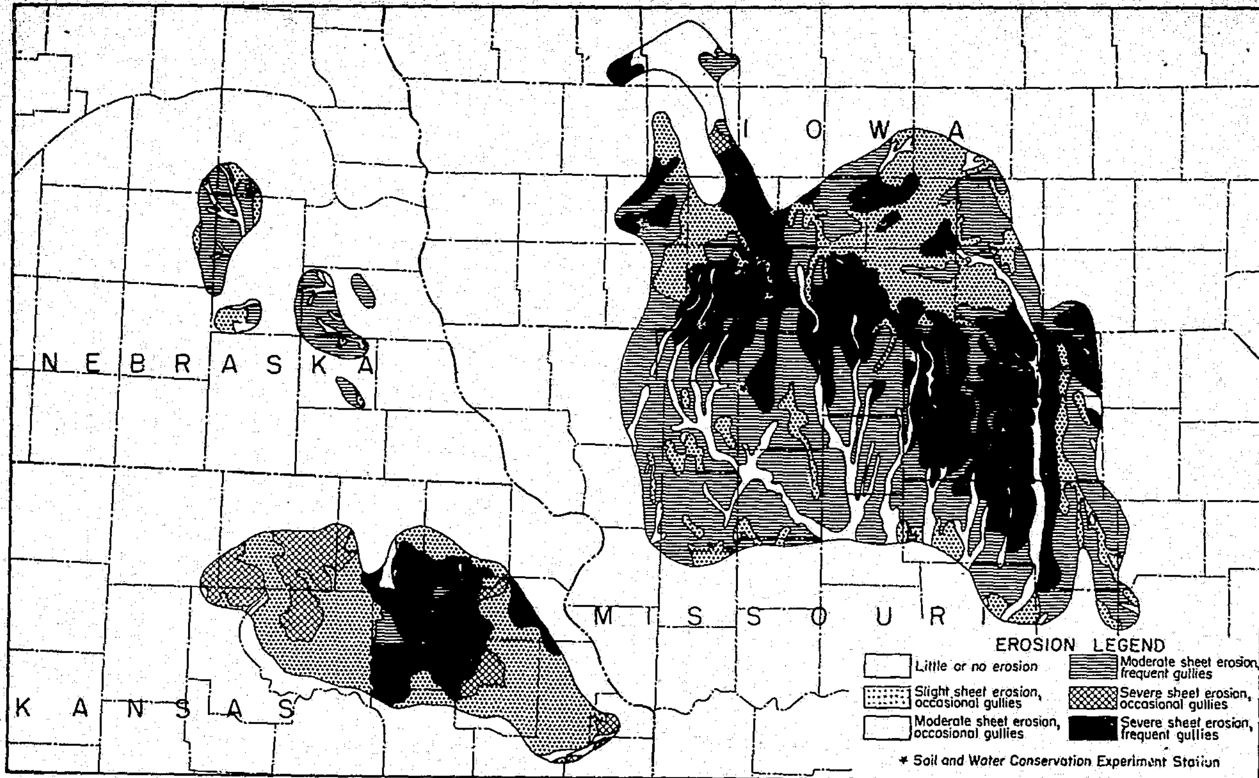

FIGURE 1.—Map of the problem area of Shelby loam and related soils, as compiled from the reconnaissance erosion survey maps of the several States.

The Shelby loam.—This soil is developed from glacial till under a cover of prairie grass. It occurs on a rolling relief characterized by low, rounded hills, with soil slopes most commonly ranging from 6 to 15 percent. This soil has been well described by Miller and Krusekopf (*17, p. 35*), as follows:

> * * * Typically, it consists of a black, dark-brown or yellowish-brown, friable loam, varying from 6 to 12 inches deep. The content of sand in the surface soil is sufficient to give a gritty feel, and to make it loose and friable. The percentage of silt, however, is nearly always rather high for a loam, and in many cases it might be called a silt loam. The subsoil, from 15 to 36 inches, is a . . . yellowish-brown, tenaceous, sandy clay, mottled brown, red and gray. The content of organic matter in the surface soil varies considerably; on the steeper slopes it is quite low, but on gently rolling areas and especially at the base of slopes it is much higher.
>
> The characteristic feature of the Shelby loam is the presence of sand and fine gravel throughout the soil mass. Both sand and gravel are rounded, and are largely of foreign origin, consisting of quartz, granite, greenstone, gneiss, diabase, and many other crystalline rocks. This coarse material is not present in quantities sufficient to affect the soil appreciably, although it tends to make it more porous. Lumps of lime concretions and calcareous streaks are present in considerable quantity in the subsoil and extend to great depth.

Figure 2 is a profile picture of uneroded and eroded Shelby loam, taken at two locations on the Bethany station.

The Lindley loam.—This soil has developed under forest cover and is slightly podzolic. The Lindley loam soil is closely associated with the Shelby loam and occurs primarily along the streams, but is of less value for cultivated crops. The topsoil is a yellowish-gray loam, 5 to 10 inches deep, underlaid by a gray, ashy layer, which is not always clearly defined. The subsoil to a depth of 12 to 16 inches is normally a light-brown loam, which grades into a compact, silty clay. The lower subsoil material, or that occurring below a depth of 30 inches, is usually a light-gray or drab, silty clay, although it varies in different sections. It appears to be partly glacial and partly residual and is intermingled with wind-blown material of glacial origin.

The Grundy silt loam.—In the problem area served by the Bethany station, the largest sections of Grundy silt loam are on the broad interstream divides of the undulating prairies. In the more rolling sections of Shelby loam, nearly every ridge top is capped with Grundy silt loam, so that altogether it constitutes a considerable part of the total area. The Grundy soil is derived largely from wind-laid material. The typical profile consists of a dark-brown to black surface soil 12 to 15 inches deep, underlaid by a gray to grayish-brown layer of heavy silt loam or clay loam, which at 18 inches grades into a dark-drab or yellowish-brown, heavy, tenacious, silty clay or clay. Small iron concretions are present throughout. The value of this soil for cultivated crops probably exceeds that of the Shelby loam because the topography is not so rolling.

Topography.—Following recession of the ice-age glaciers, the Shelby loam soils area of northern Missouri and southern Iowa was probably a gently undulating or nearly level plain. As the soil mantle was deep, this plain has been dissected by geological erosion to its present topography with a wide variation in degree, length, shape, and direction of slopes. The main streams have cut through the top deposits to, and in some cases through, the upper underlying

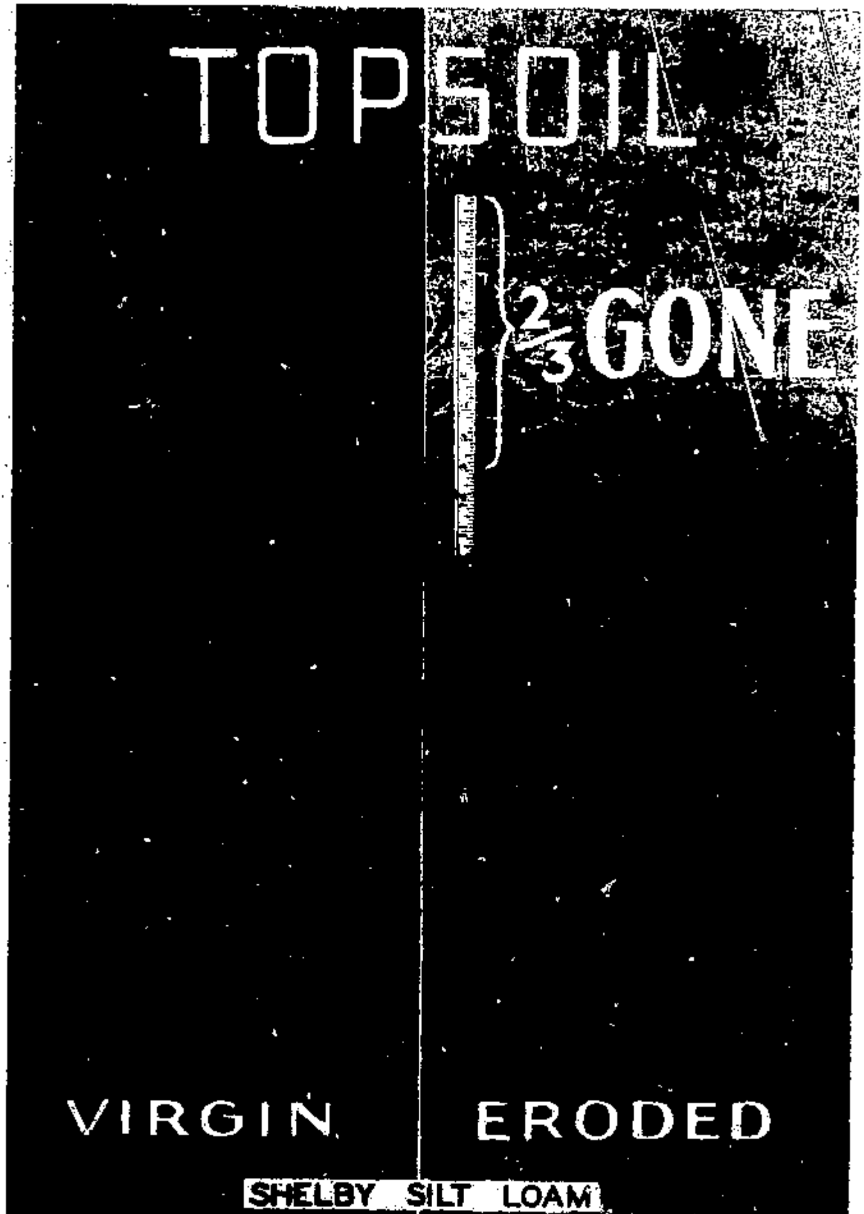

FIGURE 2.—Profile of uneroded and eroded Shelby soil on the Soil and Water Conservation Experiment Station, Bethany, Mo.

shale and limestone deposits. They have low gradients and meandering courses, so may be considered as streams in old age.

Drainageways entering the main streams usually drain from 80 to 2,000 acres. They normally carry water only from storm runoff, although they may flow for prolonged periods in times of excessive rainfall. These branches are generally mature, having wide, meandering channels containing deposits of silt. The smaller branches, however, have steeper gradients and are in reality V-shaped depressions with side slopes of 10 to 20 percent. They are generally timbered, and are quite numerous along the hills adjacent to the flat bottoms of the main streams.

In the upper parts of the medium to large branches, there is a transition to what is locally known as a ravine. This section is characterized by relatively steep banks which are close enough together to confine most of the storm runoff to a definite channel. The banks are generally grassed or timbered. The channels have a fairly uniform gradient of 1½ to 2½ percent, except in the upper reaches where the gradient becomes steep and blends into the originally grassed depression of the field drainageways. The drainage area of the ravine is generally from 30 to 200 acres.

Away from the main streams the topography is less rough and broken. Long, wide ridges slope into broad, concave, or saucer-shaped depressions which are the field drainageways. The slopes range from 5 to 15 percent.

Breaking of the native sod for cultivation included the destruction of the majority of the grassed field drainageways. The subsequent erosion resulted in deepening silt deposits in the ravine, which, when coupled with their steeper upper-end gradients, has produced overfalls which range up to 20 feet in depth and which progress upstream as much as 15 feet per year. Field drainageways entering the ravine below these overfalls have also developed overfalls.

Cultivation without regard to erosion has eventually led to the formation of hillside gullies. They have often been formed from furrows, wagon or implement wheel tracks, or cattle paths. These hillside gullies develop steep gradients and steep unvegetated sides. Often they are not connected with ravines or branches below by active gully erosion. In the advanced stage they have eaten back to within 20 to 30 feet of the crest of the hill, and represent the last stage of severe sheet and gully erosion. These gullies generally drain less than 4 acres.

The aerial view of the central portion of the Big Creek watershed just north of Bethany, Mo., presented in figure 3, illustrates the topography of the problem area, of which this watershed is typical.

Precipitation.—The problem area has an average annual precipitation of 30 to 40 inches, average spring precipitation of 8 to 14 inches, summer precipitation of 10 to 14 inches, fall precipitation of 8 to 10 inches, and winter precipitation of 2 to 6 inches (*34*). Precipitation at Bethany has averaged 34.18 inches per year during the past 51 years. A rainfall of 34.18 inches or greater occurred in 47 percent of the years. Table 1 has been prepared from records of the weather bureau at Bethany, and shows the average rainfall for each month of the year, and for each year, in addition to frequency distribution of different amounts for each month of the year, and for the year.

A study of table 1 will reveal definite rainfall characteristics for each month of the year. December, January, and February have on the average about equal rainfall. An appreciable increase in the monthly rainfall begins in March and continues through April, May,

FIGURE 3.—An aerial view of the central part of the Big Creek watershed north of Bethany, Mo.

and June. June has the greatest rainfall. July rainfall is appreciably less than June, with August and September rainfall about equal, but greater than July. Rainfall drops off appreciably in each of the remaining months of the year.

615654—45——2

Table 1.—*Frequency of occurrence of different amounts of annual and monthly precipitation for the 51-year period 1890 to 1940, Bethany, Mo.*

DISTRIBUTION OF ANNUAL PRECIPITATION

51-year period	Cases in which precipitation amounted to—														
	20.00 to 22.49 inches	22.50 to 24.99 inches	25.00 to 27.49 inches	27.50 to 29.99 inches	30.00 to 32.49 inches	32.50 to 34.99 inches	35.00 to 37.49 inches	37.50 to 39.99 inches	40.00 to 42.49 inches	42.50 to 44.99 inches	45.00 to 47.49 inches	47.50 to 49.99 inches	50.00 to 52.49 inches	52.50 to 54.99 inches	Mean precipitation
	Number 2	*Number* 3	*Number* 8	*Number* 3	*Number* 7	*Number* 6	*Number* 8	*Number* 2	*Number* 6	*Number* 2	*Number* 0	*Number* 1	*Number* 1	*Number* 2	*Inches* 34.18

DISTRIBUTION OF MONTHLY PRECIPITATION

Month	Cases in which precipitation amounted to—														
	0.00 to 0.99 inches	1.00 to 1.99 inches	2.00 to 2.99 inches	3.00 to 3.99 inches	4.00 to 4.99 inches	5.00 to 5.99 inches	6.00 to 6.99 inches	7.00 to 7.99 inches	8.00 to 8.99 inches	9.00 to 9.99 inches	10.00 to 10.99 inches	11.00 to 11.9 inches	12.00 to 12.99 inches	13.00 to 13.99 inches	14.00 to 14.99 inches	Mean precipitation
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Inches*
January	26	14	7	3			1									1.21
February	22	21	5	2		1										1.28
March	7	24	6	9	4	1										2.08
April	3	12	15	10	4	4	3									3.04
May	3	8	12	8	5	3	1	2	4	3	2					4.24
June		9	7	7	4	8	6	3	3	3			1			4.75
July	7	8	8	6	8	4	6	1			1		1		1	3.87
August	2	6	8	12	11	2	4	2	1	2	1					4.05
September	7	6	6	9	4	10	4	2	1		1				1	4.03
October	10	15	13	5	3	2	2	1								2.41
November	16	16	9	5	1	1	2	1								1.93
December	27	13	7	3	1											1.29
Total																34.18

Rainfall intensity is of utmost importance in its effect on runoff and soil loss. The maximum amounts of rainfall for periods of 5-, 10-, 15-, and 30-minute periods and 1 and 2 hours, that may be expected to occur once in 2, 5, 10, 25, 50, and 100 years, and the maximum precipitations for 4, 8, 16, and 24 hours expected to occur once in 5, 10, 25, 50, and 100 years for Bethany, Mo., were calculated from Yarnell's isohyetal map (*34*).

The amount of rainfall to be expected for various intensity and frequency periods is not constant throughout the area, although the variation is not great. The variation in amount of rainfall in the problem area for any intensity and frequency period is not more than 6 percent from that shown for Bethany. The amounts of rainfall for the Kansas portion of the area are in general greater than those for the Missouri-Iowa portion. The greater amounts for the latter portion are in general in the southern, or Misssouri, part. A tabulation of the approximate number of excessive rain storms [6] that occurred in the problem area during a 30-year period, by months, shows a gradual increase from January until June.

Month:	*Number of storms*	Month:	*Number of storms*
January	0	July	40
February	0-1	August	40
March	3-10	September	40
April	6-10	October	9-10
May	20-30	November	2-3
June	40-60	December	0-1

Appendix table 76 gives the total amounts and duration of precipitation at Bethany, Mo., by calendar months for the 10-year period 1932-41.

During the 35 years of record the annual average snowfall for Bethany was 23 inches. Snow has fallen in all but the 3 summer months and September. The highest average snowfall, of 6.2 inches, occurred in February, followed closely by the January average of 5.5 inches, and by December with 4.3 inches and March 3.6 inches.

Temperature.—The known effects of temperature on erosion are less apparent than that of rainfall, and can be considered only in connection with variables that affect general agricultural practices, vegetative cover, and soil moisture. Average monthly temperatures and the frequency of occurrence of different monthly averages since 1893 are presented in table 2. These data are from United States Weather Bureau publications. January is the coldest month of the year and July the hottest, although considerable variation may be experienced in these months. For certain individual years January has been as warm or warmer than March or November, and September has been as hot or hotter than July or August.

A study of Weather Bureau records from 1890 to 1941 shows that the first killing frosts have occurred between September 12 and November 2 and the last killing frosts have occurred between March 24 and May 27. The length of the growing season has ranged from 115 to 213 days; the average length being about 166 days. Table 3 shows the frequency of occurrence of dates of the first and last killing frosts, and the different length of growing seasons for the period.

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[6] An excessive rain is defined by the Weather Bureau as a storm in which the amount of rainfall in inches for any given time period, t, in minutes exceeds $0.01t+0.20$.

Table 2.—*Frequency of occurrence of different mean monthly temperatures for the 51-year period 1890–1940,[1] Bethany, Mo.*

	Frequency distribution of monthly mean temperature (°F.)																	Mean monthly temperature (°F.)
	5.0–9.9	10.0–14.9	15.0–19.9	20.0–24.9	25.0–29.9	30.0–34.9	35.0–39.9	40.0–44.9	45.0–49.9	50.0–54.9	55.0–59.9	60.0–64.9	65.0–69.9	70.0–74.9	75.0–79.9	80.0–84.9	85.0–89.9	
Month:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	
January	1	3	3	7	10	9	1											24.5
February		1	2	9	13	5	5											28.3
March					2	3	10	14	4	1								40.2
April								1	9	21	3	1						51.4
May										6	5	16	8	1				62.6
June												1	9	17	8			72.1
July													1	8	17	8	2	77.8
August													2	15	13	4	1	75.7
September											1	6	21	5				66.8
October									1	17	11	3	1					55.5
November						3	12	14	3									40.6
December			2	5	12	12	3											28.7

[1] Where records are incomplete the mean is based upon available data.

The present-day effects of wind are largely secondary. Dust storms were unknown to early settlers. During exceedingly dry periods traces of soil movement by wind have been noticeable in cultivated fields, but the effects were of little importance. Hot, dry winds during the early summer months often reduce the moisture of the soil and leave it receptive to later rainfall. High winds, common during March, are less effective in this respect because of the lower prevailing temperatures.

TABLE 3.—*Frequency of occurrence of dates of first and last killing frosts, by week periods and length of growing season*

Last killing frost in spring		First killing frost in fall		Length of growing season	
Period	Cases	Period	Cases	Range	Cases
	Number		*Number*	*Days*	*Number*
Mar. 24–31	2	Sept. 7–13	1	115–124	1
Apr. 1–7	2	Sept. 14–20	3	125–134	0
Apr. 8–14	10	Sept. 21–26	6	135–144	4
Apr. 15–21	7	Sept. 27–Oct. 3	5	145–154	6
Apr. 22–28	13	Oct. 4–10	11	155–164	13
Apr. 29–May 5	7	Oct. 11–17	9	165–174	6
May 6–13	5	Oct. 18–24	6	175–184	5
May 14–20	1	Oct. 25–31	6	185–194	8
May 21–28	2	Nov. 1–7	1	195–204	1

EROSION AND RUNOFF HISTORY

Settlement of north-central Missouri, included in the Shelby loam and associated soils area, began about 1836. Settlement in general followed construction of the railroads, but was slow until immediately before the Civil War. The area in farms in 1880 was about 84 percent of the maximum which was reached in 1900. Assuming that the average date of settlement of the area was some time between 1860 and 1880, much of the land would have been under cultivation for about 70 years at the time of the reconnaissance erosion survey in 1934. Calculations based on this survey showed 5 inches of surface soil gone from an original 10 inches, in five Shelby-Grundy-soils counties of Missouri, and a little over 4 inches of surface soil lost from an original 8 inches in seven Shelby-Lindley-soils counties in Missouri. Thus, in 70 years of farming, approximately one-half of the surface soil had been lost by erosion, or on the average 0.7 percent of the surface soil was lost each year.

Reconnaissance erosion surveys were made in 1934 by the different States in cooperation with the Soil Erosion Service. Detailed results of the surveys for that portion of the area lying in Missouri and Iowa may be found in reports of the Missouri and Iowa agricultural experiment stations (*1*) (*29*). Figure 5 (p. 25) shows the extent of different classes of erosion as determined by these surveys. Results of the surveys for a group of counties in the Missouri-Iowa section, typical of the Shelby-Grundy soils, and another typical of the Shelby-Lindley soils, are shown in table 4.

Loss of topsoil and gullying have been more severe on the Shelby-Lindley soils than on the Shelby-Grundy. Table 4 also shows the area percentages for the different erosion classes for the remainder of Missouri. Reducing these figures to the average percentage of the top soil remaining shows that the Shelby-Grundy counties have lost 50 percent of the topsoil, the Shelby-Lindley group 53 percent, and the other sections of the State 35 percent. Serious and severe gullying is also much greater on the Shelby and associated soils than on the other soils of the State. For the Shelby-Grundy counties about 51 percent of the area is affected by serious and severe gullying, while on the Shelby-Lindley group approximately 71 percent is affected, but on the other soils of the State only 18 percent is severely gullied. Gully erosion does not precede but closely follows extended sheet erosion.

TABLE 4.—*Extent and degree of erosion in 2 groups of counties typical of the soils of the Missouri portion of the problem area of Shelby loam and related soils,*[1] *expressed as percentages of farm acreages*

County	Approximate total farm acreage	Erosion class				
		None to slight [2]	Moderate [3]	Serious sheet erosion		Severe erosion [6]
				Moderate gullying [4]	Serious gullying [5]	
	Acres	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
SHELBY-GRUNDY SOIL						
Worth	169,000	20.6			43.8	26.6
Gentry	310,000	32.3		29.0	38.7	
De Kalb	265,000	20.8	17.0	22.6	39.6	
Harrison	460,000	29.8	13.0		40.9	16.3
Daviess	365,000	19.7	15.1	13.7	51.5	
Total	1,500,000	26.4	10.2	12.7	43.0	7.7
SHELBY-LINDLEY SOIL						
Mercer	291,000	8.6	2.1	10.3	44.6	34.4
Linn	398,000	18.8	19.8		41.0	20.4
Putnam	330,000	12.1			37.9	50.0
Sullivan	415,000	18.1			32.5	49.4
Schuyler	197,000	5.1	5.1	12.7	36.5	40.6
Adair	375,000	18.9	8.3	11.5	20.0	41.3
Macon	522,000	22.4	19.1		34.5	24.0
Total	2,528,000	16.3	8.9	3.9	34.8	36.1
OTHER SOILS						
Remaining counties of the State	30,450,000	23.6	29.1	28.8	16.4	1.9

[1] The counties of the first group are typical of the Shelby-Grundy soil, which predominates in the western part of Missouri; those of the second group represent the Shelby-Lindley soil in the eastern part of the State.
[2] 80 or more percent of the surface soil remaining.
[3] 60 to 80 percent of the surface soil remaining, with occasional gullying.
[4] 40 to 60 percent of the surface soil remaining, with moderate gullying.
[5] 40 to 60 percent of the surface soil remaining, with serious gullying.
[6] Less than 40 percent of the surface soil remaining, with severe gullying; practically unfit for further cultivation.

The amount, intensity, and distribution of rainfall, all affect erosion, although the effect of intensity is probably greater than that of distribution or amount, as has been shown by Neal (*20*). Erosion due to concentrated rainfall at the times when vegetative cover is absent is the result of man's mismanagement and not the fault of vegetation. When undisturbed, natural vegetation provides maximum protection during all the year.

Yarnell's rainfall intensity-frequency maps (*34*) show that the Bethany area is located fairly close to the areas of maximum intensities as reported by Meyer (*14*), and they have divided the United States into areas of similar rainfall intensities. This problem area is located in group 2. Group 1 has the greatest intensities, although for the shorter time periods and less frequent storms. There is little difference in the rainfall intensities for the two groups.

The rate of soil loss increases at an accelerated rate with increase in degree of slope. This has been shown by Duley and Hays (*8*), Diseker and Yoder (*7*), and Neal (*20*). This increased rate is of major importance for slopes above 4 or 5 percent. The same principle applies to length of slope, although in general the shorter slopes are associated with those of greater steepness. Slopes in the problem area range from 5 to 20 percent, the average being about 8 percent. Length of slope ranges from 200 to 1,000 feet, although runoff seldom travels over 400 feet before it reaches a definite depression or waterway. From a topographic aspect, the area is not the most difficult of the agricultural areas in the Nation, but rather close to that extreme.

Soil structure and infiltration capacity largely measure a soil's ability to resist erosion. The soil of the problem area has a satisfactory structure, but a limited infiltration capacity. As noted in the section on soils, the surface layer is relatively shallow and is underlain by a rather impervious clay subsoil, although it is not impervious to the same degree as the claypan soils. The minimum infiltration rate for the Shelby has been reported by Musgrave (*18*) as about 0.1 inch per hour, whereas that of the Marshall is about 0.7 inch per hour, and that of the claypan soils 0.02 inch per hour. The problem area is largely agricultural. In early times there were a few small lumber enterprises. Coal has been mined in parts of the area, although not on a commercial basis beyond supplying local demands.

Ten counties were selected in which the Shelby-Grundy soils predominated, and 9 in which the Shelby-Lindley soils predominated, for a study of cropping practices on the average farm. Only those counties were selected in which Grundy silt loam, Shelby loam, and Lindley loam represented over 70 percent of all the soils of the county. The percentage distribution of these soils in the counties (*17*) is shown in table 5.

Census reports of 1880, 1910, 1920, 1930, and 1940 were utilized as the source of statistics to show past and present trends in the general farming operations. Data for 1880, 1910, and 1920 are reported in table 6, and for 1930 and 1940 in table 7, as census figures from the different reports are not directly comparable.

TABLE 5.—*Areas of various soils in 2 groups of counties representing typical soils sections of the problem area, expressed as percentages of total areas of the counties* [1]

County and State	Shelby-Grundy-Lindley soil	Lindley soil	County and State	Shelby-Grundy-Lindley soil	Lindley soil
GROUP 1. WESTERN SECTION OF PROBLEM AREA, SHELBY-GRUNDY SOIL					
	Percent	*Percent*		*Percent*	*Percent*
Worth County, Mo.	73.6	4.7	Ringgold County, Iowa	83.7	1.2
Gentry County, Mo.	81.8	([1] [2])	Decatur County, Iowa	([3])	([2])
De Kalb County, Mo.	70.7	([2])	Wayne County, Iowa	92.8	.0
Harrison County, Mo.	70.1	2.7	Clark County, Iowa	85.7	1.9
Daviess County, Mo.	76.3	([2])	Lucas County, Iowa	([3])	([3])
GROUP 2. EASTERN SECTION OF PROBLEM AREA, SHELBY-LINDLEY SOIL					
Mercer County, Mo.	90.5	([2])	Adair County, Mo.	90.6	39.5
Linn County, Mo.	84.1	8.4	Macon County, Mo.	71.0	16.7
Putnam County, Mo.	90.7	24.7	Appanoose County, Iowa	76.6	10.8
Sullivan County, Mo.	91.6	25.0	Davis County, Iowa	([3])	([3])
Schuyler County, Mo.	95.0	16.7			

[1] Data from U. S. Dept. Agr. soil survey reports.
[2] Trace.
[3] Survey incomplete.

TABLE 6.—*Farm trends after counties 85 percent settled, before and after first world war*

Factor	Shelby-Grundy soils (10 counties)			Shelby-Lindley soils (9 counties)		
	1880 (20,182 farms)	1910 (21,556 farms)	1920 (20,320 farms)	1880 (20,588 farms)	1910 (22,530 farms)	1920 (21,191 farms)
Average size at farm ....acres..	152.2	139.5	142.3	125.7	132.6	139.9
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Land in crops [1]	70.6	66.2	74.8	60.0	54.8	62.0
Corn and sorghums	34.2	34.3	35.1	26.0	20.1	27.6
Small grains	13.0	9.9	25.3	9.1	6.1	15.9
Wheat	5.0	1.9	13.5	2.4	1.1	5.7
Meadow	23.4	21.3	13.8	24.9	22.0	10.1
Grasses	--------	6.6	7.2	--------	6.1	10.0
Legumes	--------	.2	.0	--------	.2	.3
Timothy and clover	--------	14.6	5.7	--------	15.7	8.8
Miscellaneous crops	--------	.7	.6	--------	.6	.3
Permanent pasture [2]	21.9	51.3	45.8	21.0	55.5	54.1
Timber	22.0	13.7	14.8	34.8	18.2	17.9
Unimproved	10.7	8.3	6.9	6.9	4.1	5.0
Livestock per farm:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Cattle	13.5	15.3	14.4	11.4	13.6	14.5
Horses and mules	4.3	7.0	6.4	3.8	5.5	5.6
Sheep	5.9	9.5	10.1	7.6	14.0	13.6
Hogs	25.6	21.9	22.6	20.5	12.5	15.4

[1] Not comparable with 1930–40.

[2] 1880 not comparable with 1910–20 figures.

TABLE 7.—*Farm trends for the period 1930–40*

Factor	Shelby-Grundy soils 10 counties		Shelby-Lindley soils 9 counties	
	1930 (19,725 farms)	1940 (18,709 farms)	1930 (19,710 farms)	1940 (19,306 farms)
Average size per farm ....acres..	150.6	159.4	146.8	152.6
	Percent	*Percent*	*Percent*	*Percent*
Cropland [1]	81.5	71.2	67.6	52.0
Corn	31.9	24.9	23.1	16.9
Sorghums	.2	1.5	.1	1.1
Soybeans and cowpeas	.5	2.4	1.2	1.7
Small grains	16.6	19.4	10.1	8.9
Grass or legume meadow	19.9	10.7	26.1	15.1
Miscellaneous crops	2.0	5.7	1.6	3.3
Crop failures	2.6	2.9	1.8	1.4
Idle land	3.0	4.0	3.6	3.6
Plowable pasture	40.3	52.0	46.7	71.3
Timberland	14.8	10.2	21.4	17.2
Nonplowable pasture (not timber), lots, etc	13.4	20.1	12.6	17.9
Livestock per farm:	*Number*	*Number*	*Number*	*Number*
Cattle [2]	13.1	14.6	12.3	13.1
Horses or mules [2]	4.5	3.5	3.0	3.1
Sheep [2]	8.5	12.1	12.5	18.0
Hogs [2]	20.3	13.3	8.7	8.2

[1] Not comparable with 1880–1920 figures.

[2] Number per farm, not comparable with 1880–1920 figures as colts and calves under 3 months, pigs under 4 months, and lambs under 6 months not included.

The number of farms in 1880 was about 85 percent of those recorded for 1900. By 1910 the number had declined and the decline has continued, but the acreage per farm has slowly increased since 1880. Between the two groups of counties, more intensive cultivation was practiced on the Shelby-Grundy group. This is shown by the greater crop area and the smaller proportion of pasture and timber lands on the Shelby-Grundy group. The main livestock difference is the larger number of hogs on the Shelby-Grundy farms and the large number of sheep on the Shelby-Lindley farms.

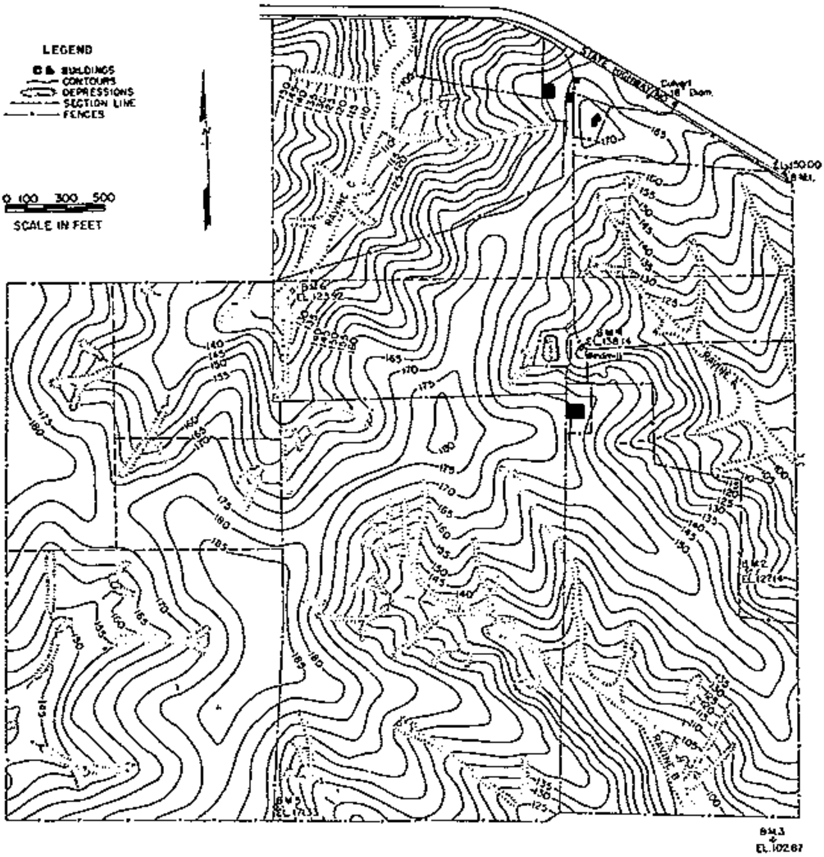

FIGURE 4.— Contour map of the Soil and Water Conservation Experiment Station near Bethany, Mo., before installation of experiments. (Elevation data assumed on this and other maps.)

Corn acreage, contrary to what has often been assumed, did not increase appreciably during the first world war, but remained relatively constant until after 1930 and before 1940 when reductions of 29 and 27 percent in acreage were made for the two groups. During the first world war the acreage of small grain, particularly wheat, increased about 150 percent. Accompanying this increase in small grain was an increase in cultivated acreage and a reduction in meadow. The increase in crop acreage was accompanied by an increase in farm size and decrease in pasture lands. Acreages of sorghum for grain and soybeans increased several fold during the period. Lespedeza increased from almost nothing in 1930 to about 5 acres per farm in 1940 on the Missouri farms of the groups.

Marked improvement in land use was made during 1930–40, although much remains to be done. Statistics indicate better land use on the Shelby-Lindley group, although this is probably offset by the more critical aspects of soil and topography. The kinds of crops grown are about the same for the two groups, although the percentage of crop acreage is about 33 percent more on the Shelby-Grundy group than on the Shelby-Lindley group. The ratio of small-grain and meadow land to cornland indicates that corn is grown continuously year after year on an appreciable acreage.

THE STATION FARM

Originally the station consisted of 220 acres, the central part of an old livestock farm. In 1936 an additional 80 acres adjacent to the southwest part of the farm were added.

The soil and topography of the farm in 1930 were characteristic of the better agricultural land of the problem area. Both soil and topographic surveys were made prior to detailed planning of the investigational work. The original contour map is given in figure 4 and the soil type boundaries are shown in figure 5. The 80-acre addition to the station made in 1936 is shown on both maps.

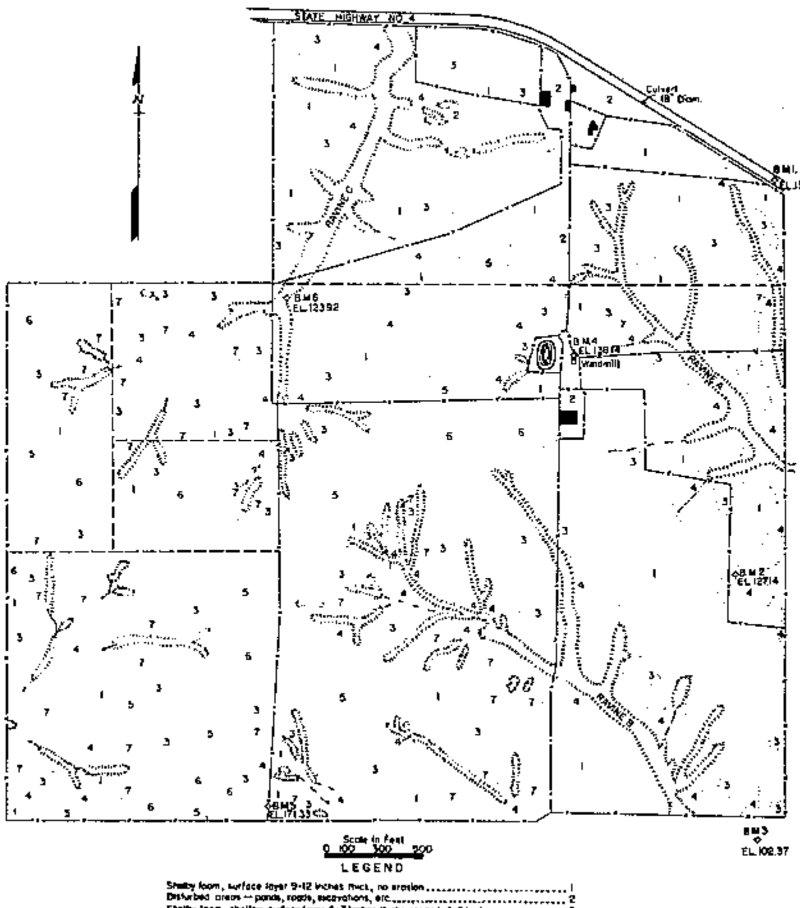

FIGURE 5.—Soil map of the Soil and Water Conservation Experiment Station near Bethany, Mo.

The soil at the station is largely Shelby with the main ridges capped with Grundy, and material washed from the uplands occupying the drainageways. On the 80-acre addition to the station the areas of Grundy equal those of Shelby. The shallower soil is in the northeast and southwest parts of the original station, which had been in cultivation for 35 to 40 years prior to 1930, and on the Shelby soil sections of the 80-acre addition. Only in these fields was there exposed subsoil.

Slopes up to 16 percent are on either side of ravine C, and also on the southwest side of ravine B. On the other areas of Shelby soil the slopes vary from 5 to 10 percent, with the average about 8 percent. Three ravines had cut into the farm, with a fourth depression at the line fence crossing the southwest drainageway.

The agriculture practiced on the farm prior to 1930 was typical of the better agricultural land of the problem area. The section northwest of the feed barn, which is in the center of the farm, was in virgin bluegrass pasture when the station was acquired. The small field east of the farmhouse and the irregular area east of the feed barn were also in virgin pasture. The portions south and east of the feed barn in the center of the farm had been in cultivation only 4 to 5 years before 1930. The fields south and west of the feed barn and the fields north and east of the pond had been cropped continuously for 35 to 40 years and the most severe gully formation had occurred in these fields. The 80-acre addition to the station had been in cultivation for an extended period before acquisition by the station.

PURPOSE AND PLAN OF EXPERIMENTS

The experimental planning for the station resulted in the establishment of the different studies shown on the map of the station (fig. 6). The studies shown represent the maximum development of the station, which was reached in 1938.

Methods of Investigations

The investigations have been conducted on plots, individual terraces, terraced watersheds, natural watersheds, and gullies under various experimental conditions, subject to natural conditions of rainfall, temperature, and wind. The effects of these conditions were determined by measurements of soil and water losses, elevation reading, observation, crop yields, and pictures. The soil and water loss measurements were made by various devices, depending on the size and type of area under study.

Plots.—Two types of plots were employed at the station. The plots of the first type are surrounded by steel border plates and range in size from 0.01 to 0.03 acre; the plots of series 1, 2, and 3 are of this type. The others are surrounded by dykes or ridges of earth, and vary from 0.05 to 0.34 acre; the plots of series 5, 9, and 15 are of this type. The plots of each series are immediately adjacent to each other without plot borders, and are installed on areas that have slopes and depths of soil as nearly uniform as possible from the top to the bottom of the plots. A description of each plot and cultural treatment is given in Appendix, table 50.

The plots of series 1, known as the control plots, have a catchment basin of concrete large enough to hold the greatest amount of surface

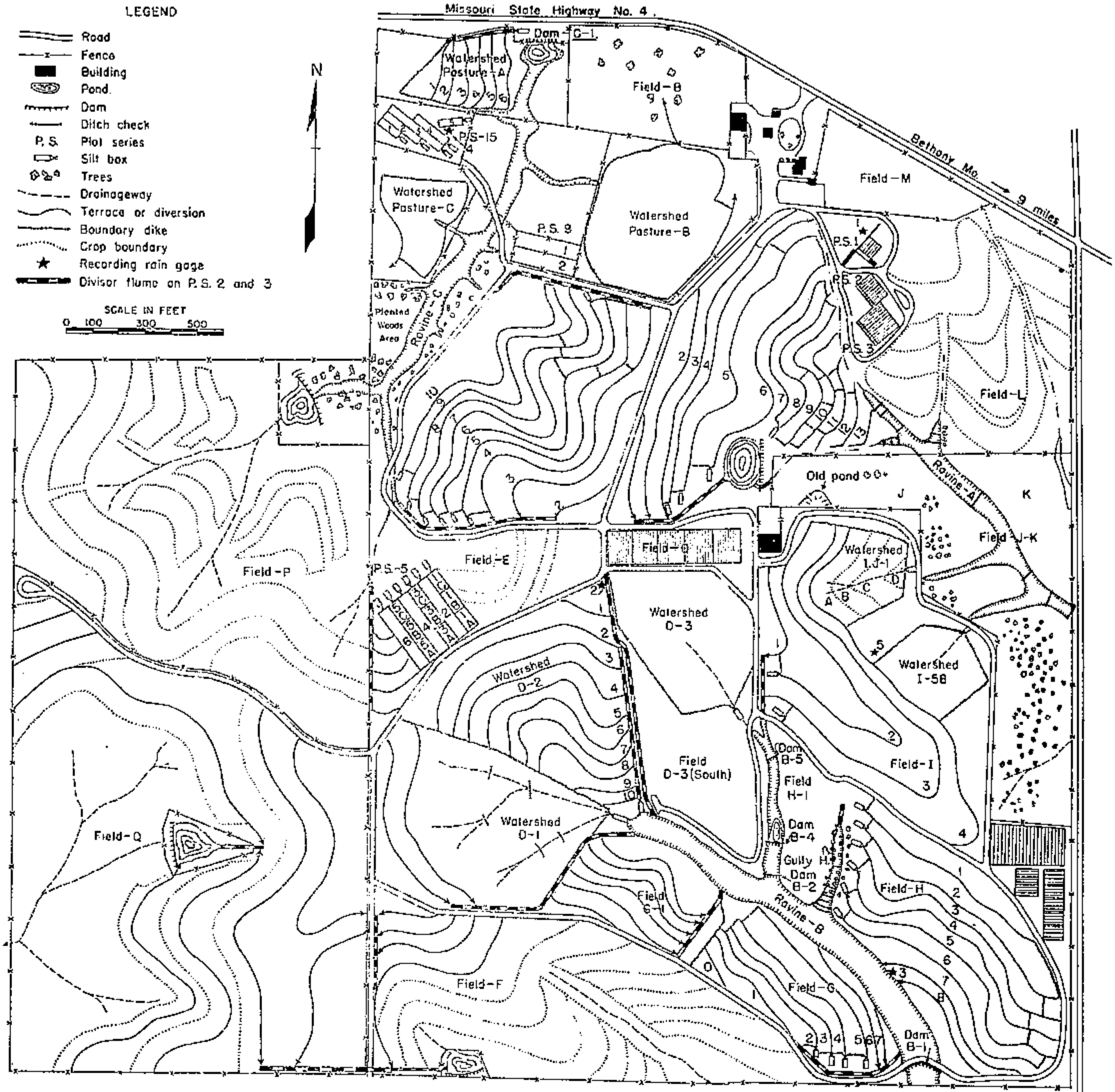

FIGURE 6.—Map of the Soil and Water Conservation Experiment Station near Bethany, Mo., 1938, showing fields and experimental areas.

runoff expected in any 24-hour period at the lower end of each plot. The plots of the other series (2, 3, 5, 9, and 15) are equipped with sludge tanks, multislot divisor units, and silt-catchment tanks at the lower end of each plot. The tank equipment was designed to hold a maximum of about 7 inches of surface runoff.

Terraces.—The terraces were of various designs, for studies of spacing, grade, length, cross section, crop rotations, construction, and farming methods. A description of each terrace is given in Appendix, table 51.

Measurements of amount and rate of runoff and soil loss from individual terraces were made by means of Parshall flumes with float water-stage recorders and sludge boxes with Ramser silt samplers installed at the outlet end of each terrace.

The silt samplers at the lower edge of each sludge box were tested for accuracy during 1931, 1932, and 1933, by securing simultaneous samples from the weir of the silt box and the outlet of the sampler during runoff periods. From these tests correction factors were determined and used in the calculation of soil loss as measured by this type of equipment.

Field watersheds.—Measuring equipment for the field watersheds was installed at the lower end of the fields, and dikes were established along natural divides to define the watersheds without permitting artificial concentration of runoff water. Where soil series vary on a slope, the runoff from the upper portion was diverted from the experimental area below by means of terraces on diversion dikes. The measuring equipment for a terraced watershed was installed at the end of the outlet to measure the losses from the entire field. Measurements are by Parshall flumes and Ramser silt samplers, the same as for the individual terraces, except larger in capacity. Description of each watershed is given in the Appendix, table 52.

Other field areas have been formed under different conservation systems to observe the practical operation of conservation methods developed from the other studies.

Sampling methods and records.—In cleaning measuring equipment on the plots, the silted water above the more dense sludge was volume measured, sampled, and drained. Samples were secured from the silted water in each tank and any sludge in a tank was weighed and samples secured. A similar procedure was followed for the terraces and watersheds, except that the sludge was measured by volume, when of such an amount that weighing was impractical.

In the laboratory, the samples were weighed and dried, and the percent of dry matter calculated.

Records covered dates of soil treatments, cultural operations, crop yields, and observations for all experimental fields and areas. Cost and maintenance records and observations of performance were also secured for gully control structures. Photographs were taken when physical evidence was present.

The Investigations

Control plot study.—All of the 10 original soil erosion stations installed a set of plots for the purpose of studying the effects of various crops and cultural practices on erosion. On the Bethany station these plots are designated as plot series 1 to 10, inclusive.

Effects of erosion on crop production.—This study compared the productivity of normal and desurfaced soils under various crops and cropping treatments. Data are from plot series 2 and 3. Data are also given to show the variations of corn yield with depth of surface soil for a terraced field on the station and from several farm fields north of Bethany, Mo.

Meteorological studies.—Meteorological data were secured for the purpose of studying weather effects on soil and water loss, and as supplemental data for soil and water loss measurements and observational data from the various experimental areas. Rate, amount, and distribution of rain and snow were secured, and also daily maximum and minimum temperatures. During the last few years, wind velocity measurements were secured.

Soil studies.—Soil-chemistry studies have included the effects of soil treatments and organic matter on soil and water losses and crop yields. The effects of erosion on fertility changes as measured by laboratory analyses of soil samples are reported. Data are from plots of series 1, 2, and 3.

Physical measurements have been made on typical profile samples. The effects of soil moisture, loss of topsoil, and tillage practices, on soil and water loss are also reported. Data are from series 1, 2, and 9. Data secured from terraced fields on the station and from several farms on the Big Creek watershed, north of Bethany, show the relationship between corn yields and depths of surface soil.

Vegetation studies.—Vegetation studies have included the canopy interception crops, the effects of vegetation on runoff velocity, methods of establishing meadows, the soil and water loss from various crops and cropping systems, the effect of intensity of grazing on soil and water loss and production, and a limited study on the effects of vegetation on soil properties. Data are from plot series 1, 2, 3, 9, H terraces, and watersheds D-3 and pasture B.

Topography.—Evaluation of the influence of length of slope on erosion was made by comparing runoff and soil loss from slopes of different lengths under various cropping conditions. Data are from plot series 1 and 15. Rainfall simulator studies were made to determine the effect of length and degree of slope on runoff and erosion. Laboratory tests with fine sand were made to measure rate and density of runoff from slopes of different degrees. Data from topographic mapping and surface-soil-depth readings from several fields of Shelby and Marshall soils are shown and discussed.

Supporting conservation practices.—A large part of the field work at the station has been devoted to a study of terracing. The different phases studied were construction, size and shape, soil movement on terraced slopes, maintenance and farming, vertical spacing on moderate and steep slopes, channel grades, length, overtopping, and outlets.

Rotation strip cropping has been studied by observation on field areas and with measurements of soil and water loss on 6 plots and one watershed. The plots, known as series 5, are operated so that each crop of the rotation is on a check plot and is also in each of the three possible positions on the strip-crop plots, each year. The watershed on which rotational strip cropping has been practiced is known as IJ-1.

Contour tillage on terraces, watersheds, and plots, has been studied as to its effect on soil and water losses. Direct comparisons were possible for the watershed data, although adjustments for physical variations were necessary on the terrace and plot data before comparisons could be made. Data are from plot series 1, 5, and 15, terraced fields N and G in 1931, and watershed D–1 and D–3.

Contour-furrow data from watershed pasture C in comparison to natural pasture B and terraced pasture A are reported.

Field trial of soil conservation practices.—Rotation strip cropping with diversions and terraces has been studied on field areas and also buffer strip cropping, alone, with wide-spaced terraces, and on the slope below a series of terraces. Three of these fields have been operated together with livestock to study the practical problems involved. Fields utilized are L, F, P, and Q.

Reclamation of severely eroded land.—Several plots of series 2 were artificially eroded to the subsoil to study the effect of crops, cropping systems, soil treatments and cultivation on soil and water loss for Shelby subsoil. Field trial of the study was applied to seriously eroded field G–1, on which the effect of terracing, soil treatments, and cropping was observed.

Water-disposal studies.—Vegetation studies in field drainageways, terrace outlets, and gullies on the station have included observations of methods of establishing different grasses, legumes, and trees, also of their adaptability to protective use. Sod structures, including strip checks, hump dams, sod-bag barriers, and sod flumes were used.

Structures for water disposal were studied from the standpoint of adaptability, first cost, maintenance, and durability. Installations included: Wire and brush checks; wood, sheet metal, asphalt, and rock-masonry dams; concrete spillways; detention reservoirs; and drop-inlet dams; farm ponds; tile drainage of silt deposits in ravines; tile and sod channel linings; and diversion dikes.

Hydraulic characteristics of bluegrass terrace outlets have been studied on 5½-percent (D–2 outlet), and 12-percent (G outlet) slopes by measuring runoff from natural storms. A similar study was made of terrace channel 4–I.

Watershed studies.—Rate and amount of runoff and soil loss have been secured from 8 watersheds. Three watersheds are in bluegrass pasture, one natural (Pa–B), one terraced (Pa-A), and one contour furrowed (Pa-C). Of the 5 cultivated watersheds, D–2 is terraced, D–1 contour tilled, D–3 uncontrolled, I–58 in annual rotation and contoured, and IJ–1 in rotation and strip cropped.

Rainfall simulator studies.—In 1936 and 1937 a rainfall simulator apparatus was designed and constructed at the station for a plot 6 feet wide and 72.6 feet long. Tests were made on bluegrass sod for different moisture contents of the soil, and at different rates of application. Later the sod was replaced by an equivalent depth of surface soil from a cultivated field and similar tests performed.

RESULTS AND DISCUSSION OF THE INVESTIGATIONS

Effect of Erosion on Crop Production

By observation it has been evident for many years that the yield as well as the quality of crops decreased on Shelby soil as more and more of the surface soil was lost.

The basic reason for the decrease in productivity with loss of surface oil has been the difference in the fertility of the soil lost and the sub-

FIGURE 7.—Plot series 3, growth of oats on surface soil untreated (left), subsoil untreated (middle), and subsoil treated (right).

soil that is consequently brought into the plow layer from below. After the top 4 to 6 inches is removed on this soil, plowing mixes subsoil with the remaining surface soil. The Shelby subsoil is extremely low in organic matter and nitrogen as reported by Middleton, Slater, and Byers *(15)* and recorded in table 8.

Comparisons of crop yields on surface and subsoil are available on the station. Table 9 gives three comparisons of yields from corn, oats, and meadow rotations with and without treatment. In the first comparison of an untreated rotation of corn, oats, and 2-year meadow, the oat yield and second-year meadow yield were four times as large on surface soil as on subsoil of the desurfaced plot. The difference in the growth of oats on these plots is shown in figure 7.

TABLE 8.—*Organic matter and nitrogen content in the Shelby soil profile*

Depth	Nitrogen	Organic matter
Inches	*Percent*	*Percent*
0–7	0.16	3.23
7–12	.11	2.17
12–20	.09	1.59
20–24	.07	.82
24–48	.03	.27
48–60	.02	.14
60–84	.02	.07

In the second comparison, with treatment, the spread between yields was not as great as on untreated plots, but it was still appreciably larger on surface soil. Where 8 tons per acre of barnyard manure was applied before corn, in the last comparison, it should be noted that the meadow crop was sacrificed on the subsoil. Even here, the corn yield was over twice as large on surface soil as on the desurfaced plot.

TABLE 9.—*Crop yields from normal and desurfaced shelby loam with and without treatment for the 12-year period 1931–42*

Plot designation	Cropping system	Soil treatment	Years	Crop	Yield per acre: Grain: Normal soil	Yield per acre: Grain: Desurfaced soil	Yield per acre: Forage: Normal soil	Yield per acre: Forage: Desurfaced soil
			Number		*Bushels*	*Bushels*	*Tons*	*Tons*
Plot series 2: Plot 1, normal; plot 2, desurfaced.	4-year rotation of corn, oats, clover with timothy, and clover with timothy.	None	3	Corn[1]	14.3	6.8	1.30	1.17
			3	Oats	23.2	5.9	.97	.30
			3	First-year meadow			.75	.50
			3	Second-year meadow.			1.28	.33
Plot series 3: Plot 3, normal. Plot series 2: Plot 4, desurfaced.	3-year rotation of corn, oats, and clover with timothy.	Lime; 180 pounds 20-percent phosphate per acre, drilled with oats. Lime; 188 pounds 4-12-4 fertilizer per acre, drilled with oats.	3	Corn	26.0	12.5	1.42	1.56
			4	Oats	33.5	19.9	.94	.60
			4	Meadow			1.33	.72
Plot series 3: Plot 2, normal / Plot series 2: Plot 6 desurfaced.	3-year rotation of corn, oats, and clover with timothy. / 3-year rotation of corn, oats with sweetclover plowed under.	Lime; 180 pounds 20-percent phosphate per acre on oats; 8 tons manure per acre on corn; cornstalks and second clover crop under. / Lime; 188 pounds 20-percent phosphate per acre on oats; 8 tons manure and sweetclover plowed under before corn; cornstalks removed.	3	Corn	37.3	17.3	2.09	2.15
			4	Oats	46.9	25.7	1.14	.89
			4	Meadow			1.46	(2)

[1] No corn yields in 2 of the 3 years, 1934 and 1938, because of droughts and insect damage.
[2] Plowed under.

For the past 3 years the station has pursued a study of crop yield and soil fertility in collaboration with the Operations Division on the Big Creek Watershed (*27*). Fields on which the past history has been obtained have been studied to determine the relationship between surface-soil depth, organic-matter content, and corn yields. Figure 8 shows a summary of the results for 1939. A close relationship between organic-matter content, depth of surface soil, and crop yield is apparent.

In the fall of 1940, corn yields were secured from a strip 100 feet wide over three experimental terraces on the station, as reported by Zingg and Whitt (*39*). One of the objectives was to compare the yield of corn on terraced land with the variation in surface-soil depth. Figure 8 shows the relationship between soil depth and corn yield. The yield of corn increased with depth of surface soil, regardless of its

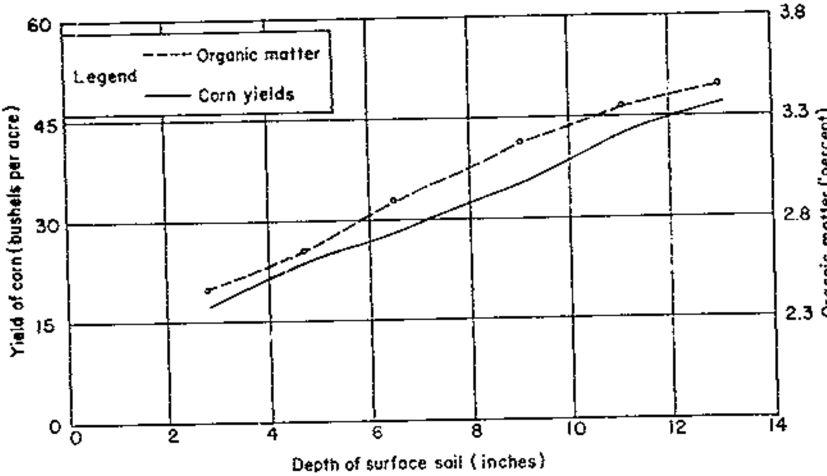

FIGURE 8.—Soil depth, organic-matter content, and corn yield from 4 fields of Shelby loam soil in the Soil Conservation Service demonstration project north of Bethany, Mo.

location on the terrace, to surface-soil depths up to 1 foot. Soil depths over 1 foot were found in the terrace ridge only, and a decline in yield was noted for these greater depths. This decline may very likely be attributed to a moisture deficiency in the terrace ridge.

It seems conclusive that crop yields are affected directly by surface-soil depths on the Shelby soil. Whether the soil is lost from the field by erosion or manipulated in the construction of terraces, the effect is the same. It seems clear, therefore, that to maintain yields the surface soil with its supply of organic matter must be conserved.

CONTROL PLOT STUDIES

The 10 original soil conservation experiment stations each had a group of plots installed for the purpose of studying the effects of various crops, length of slope, fertilizer treatment and loss of topsoil on soil and water loss. They were patterned somewhat after the plots installed in 1917 by M. F. Miller and F. L. Duley of the Missouri Agricultural Experiment Station.

Ten plots known as control plots and identified as plot series 1 were installed on the Bethany Station in 1930 (fig. 9). Official records began January 1, 1931. The cropping system and specifications of the plots are given in Appendix, table 50. The area on which they were installed had been cropped approximately 35 years prior to the establishment of the study and about 7 inches of surface soil remained. A detailed study of soil profiles from the plots has been reported by Middleton, Slater, and Byers (*15*, *16*).

Soil treatments with lime and fertilizer reduced both the soil and water loss over no treatment in the 3-year rotation. Border effect

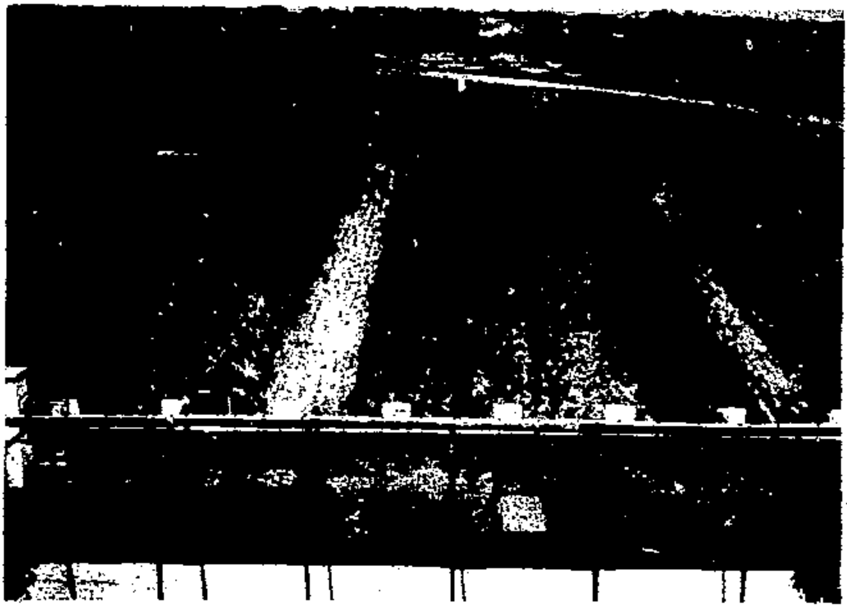

FIGURE 9.—The control plots, numbered from 1 to 10, left to right.

of alfalfa lying adjacent to the treated plot undoubtedly minimized the effect of treatment.

Under bare fallow conditions, the subsoil eroded at a rate somewhat lower than surface soil. This has been explained on the basis of the differences in soil structure. The fact that subsoil erodes at a higher rate than surface soil under crop conditions is in part due to the difference in the density of vegetation the two soils will support.

The loss of surface soil from land in corn on plot 2, planted up and down the hill, which occurred at a rate of 7 inches in less than 20 years makes it easy to understand the seriously eroded condition of many land areas in this soils region at the time of the reconnaissance erosion survey in 1933. This plot is only 72.6 feet long, or approximately equal to the horizontal spacing between terraces on an 8-percent slope. Likewise, the saving attained by the use of a rotation, even while the land is in corn, is illustrated in figure 10 by data for corn over its 5.5-month season on plots 2, 3, 4, and 5. Over twice as much soil was lost from corn following corn during this period as from rotation corn, or corn following meadow.

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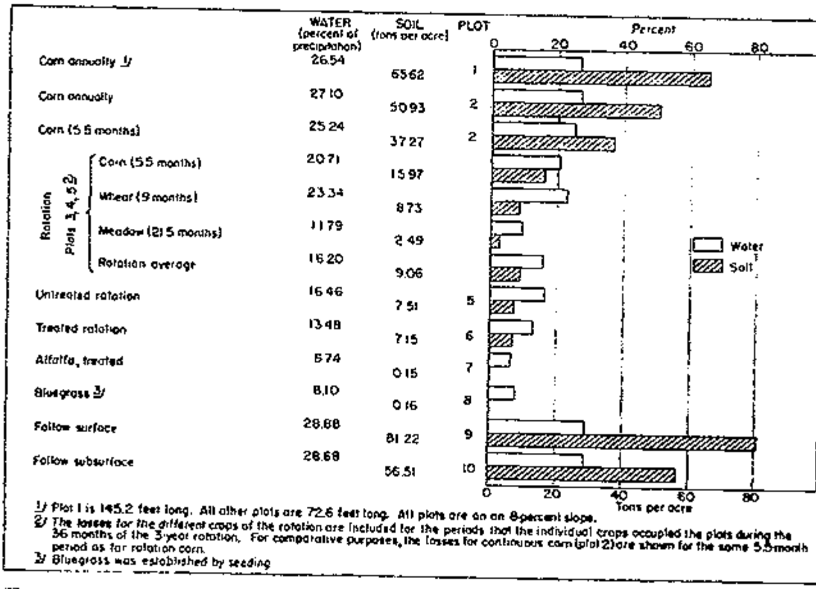

FIGURE 10.—Average annual runoff and soil loss for the 10-year period 1931–40, from the control plots which are of Shelby loam soil.

These plots were under study for the 10-year period 1931–40. Measurements, in addition to runoff and soil losses by individual storms, included crop yields, elevation readings, and collection of soil samples for laboratory analyses. Supplementary information, such as observations of crop and soil condition, dates of seeding, cultivating and harvesting, have been collected and recorded in the Appendix as an aid to interpreting the data.

Appendix tables 53, 54, and 55 give runoff and soil losses by seasons. A summary for the 10-year period showing the average annual runoff and soil losses is shown graphically in figure 10. Comparison of plots 1 and 2 shows that the soil is leaving the long plot at a rate 1¼ times that of the plot which is half as long. The water loss is essentially the same from the two lengths. The reduction of soil and water loss by the use of a rotation or close-growing crops, such as alfalfa and bluegrass, is shown by these data.

Mean height of corn.—Though corn height cannot be taken as a direct measure of corn yield, it does give an indication of the productivity of the soil upon which the crop is grown. Height measurements were made of all corn plants on the control plots (continuous corn and rotation corn) for the 4-year period 1933–36, inclusive. An average for each plot was calculated for the readings secured each week. Height measurements were also secured for corn following corn (plot B, series 2) on subsoil. The corn on subsoil was fertilized annually with 250 pounds per acre of 20-percent superphosphate, while the surface soil plots received no treatment.

The measurements showed that the growth of corn following meadow was superior to the growth of annual corn for each of the 4 years in which height measurements were made. In the abnormal year of 1934, when May, June, and July had only 34 percent of the average rainfall for this period, all corn fired badly. That year, corn on subsoil, with its slow early growth, exceeded corn grown annually on surface soil the latter part of the season. This was attributed to the fact that larger plants suffer more, with their greater water requirement, in periods of drought than smaller plants growing on subsoil. A parallel condition has been observed where large quantities of manure have been applied before corn.

The extremely wet spring of 1935 delayed corn planting until June 11, a month past the normal planting time. Here the rates of growth were in the descending order, rotation corn, corn annually on surface soil, and corn annually on subsoil. The rates of growth were in this order again in 1936 when all plots suffered from high temperatures and drought in June and July.

Crop yields.—The crop yields on the control plots have been somewhat erratic. No border area existed between plots, and soil moisture under some crops was affected by the vegetative growth on adjacent plots. This effect was particularly noticeable on the fertilized rotation plot where alfalfa with its deep root system reduced the available moisture under the crops on the adjacent plot 6. In dry years the corn on these plots suffered more from drought and hot winds than corn grown on field areas, since there were only two rows of corn on each plot. On the field areas the damage was generally more pronounced on the border rows. Insect damage was also more severe on the plots than on the larger areas.

Table 10 gives the yield from the control plots for the 12-year period 1931–42.

TABLE 10.—*Crop yields on control plot, series 1 for the 12-year period 1931–42*

Plot No.	Crop	Yield of corn and what (bushels per acre) and meadow (tons per acre)											
		1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942
1	Corn	20.0	44.1	43.7	0.0	17.8	0.0	41.6	4.5	16.8	22.2	7.9	21.2
2	Corn	20.7	36.7	49.3	0.0	16.7	0.0	35.0	5.0	11.8	26.4	9.6	25.8
3	Corn	30.6			0.0			37.0			26.1		
3	Wheat		30.9			12.6			4.0			32.8	
3	Clover-timothy			1.61			1.72			1.10			1.47
4	Corn			43.3			0.0			21.4			46.7
4	Wheat	31.4			8.7			20.7			10.0		
4	Clover-timothy		1.63			1.38			1.48			.56	
5	Corn		49.7			15.0			4.0			13.3	
5	Wheat			10.6			22.5			1.7			13.1
5	Clover-timothy	2.65			.34			.57			.99		
6	Corn		51.6			12.9			1.0			15.9	
6	Wheat			24.4			31.7			1.6			17.6
6	Clover-timothy	3.14			.52			1.55			.87		
7	Alfalfa	2.21	5.68	5.41	2.50	3.05	1.85	2.01	3.01	4.33	4.30	2.66	2.28
8	Bluegrass	[1]2.89	[1]2.29	(2)	(2)	.85	.47	.95	.59	.42	.67	.96	.28

[1] Timothy.
[2] Not harvested.

Corn in the unfertilized rotation averaged 2.6 bushels more than corn annually on plot 2. This included 5 years when drought damage was severe on all cropped plots.

Fertilizer applied on wheat in the 3-year rotation increased the yield from 11.6 bushels per acre on plot 5, not treated, to 19.1 bushels on plot 6, treated. This increase of 7.5 bushels of wheat more than paid for the fertilizer treatment. Plot 6 also received lime. This and the phosphate accounted for the average increase in clover and timothy meadow yield from 1.14 to 1.52 tons per acre. From these data, along with extensive observations on the Big Creek watershed it seems conclusive that phosphate and lime are essentials for proper management of the Shelby soil.

Alfalfa averaged 3.53 tons of hay per acre annually for the 10-year period 1931–40. The application of 250 pounds of 20-percent superphosphate per acre once in 3 years has resulted in good yields throughout the period. These yields were not equalled on similarly treated field areas during the same period.

Changes in surface configuration of plots.—Each fall, elevation readings were secured to determine from what point on the plot soil had been moved. They were procured by starting at the top of the plot and taking five readings across the plot at 10-foot intervals down the slope. All elevation readings, including those of a sheet-metal-covered headwall at the lower end of each plot, were taken with reference to a permanent bench mark. The elevation readings showed that the concentrating troughs at the end of the plots did not remain stationary during the 10-year period, but raised as much as 0.19 foot due to frost action. Since they were not lowered each spring, a small amount of deposition occurred on the lower ends of the plots.

The 1940 elevation line was plotted and adjusted vertically so that the cut equalled the deposition plus the soil loss at the ends of the plots. This in effect corrected the difference between the lines due to moisture differences at the time the readings were taken. Swelling and shrinking, which accompanies changes in moisture content of the Shelby soil, had been found to cause a difference in elevation of as much as 0.2 foot in the season as discussed by Woodruff (*32*).

The plots were spaded each time from the upper end down. This caused some accumulation of soil on the upper ends of some of the plots that were cultivated. Plots 1, 9, and 10 had soil losses amounting to well over 500 tons per acre in the 10-year period. This has overcome the cumulative effect on the upper ends of these plots.

The greatest change in surface profile occurred on fallow surface soil, plot 9, with a cut of 826 tons per acre. Next in order were: the lower half of plot 1, 145.2 feet total length, in corn annually; subsurface fallow plot 10; the upper half of plot 1 followed by plot 2, which is in corn annually. On plot 2 the cut was not as great as that on the upper end of long plot 1. This illustrates the effect of a fixed point at the end of the plots, indicating clearly that the soil loss figures for all plots are not so high as they would be from a field section with identical specifications and management.

The plotted data for plots 3, 4, and 5 showed a deeper cut on the upper end than on the lower portion. This may have been due to moisture conditions which produced somewhat superior meadow on the lower ends of the plots in some years.

The change in the profiles of plots 7 and 8 in alfalfa and bluegrass, respectively, has been slight. Most of the soil moved has been deposited on the lower end of the plots with a total of only a ton and a half of soil per acre being lost.

It was noted on all the plots that the original slope was not uniform but was slightly convex. Soil movement which has occurred has had the tendency to straighten out the slopes, although on the plots with the greater losses, the fixed headwall at the lower ends of the plots has resulted in a concave shape by the end of the 10-year period of operation.

METEOROLOGICAL RECORDS

The total rainfall, its intensity and its distribution throughout the year, are the principal factors of interest in conservation planning.

During the 10-year period, 1931–40, the annual average precipitation has been 29.5 inches. The amounts by months and years, and their averages are given in table 11. A more detailed summary covering duration, and intensity of rainfall, is given in Appendix, table 77. A previous publication by Zingg [7] contains individual storm data from this location for the period 1933–40.

Annual amounts precipitation at Bethany, Mo. for the 51-year period 1890–1940 are shown graphically in figure 11. The highest annual rainfall recorded was 53.52 inches in 1902, and the lowest was 21.72 inches in 1937.

TABLE 11.—*Ten-year summary of rainfall, 1931–40, by years and months* [1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1931	0.40	0.76	1.13	2.40	3.46	3.02	3.73	7.27	5.74	4.42	6.61	3.16	42.10
1932	1.01	.33	.30	1.71	2.72	3.80	4.94	5.23	2.76	1.73	1.66	1.17	27.36
1933	.54	.00	1.44	.83	5.05	2.12	3.05	10.78	5.32	.73	.40	1.11	31.37
1934	.67	1.02	.13	4.20	1.65	2.25	.80	4.22	6.48	2.60	7.32	.14	31.48
1935	4.06	1.01	1.47	2.72	9.51	5.74	.14	1.47	5.34	1.54	2.58	.49	36.07
1936	2.28	.27	.41	1.94	4.57	1.34	.50	1.24	7.60	2.57	.11	1.46	24.29
1937	2.88	.64	1.39	3.34	2.81	1.11	5.06	1.08	.49	1.30	1.00	.55	21.72
1938	1.30	.39	1.68	2.92	5.31	1.25	2.80	6.40	.74	.31	2.27	.79	26.16
1939	.60	.66	2.70	2.96	.74	9.55	2.67	2.78	.35	1.12	1.09	.72	26.84
1940	1.02	1.19	2.02	2.49	2.77	6.48	1.06	4.13	.44	1.41	2.41	1.44	27.76
Avg	1.18	.63	1.27	2.56	3.86	3.97	2.54	4.46	3.53	1.78	2.04	1.10	29.50

[1] Amounts from rain gage No. 2, located near the center of the experimental site.

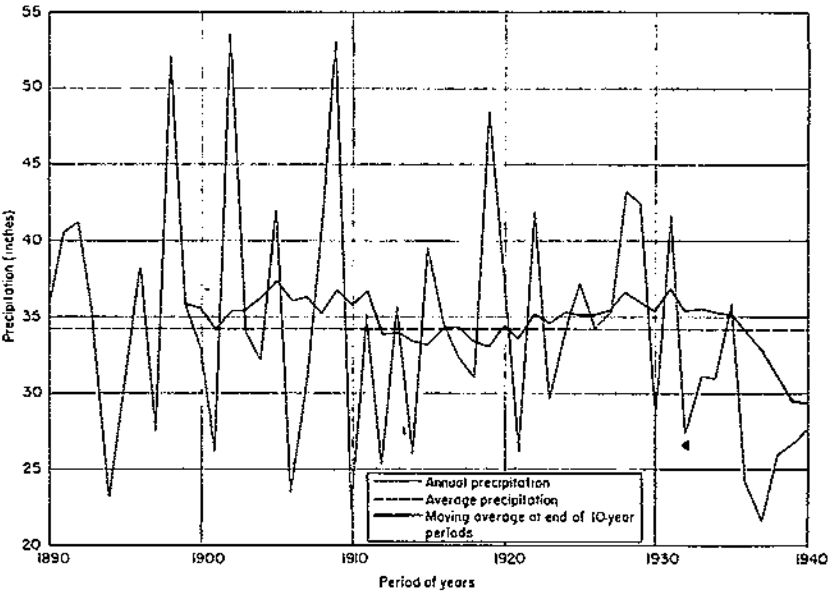

FIGURE 11.—Annual and average precipitation for the 51-year period 1890–1940 and a 10-year moving average of precipitation with the points plotted at 1-year intervals at the end of each 10-year period

[7] ZINGG, A. W. COMPILATION OF RAINFALL AND RUNOFF FROM THE WATERSHEDS OF THE SHELBY LOAM AND RELATED SOILS, CONSERVATION EXPERIMENT STATION, BETHANY, MO. U. S. Dept. Agr. Soil Conserv. Serv. TP-39. 1941.

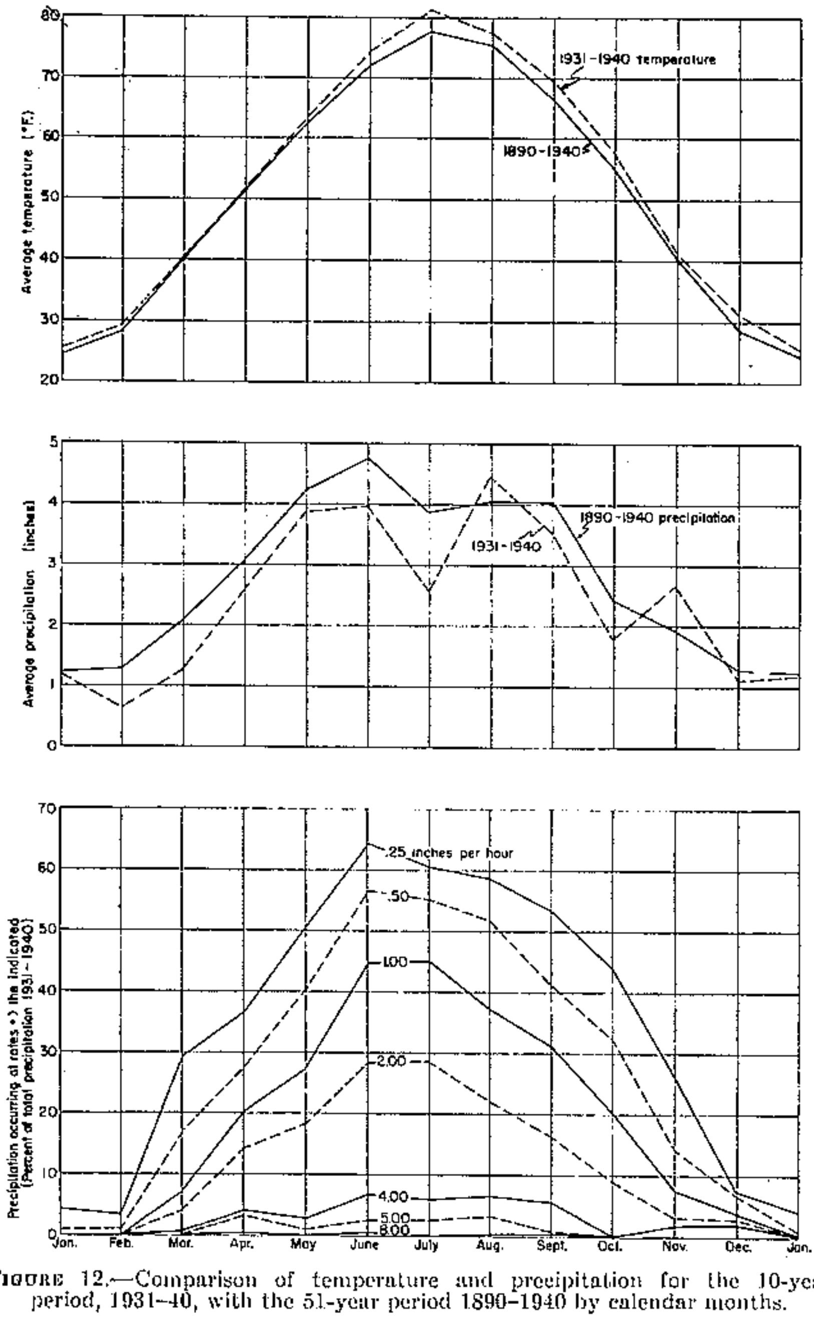

FIGURE 12.—Comparison of temperature and precipitation for the 10-year period, 1931–40, with the 51-year period 1890–1940 by calendar months.

Superimposed on the graph is a 10-year moving average, with the points plotted at 1-year intervals, at the end of each 10-year period. The average of 29.5 inches for the decade ending in 1940 is much lower than that for any other 10-year period of record. The decade ending in 1905 had an average of 37.5 inches, which is the highest recorded. It is of interest that the peaks of greatest 10-year rainfall are approximately 25 years apart. Likewise, the present cycle of low rainfall amounts has occurred approximately 25 years after the previous low.

The average maximum, minimum, and mean temperature for the 10-year period 1931–40 are given in table 12.

The distribution of temperature and amounts of rainfall by calendar months for the 10-year period, 1931–40, are shown graphically in relation to the 51-year average in figure 12. Average monthly temperatures for the 10 years have exceeded the long-time average for each of the 12 months of the year. Average monthly rainfall for the 10-year period had its greatest departure from the long-time average during the month of July. This midsummer depression in rainfall during the month of July has also been reflected in small amounts of runoff from all experiments.

While the distribution of average monthly rainfall amounts during the 10-year period has been irregular, the type of rainfall has had definite characteristics throughout the year. The percent of total monthly precipitation, falling at rates equal to or greater than selected intensities, is also shown in figure 12. The most intense rainfall has occurred in June, July, and August, when approximately 60 percent of the total rainfall came at a rate equal to or greater than 0.25 inch per hour. Rainfall became increasingly torrential from February to June and less torrential with progression from August to January. It will be seen that the pattern of rainfall intensity follows temperature very closely.

The percent of total monthly precipitation occurring at rates equal to or greater than 4.0 inches per hour has been almost constant from April through September. These appear to be the months during which protection of the soil from torrential rainfall must be provided in conservation planning.

During the 10-year period of measurements, six storms having an intensity-expectancy of once in 2 years, four storms of once in 5 years, and one storm of once in 25 years have occurred as reported by Yarnell (*34*).

The role of these 11 intense storms in the soil and water loss history of the station is important. Losses from plot 2 of plot series 1, in corn annually, illustrate this fact. Total rainfall from the 11 storm periods was measured at 33.07 inches. Of this rainfall, 18.67 inches, or 56.5 percent, appeared as surface runoff. Soil loss in runoff aggregated 185 tons per acre. In comparison with data for the 10-year period, this constituted 10.9 percent of the total rainfall, 22.8 percent of the total runoff and 36.3 percent of the total soil loss in runoff.

TABLE 12.—*Average maximum, minimum, and mean temperatures, °F., for the 10-year period 1931–40*

Year	January			February			March			April			May			June		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
1931	43.9	22.4	33.2	49.5	27.5	38.5	45.5	27.2	36.3	63.8	39.9	51.9	70.8	47.4	59.1	86.8	65.3	76.1
1932	36.2	22.3	29.3	47.1	25.4	36.3	42.9	23.4	33.2	61.1	42.5	51.8	75.4	52.4	63.9	82.8	63.2	73.0
1933	47.9	24.6	36.3	41.0	15.5	28.3	51.0	32.0	41.5	62.9	40.0	51.5	72.0	51.0	61.5	95.0	64.5	79.8
1934	40.0	23.3	31.7	40.6	18.5	29.6	51.7	28.5	40.1	68.5	38.7	53.6	85.4	54.7	70.1	94.6	64.5	79.6
1935	36.0	18.0	27.0	41.0	25.0	33.0	56.3	34.8	45.6	58.1	39.5	48.8	64.3	49.9	57.1	76.5	58.2	67.4
1936	22.8	3.8	13.3	21.5	2.2	11.9	57.6	31.7	44.7	62.2	37.7	50.1	77.6	55.6	66.6	86.9	61.0	74.0
1937	27.8	9.6	18.7	32.3	17.2	24.8	45.0	28.8	36.9	60.5	40.7	50.6	76.0	53.9	65.0	83.9	61.2	72.6
1938	32.2	18.7	25.5	45.8	26.6	35.2	64.7	23.5	44.1	65.5	41.6	53.6	72.4	52.8	62.6	84.5	63.9	74.2
1939	44.5	23.1	33.8	40.9	13.8	27.4	52.7	29.1	40.9	63.5	40.0	51.8	83.0	55.9	69.0	82.1	63.7	72.9
1940	18.9	−1.6	8.7	35.6	19.9	27.8	49.2	29.1	39.2	62.8	39.6	51.2	73.4	48.4	60.9	85.6	61.4	73.5
Average	35.0	16.4	25.7	39.5	19.2	29.3	51.7	28.8	40.3	62.9	40.0	51.5	75.0	52.2	63.6	85.9	62.7	74.3

Year	July			August			September			October			November			December		
1931	90.8	67.1	80.0	85.2	61.1	73.2	85.0	62.3	73.7	69.6	49.4	59.5	57.6	38.9	48.3	45.4	31.3	38.4
1932	92.4	68.6	80.5	91.4	61.2	76.3	82.7	53.4	68.1	65.6	38.3	52.0	45.1	24.3	34.7	33.0	18.0	25.5
1933	92.0	63.0	77.5	86.0	61.0	73.5	85.6	58.9	72.3	68.1	44.3	56.2	56.0	33.0	44.5	39.6	23.3	31.5
1934	101.5	74.7	88.1	91.6	68.0	80.0	72.9	51.7	62.3	71.9	46.6	59.3	56.0	35.0	45.5	34.0	18.0	26.0
1935	92.7	70.3	81.5	89.9	64.8	77.4	77.6	55.2	66.4	64.3	41.8	53.1	44.7	29.1	36.9	35.8	18.6	27.2
1936	102.2	70.6	86.4	99.4	69.6	84.5	81.8	60.8	71.8	64.5	44.8	54.7	51.5	27.5	40.0	41.7	25.0	33.4
1937	90.7	65.8	78.3	93.6	68.5	81.1	83.5	54.8	69.2	66.3	42.4	54.4	31.7	26.3	39.0	37.3	19.6	28.5
1938	92.3	67.0	79.9	92.2	67.1	79.7	83.7	56.5	70.1	79.9	52.9	66.4	54.0	29.4	41.7	41.7	21.2	31.5
1939	91.9	67.6	79.8	85.1	62.5	73.8	88.7	59.1	73.9	73.9	45.6	60.0	53.6	34.2	43.9	47.3	26.2	36.8
1940	92.2	65.7	79.3	84.1	63.8	74.0	83.3	55.9	69.6	79.1	48.5	63.8	48.3	28.2	38.3	41.6	24.7	33.2
Average	93.9	68.0	81.1	89.9	64.8	77.4	82.5	56.9	69.7	70.3	45.5	57.9	51.9	30.6	41.3	39.7	22.6	31.2

Soil Studies

The character of the soil affects runoff and erosion both directly and indirectly. In general, the physical properties of the soil affect soil and water loss directly. On the other hand, the chemical or fertility properties have their main influence through the type and density of vegetation the soil supports. It will be recognized that the chemical properties may, and in most cases do, have an influence on the physical properties of the soil. This latter problem has not been studied at this station, but the results of fertility treatments and physical property studies are reported.

With the establishment of the control plots, series 1, a composite of a typical profile of the soil was procured for a complete chemical and physical analysis. In addition, composite samples of the profiles of individual plots were secured. Analyses of these samples were made and reported by Middleton, Slater, and Byers (*15, 16*).

Fertilizer treatments.—Two plots of series 1 were cropped to a 3-year rotation of corn, wheat, red clover with timothy. Plot 5 received no treatment. Plot 6 was limed with 3 tons per acre in 1930 and received 250 pounds per acre of 20 percent superphosphate fertilizer with the wheat. The treated plot was adjacent to the plot devoted to continuous alfalfa. The boundary steel plate separating the plots was not deep enough to prevent the alfalfa from using moisture from the subsoil under the treated plot. This resulted in relatively poor crop growth on the side of the plot adjacent to the alfalfa, particularly in dry years. This border effect has upon occasion been reflected in relatively high soil and water losses from the treated plot, in comparison with the untreated plot upon which the plant growth does not compete with the alfalfa for moisture. The border effect in this instance assumes considerable importance due to the narrow 6-foot width of the plots and the high ratio of border to total plot area.

Averages of the data for the 10-year period, 1931–40, however, show that the treated plot was superior to the untreated plot in density of cover and yield of crops and also in reducing soil and water losses. Table 13 summarizes these data for the period. It is logical to assume that greater differences would occur if the comparison were made on a field basis where border effects tend to be negligible.

Observations throughout the area indicate that the lack of soil fertility may make the difference between a crop and no crop. For example, fall-seeded small grain is much more subject to winterkilling if it is not fertilized. Many cases of thin stands of small grain and meadow on the Shelby soil can be traced to a lack of lime and phosphate.

TABLE 13.—*Rainfall, runoff, soil loss, and crop yields from treated control plot 6 and untreated plot 5 on Shelby loam, 1931–40* [1]

Crop	Rainfall	Surface runoff: Amount, Untreated	Surface runoff: Amount, Treated	Surface runoff: Percent of rain, Untreated	Surface runoff: Percent of rain, Treated	Surface runoff: Density per acre-inch, Untreated	Surface runoff: Density per acre-inch, Treated	Soil loss in runoff per acre, Untreated	Soil loss in runoff per acre, Treated	Crop yields per acre, Untreated	Crop yields per acre, Treated
	In.	*In.*	*In.*	*Pct.*	*Pct.*	*Tons*	*Tons*	*Tons*	*Tons*	*Bu. or tons*	*Bu. or tons*
Corn	31.14	5.02	3.90	16.1	12.5	2.71	2.76	13.73	10.76	22.0	21.8
Wheat	28.12	6.07	4.91	21.6	17.5	1.39	2.30	8.43	11.28	11.6	19.1
Meadow	31.21	4.14	3.59	13.3	11.5	.52	.37	2.16	1.34	1.14	1.52
Rotation average	30.16	5.08	4.13	16.8	13.7	1.60	1.89	8.11	7.79	------	------

[1] Plots of series 1, 0.01 acre in size, 72.6 feet long on an 8-percent slope. Plot 5 is untreated; plot 6 was limed and received 250 pounds per acre of 20-percent superphosphate on wheat.

TABLE 14.—*Rainfall, runoff, soil loss, and crop yields from a plot receiving organic matter additions and one receiving no organic matter treatment 1932–41* [1]

Crop	Rainfall	Surface runoff: Amount, Untreated	Surface runoff: Amount, Treated	Surface runoff: Percent of rain, Untreated	Surface runoff: Percent of rain, Treated	Surface runoff: Density per acre-inch, Untreated	Surface runoff: Density per acre-inch, Treated	Soil loss in runoff per acre, Untreated	Soil loss in runoff per acre, Treated	Crop yields per acre, Untreated	Crop yields per acre, Treated
	In.	*In.*	*In.*	*Pct.*	*Pct.*	*Tons*	*Tons*	*Tons*	*Tons*	*Bu. or tons*	*Bu. or tons*
Corn	28.15	4.94	3.27	17.5	11.6	2.07	1.38	10.22	4.51	26.0	37.3
Oats	27.67	5.02	1.91	18.1	6.9	1.59	1.72	8.00	3.29	32.5	48.8
Meadow	32.12	2.58	.088	8.0	2.7	.09	.10	.23	.09	1.37	1.46
Rotation average	29.31	4.18	2.02	14.3	6.9	1.47	1.30	6.15	2.03	------	------

[1] Plots of series 3, 0.03013 acre in size, 125 feet long, on an 8.1 percent slope. The untreated plot is plot 3, and the treated plot is plot 2. The latter had 8 tons per acre barnyard manure and second clover crop turned under before corn, and the corn stalks remained on the plot. Both plots received lime at the rate of 3 tons per acre and 180 pounds of 20-percent superphosphate.

Organic matter.—Organic matter plays a dual role in reducing soil and water loss. The organic matter and its effect on the structure of the soil provides a favorable condition for the physical absorption of water as discussed by Brown (*6*) and Peele (*21*). Chemically, it contributes to the exchange complex of the soil and provides a source of energy for the micro-organisms for decomposing and making available to the plant many of the elements necessary for growth. Organic acids, products of decomposed organic matter, have been shown by Graham (*10*) to be active in releasing plant nutrients from the mineral fraction of the soil.

With plot studies alone it is not possible to separate the physical, chemical, and biological effects of organic matter. Generally, however, under intertilled-crop conditions, the main effects appear to be physical. Two plots in corn annually for a 7-year period were used to compare the soil and runoff loss occurring from manured and fertilized plots. The manured plot (plot A–1, series 3) received 16 tons per acre annually of barnyard manure. The check plot (plot 1, series 3) was treated annually with 250 pounds per acre of 4-12-4 fertilizer.

Over the 7-year period of study, 1933–39, the soil loss ranged from 10 to 98 tons per acre per year on the check plot, and from 7 to 71 tons per acre per year on the manured plot. The average data for the period of study showed a 34-percent reduction in soil loss and a 35-percent reduction in water loss.

The effect of organic matter additions to a 3-year rotation of corn, oats, clover with timothy, received study for 10 years (table 14). Plots 2 and 3 of series 3 were limed with 3 tons per acre in 1930 and received 180 pounds of 20-percent superphosphate fertilizer per acre

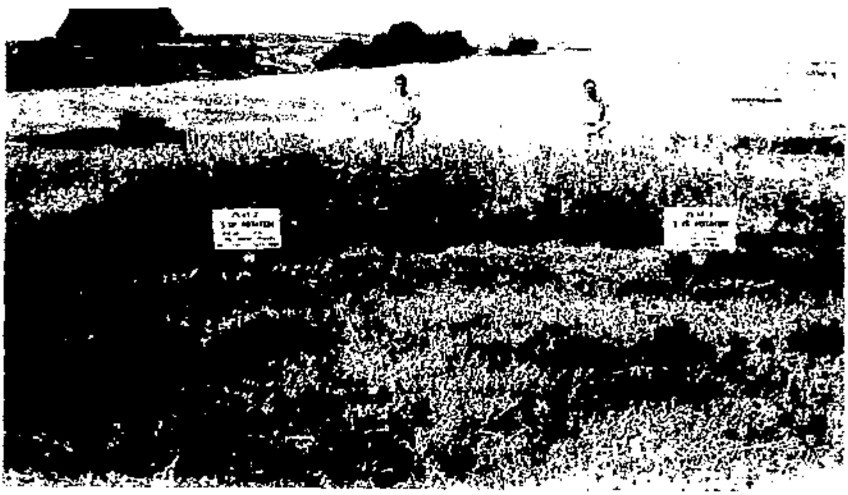

FIGURE 13.—Increased meadow growth (on plot at left) produced by the addition of organic matter.

with the small grain. Plot 3 received no organic matter additions. The second clover crop and 8 tons manure per acre were plowed under before corn on plot 2. The corn stalks were also left on plot 2 but were removed from plot 3.

Over the period of study, it was noted that the organic matter treatment before corn, on plot 2, affected the soil and water losses as well as the crop yields from each of the three crops. The soil loss reduction by the use of manure, cornstalks, and second-crop clover, was 56 percent for the corn year, 59 percent for oats, and 61 percent for meadow. Reduction in water loss ranged from 13 percent on meadow to 20 percent on oats and corn. An average for the rotation shows that organic matter additions on plot 2 have reduced water loss by 50 percent and soil loss by 57 percent. Figure 13 shows the heavier meadow growth on the plot receiving organic matter additions.

The difference in yields on these two plots seems particularly important in view of fertility maintenance and improvement. If conditions are made more favorable for grasses and legumes, these crops should stimulate increased nitrogen and organic-matter accumulation in the soil. Thus, the amount of the crop available for harvest is increased and at the same time larger amounts of roots and stubble contribute to an increase in the fertility level of the soil.

The effect of organic matter on fallow plots was observed from 1932 to 1937. The stability of the soil aggregate appeared to be improved by additions of manure and crop residues. Without these additions the soil became puddled.

Texture and structure.—The texture and structure of a soil determine to a large extent the rate of infiltration and percolation of water into and through the soil. Hence, they are of major importance in the study of runoff and erosion. The Shelby and associated soils as a group are not high either in rate of infiltration or percolation. For this reason, organic matter assumes an important role in the movement of water into and within the soil.

In 1933 a study was made of the aggregation and stability of the aggregates of Shelby surface and subsoil. Duplicate samples were procured from fallow-cultivated plots 9 and 10 of series 1, representing the two soil layers. One set of samples, collected March 1, was taken from a rough surface which had been fall-spaded. Four other sets of samples were collected throughout the year to see if the aggregate composition of the soil changed as the season progressed.

The samples were first screened through a 10-mesh sieve to remove the gravel. Fractionation of the moist sample was accomplished by means of a Kopecky elutriator according to the method described by Baver and Rhoades (*3*). The elutriator removed all particles less than 0.07 mm in diameter. The remaining material was screened through a set of standard sieves that separated it into the following size classes: Particles above 0.5 mm in diameter, particles between 0.5 and 0.25 mm, and particles from 0.25 to 0.10 mm. All particles below 0.10 mm were grouped with those passing through the elutriator.

Four of the samples collected March 1 were analyzed without treatment after 0-, 5-, 15-, and 30-minute periods of mixing with an electric mixer. A fifth sample was mixed for 30 minutes with sodium oxalate as the dispersing agent. The results are reported in table 15.

TABLE 15.—*Particle-size distribution of samples of normal and desurfaced Shelby loam after shaking for various periods, expressed as percentages of the total soil sample* [1]

[Samples collected March 1, 1933, plots 9 and 10 of series 1]

Particle size	Aggregate sizes after mixing for periods of—									
	0 minutes		5 minutes		15 minutes		30 minutes		Until dispersed [2]	
	Normal soil	Desurfaced soil	Normal soil	Desurfaced soil	Normal soil	Desurfaced soil	Normal soil	Desurfaced soil	Normal soil	Desurfaced soil
Millimeter	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0.5	10.60	31.17	5.05	8.48	3.61	4.39	3.78	3.93	3.27	3.14
.5–.25	14.17	21.06	12.02	26.70	8.06	12.38	6.79	6.55	6.82	5.28
.25–.1	48.25	31.07	41.30	26.18	37.58	34.38	32.68	31.09	21.90	12.08
.1	26.98	15.86	41.63	38.50	49.85	48.83	56.75	57.53	67.95	79.47

[1] Plot 9 represents normal soil and plot 10 desurfaced soil.
[2] 30 minutes with sodium oxalate as dispersing agent.

Since the erodibility of soil is affected by its structure under field conditions, the beating action of rain in dispersing the soil aggregates should be considered. Woodruff (see footnote 4, p. 11) doubts whether the degree of mixing caused by rain would equal or exceed the results of mixing in an electric mixer for a 5-minute period. This is perhaps a fair basis of comparison when the surface plow layer is considered as a whole. Observations indicate the possibility that the immediate surface of the soil may become dispersed and partially sealed over during rains of high intensity and thus become the limiting zone for infiltration.

The results presented in table 15 help to explain why the surface soil has suffered a larger soil loss than the desurfaced plot. Water loss from both plots for the 10-year period 1931–40 was approximately 29 percent of the precipitation. Hence any difference in soil loss should be attributable to those soil properties which resist soil movement during runoff. The absence of vegetation on the two plots would limit those properties in this case to the velocity of flow and the size of particles available for movement. Since no rate data are available, that factor cannot be entirely eliminated. However, after 5 minutes of shaking, 17 percent of the surface soil was in the size groups above 0.25 mm in diameter compared with 35 percent of the subsoil so grouped. This difference in size of particles available for washing might partly explain the difference in density of runoff from the two plots. The average density for the 10-year period was 9.29 tons per acre-inch of runoff from surface soil and 6.51 for the subsoil.

Very little change in the particle size distribution of the soil occurred as the season progressed. Moisture content at the time of sampling, however, had a marked effect on aggregation. Higher field moisture at time of sampling was accompanied by an increase in the percentage of large size particles in both surface and subsoil. This again would indicate the unstable nature of the aggregates in Shelby soil.

Porosity.—Samples of soil procured by forcing a metal cylinder 3 inches in diameter into the side of the profile at various depths were taken from an area in timothy and bluegrass immediately adjacent to the plots of series 1. The analyses as reported by Middleton, Slater, and Byers (*15, 16*) are shown in table 16.

TABLE 16.—*Physical characteristics of a typical Shelby loam profile*

Depth in profile to center of core	Volume weight	Specific gravity	Porosity	Field moisture content	Calculated moisture content at saturation, by weight	Calculated weight of an acre-inch of soil	Moisture equivalent
			Percent	*Percent*	*Percent*	*Tons*	*Percent*
Surface	1.41	2.62	46.2	26.1	32.7	159.8	----------
3½ inches	1.43	2.62	45.4	26.0	31.7	162.0	24.5
10 inches	1.33	2.66	50.0	26.3	37.6	150.7	34.9
13 inches	1.30	2.69	51.7	31.1	39.8	147.3	----------
16 inches	1.43	2.70	47.0	26.6	32.9	162.0	34.2
22 inches	1.72	2.65	35.1	17.5	20.4	194.9	27.1
36 inches	1.77	2.72	34.9	15.1	19.7	200.6	23.0
54 inches	1.85	2.71	31.7	13.4	17.1	209.6	22.9
72 inches	1.85	2.71	31.7	13.3	17.1	209.6	31.7

The analyses showed decreasing porosity with increasing depth except in the B horizon. In this horizon, the volume weights were lower and the porosity higher than for the surface soil. At a soil depth of 16 inches the calculated moisture content of the soil, when all available pore space was filled with water, was less than the moisture equivalent. It continued to be lower throughout soil depths up to 72 inches or the limit of the sampling. As the moisture equivalent is an expression of the ability of a disturbed soil sample to hold water under a centrifugal force 1,000 times that of gravity, this condition obviously indicates a very compact subsoil. As would be expected, water-loss measurements indicate that virtually no movement occurs through the subsoil, during a period of precipitation, once cracks in the subsoil become sealed.

Infiltration.—Direct measurements of infiltration rates have not been made on the Shelby soil at the Bethany Station. However, a typical profile of Shelby soil from this location was studied in the lysimeters at the Clarinda, Iowa, Soil Conservation Experiment Station and the results have been reported by Musgrave and Norton (*19*). They found the infiltration of the Marshall silt loam to be from 7 to 10 times more rapid than that of Shelby silt loam.

They point out that porosity is one of the most important factors affecting the infiltration rate of a soil profile. Under three conditions of Marshall soil having average percentages of porosity of 57.4, 55.8, and 52.8, they found infiltration rates of 1.20, 1.00, and 0.77 inches per hour respectively. Thus, for intertilled Shelby, the average rate of infiltration would be somewhere in the range of 0.08 to 0.12 inch per hour.

Water intake in the Shelby soil is, however, a variable property throughout the year. Soil moisture content at the time rains occur seems to be of major importance. Another item is that of large cracks which develop during dry periods in the summer. These vary in width up to 3 inches and usually extend well into the subsoil. This is of particular importance because the rains of highest intensity are expected during the period when cracks occur. Throughout the greater part of the year, however, the soils of this area have a low infiltration rate, and conservation measures should be adapted accordingly.

Moisture content.—Many factors affect the moisture content of the soil. The physical and chemical properties of the soil join with vegetative cover to influence the amount of precipitation a given area will retain. The effect of varying amounts of soil moisture on runoff is discussed here without differentiating the factors that contribute to its presence.

That soil-moisture content plays an important role in runoff is apparent from many comparisons made on plots where the other factors were constant or nearly so. Table 17 gives one such comparison.

TABLE 17.—*Surface runoff and soil loss from the bare fallow plot 9, series I, as affected by antecedent rains and the consequent moisture content of the soil*

Date of rain	Moisture content of surface soil	Rainfall			Surface runoff on indicated date		Soil loss in runoff per acre
		Amount during preceding 15 days	Amount on indicated date	Maximum 5-minute intensity on indicated date	Amount	Percent of rainfall	
	Percent	*Inches*	*Inch*	*Inches*	*Inch*	*Percent*	*Tons*
Aug. 14-15, 1934	<10	0.09	{ 0.97 .50	3.60 .48 }	0.15	10.2	0.75
May 15, 1935	>25	3.84	.72	.34	.05	90.3	2.21

From the viewpoint of flood control, bluegrass may, in prolonged rain periods, permit considerable runoff. This can be attributed to the fact that bluegrass retains a high proportion of the rainfall until it becomes saturated, or nearly so. This means it may approach the saturation point quicker than cultivated areas. For illustration, a plot in bluegrass lost 21 percent of a 2.10-inch rain on June 8–9, 1941, and on the afternoon of the 9th lost 69 percent of a 0.65-inch rain. Another plot which was overgrazed lost 68 percent of the first rain and only 44 percent of the second. This reversal in the amount of runoff from the two areas is undoubtedly related to the moisture content of the soil resulting from the first rain.

A reversal in the effect of soil moisture has been observed on cultivated soil following periods of prolonged drought. Tillage and extremely dry weather tend to reduce the aggregated condition of surface soil so that a torrential rain compacts and seals the surface, and under such conditions a high percentage of runoff may occur. Observations following torrential rains during dry periods frequently showed that the soil was dry below a depth of 1 inch or less.

Loss of topsoil.—The effect of topsoil removal on soil and water loss has been studied under both fallow and cropped conditions. Under the former, the physical properties of the two soils have been reflected in the runoff and soil loss. Under cropped conditions, both physical and fertility differences have been measured through their effect on the vegetal cover.

Comparisons of soil losses and runoff from surface and subsoil under clean cultivated fallow conditions have been made on plots 9 and 10 of the control plots. Plot 9 had 6 to 8 inches of surface soil in 1930, and plot 10 was desurfaced to the plastic clay subsoil. The differences in the aggregation and mechanical analysis of the two soils were pointed out under the heading *Texture and structure* (p. 44). As suggested there, the difference in the size of particles has probably been the controlling factor in soil loss. Water loss was 28.9 percent for the surface soil and 28.7 percent for subsoil over the 10-year period of study. Soil loss, however, was 44 percent larger from surface soil, averaging 81.2 tons per acre per annum, compared to 56.5 tons on subsoil. This high loss of soil, equivalent to 5.4 surface inches on plot 9, has removed the original surface soil of the plot down into the subsoil. The soil lost for the past few years has, therefore, been a mixture of surface soil and subsoil.

Plots 1 (surface) and 2 (subsoil) of series 2 have been in a rotation of corn, oats, and red clover with timothy for 2 years. Neither has received soil treatment. Yields from these two plots are summarized in table 9. The common observation that the effects of erosion are cumulative seems to be borne out by these results. As fertile top soil is lost, the soil that remains supports poorer vegetative cover. Thinner vegetative cover results in higher soil and water losses when other factors remain the same. Table 18 gives the results of 12 years' work on these two plots.

A study of individual rains on these plots shows periods when the losses were greater from the normal soil. Such periods occurred during droughts when the plots were in corn and being cultivated. The soil condition then was comparable to the clean cultivated fallow condition discussed previously for plots 9 and 10 of series 1. For

TABLE 18.—*Rainfall, runoff, and soil losses from rotation plots 1 and 2 of series 2 on surface and subsurface Shelby loam, for the 12-year period, 1931–42*

Crop	Rainfall	Surface runoff						Soil loss in runoff per acre	
		Amount		Percent of rain		Density per acre-inch			
		Surface soil	Subsoil	Surface soil	Subsoil	Surface soil	Subsoil	Surface soil	Subsoil
	Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Tons*	*Tons*	*Tons*	*Tons*
Corn	30.91	7.00	5.88	22.6	19.0	2.16	3.65	15.12	21.45
Oats	32.79	11.34	8.61	34.6	26.3	2.29	4.57	25.99	30.32
First-year meadow	27.27	.49	1.92	1.8	7.0	.20	.36	.10	.69
Second-year meadow	29.89	.77	5.98	2.6	20.0	.25	.12	.19	.74
Rotation average	30.22	4.90	5.60	16.2	18.5	2.11	2.78	10.35	15.55

the most part, however, the surface soil produced a good meadow crop, which, when turned under before corn, prevented the occurrence of this condition.

Mulches.—Experiments were not originally set up at the station for the precise measurement of the effect of mulches or surface litter. Observations have been made on various land uses which would indicate a favorable response to leaving crop residues, to be worked into the soil, for the succeeding crop. Among such residues are corn stalks and small grain straw.

Preliminary mulching studies were made in 1940 on two plots with similar past treatment. The rotation study on plots A and B of series 3 was terminated December 31, 1939. Both plots were in corn that year. Plot A was disked on March 30, 1940 and received 2 tons per acre of oat straw spread as uniformly as possible on the surface. Plot B was disked on the same date and left in that condition as a check.

The rainfall, soil loss, and runoff data for 1940 are given by storms in table 19. No subsurface tillage implement was available and about July 1 wild grasses and weeds began flourishing on both plots and became heavier as the season progressed.

TABLE 19.—*Rainfall, runoff, and soil losses from straw mulch and check plots A and B of series 3, 1940* [1]

Date	Rainfall	Surface runoff						Soil loss in runoff per acre	
		Amount		Percent of rain		Density per acre-inch			
		Check	Straw	Check	Straw	Check	Straw	Check	Straw
	Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Tons*	*Tons*	*Tons*	*Tons*
May 7	0.87	0.14	0	16.1	0	3.64	0	0.51	0
May 20–21	.60	.03	0	5.0	0	.67	0	.02	0
June 9–10	1.86	.70	0.05	37.6	2.7	2.36	0.60	1.65	0.03
June 11–12	1.87	.33	.30	17.6	16.0	.73	.03	.24	.01
June 23	1.07	.09	.13	50.3	6.6	1.11	.23	1.10	.03
June 27–28	.71	.28	.01	30.4	1.4	.86	1.00	.24	.01
July 26	.90	.28	0	31.1	0	0	0	0	0
July 30	.72	.07	0	9.7	0	.14	0	.01	0
August 9	.92	.02	0	2.2	0	0	0	0	0
August 10–12	1.78	.14	0	7.9	0	.14	0	.02	0
Total		2.05	.40					3.79	.08

[1] Plot A received 2 tons per acre of oat straw cover mulch; plot B received no straw and served as a check.

This would be expected to minimize the effect of litter and decrease the differences between the two plots. Nevertheless, plot B, which received no litter, showed a consistently higher soil and water loss, and, in all but one case, a much higher density of runoff. This would indicate the value of leaving crop residues on the surface of the soil in preference to burning them.

Time of plowing.—There are two general periods for plowing land in the area, fall and spring. High soil losses have been observed for both times of plowing, and contradictory ideas are prevalent concerning the subject. The question of the time for plowing land for corn arises every year. Fall plowing is generally considered desirable for several reasons; it permits a more uniform distribution of farm work throughout the year, allows time for the development of a desirable structural condition of the soil before planting, and provides an opportunity for the proper maintenance of terraces. On the other hand, fall-plowed land is subject to severe erosion in the spring, particularly if the soil is high in moisture. Without control measures, such as terraces or strip cropping, intense rains in the early spring have been observed to remove large quantities of surface soil from the plowed layer. On the other hand, fall-plowed surface soil, in its loose condition, dries out rapidly at the immediate surface. This thin, dry layer is sometimes removed by winter and spring winds, but this loss is generally a small part of the total soil lost.

The effect of time of plowing was compared for 10 years on two plots of series 1. Plot 9, which remains fallow throughout the year, was spaded in the fall during the latter part of October.

Plot 2 was spaded as near the middle of April as possible, depending on moisture conditions. The seedbed was prepared and corn planted on this plot as near to May 10 as possible.

The average semimonthly soil and water losses from these plots from October through May for the 10-year period 1931–40 are plotted in figure 14. Also plotted on the graph are the total precipitation and the amount of precipitation occurring at rates equal to, or greater than, 0.25 inch per hour. This point of reference selected arbitrarily, is indicative of the average intensity characteristics of the precipitation for the period.

The period from October to May was selected since it covers the period from fall plowing until corn planting, when the plots were brought to a nearly comparable condition by cultivation. It will be noted in figure 15 that the amount of runoff on both plots is more directly related to the amount of precipitation falling at rates equal to, or greater than, 0.25 inch per hour, than to the total amount of rainfall.

For the first half of October, the runoff on the two plots was equal. After plot 9 was spaded, the runoff dropped sharply and continued lower than on plot 2 throughout the winter and until April, when the latter plot was spaded. During the interval, October 16 to April 15, which approximates the period from fall spading to spring spading, total runoff on the fall-spaded plot amounted to 1.56 inches. Corn stubble on plot 2 during this same period lost 2.55 inches of runoff. After plot 2 was spaded in April, the runoff from this plot dropped sharply in contrast to plot 9. Total runoff from spring spading until May 31 was 1.30 inches on the fall-spaded plot and 0.68 inch on the spring-spaded plot.

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Soil loss follows a trend somewhat similar to runoff. The soil loss from corn stubble exceeded that from fall spading, from the date of spading until the corn stubble was plowed in April. From then until May 31, plot 9 lost three times as much soil as the spring-spaded corn stubble. The total soil loss from the fall spading time to May 31 was 13 tons per acre on the spring-spaded plot and 18 tons on the fall-spaded plot.

It is rather unfortunate that it became necessary to terminate the comparison of these plots at the end of May. After this date, the

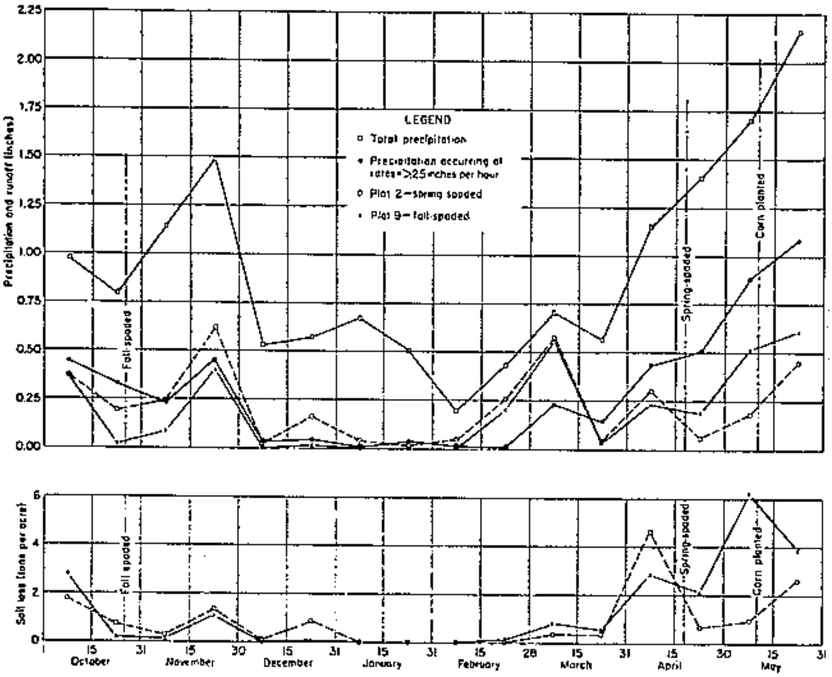


FIGURE 14.—Average semimonthly total precipitation; precipitation occurring at rates equal to 0.25 inch per hour; runoff and soil loss, from fall- and spring-spaded plots for the 10-year period, 1931–40.

high-water requirement and canopy interception of corn preclude further comparisons.

The decrease in volume weight and conversely the increase in porosity, as a result of plowing, is the basic reason for the increase in water-holding capacity of a soil following plowing. Fall plowing increased the volume of the soil in the plowed layer approximately 33 percent. After the seedbed was prepared for corn the following spring, approximately one-half of this soil volume increase, which was due to plowing, was gone.

From the rainfall data in figure 14, it will be noted that rains of higher intensity may be expected in the spring than in the fall or winter, hence it appears preferable to have the increased storage capacity in the spring. As a general practice, it would seem well to fall-plow only those areas which are protected by terraces or strip cropping. This would be particularly true for nonsodded fields to be plowed.

Effect of erosion on soil properties.—Previous work by Middleton, Slater, and Byers (*15, 16*) points out the characteristics of the various horizons of Shelby soil. As more of the plowed layer of the soil is lost by erosion, soil from the underlying layer is mixed in with the upper cultivated horizon by plowing. The resultant properties, both physical and chemical, will be changed by the difference between what is lost and that which is brought up by plowing and added by soil treatment and cropping.

In 1939 a study was made by Whitt and Swanson (*31*) to determine the effect of erosion on fertility levels in the Shelby loam profile. Annual composite soil samples, collected in 1931, 1933, 1935, and 1937 from the plots of series 1, were analyzed for several fertility elements. In addition, plot 8, which has been in bluegrass since 1931, was sampled by 1-inch horizons in 1939 to a depth of 13 inches (table 20).

TABLE 20.—*Changes in chemical composition of bluegrass control plot 8 of plot series 1 by 1-inch profile increments*

Profile depth	Exchangeable calcium per 100 grams of soil	Exchangeable magnesium per 100 grams of soil	Total nitrogen	Total organic matter
Inches	*Milliequivalent*	*Milliequivalent*	*Percent*	*Percent*
0-1	14.60	3.68	0.270	5.71
1-2	10.93	3.37	.181	3.82
2-3	11.02	3.34	.179	3.75
3-4	12.98	4.75	.178	3.71
4-5	10.63	3.59	.177	3.61
5-6	10.56	3.72	.154	3.09
6-7	11.50	3.69	.121	2.44
7-8	12.94	7.00	.111	2.29
8-9	13.79	7.12	.110	2.19
9-10	15.04	8.31	.108	2.10
10-11	16.32	9.13	.107	2.05
11-12	17.57	9.04	.105	1.94
12-13	17.48	9.10	.097	1.78

These data show that organic matter and nitrogen content decrease as the surface soil is lost. Since the exchangeable bases seem to be as high or higher in the subsoil than they are in the surface, it may be assumed that organic matter and nitrogen are the critical fertility elements in the Shelby soil.

A 3-year rotation of corn, wheat, and red clover with timothy, when limed and fertilized with superphosphate, prevented a decrease in organic matter and nitrogen supply. With this rotation on a length of slope about equal to a terrace spacing, soil loss averaged 0.025 inch per year. This suggests the minimum treatment required for maintaining the soil fertility where erosion is controlled on the soils of the Shelby region.

VEGETATIVE STUDIES

The major effects of vegetation on soil and water loss have been classified by Baver (*2*) into five distinct categories. They are (1) the interception of rainfall by vegetative canopy, (2) the decreasing of the velocity of runoff and the cutting action of water, (3) the root effects in increasing granulation and porosity, (4) biological activities associated with vegetative growth and their influence on soil porosity, and (5) the transpiration of water leading to the subsequent drying out of the soil.

Studies at the Bethany station have included the canopy interception by crops, the effect of vegetation on runoff velocity, methods of establishing meadow crops, the soil and water loss from various crops and cropping systems, and a limited study on the effect of vegetation on soil properties concerned with erosion control.

Establishing meadow vegetation. Most of the soil conservation cropping practices recommended for use on the Shelby soils depend to a large degree on securing a good meadow somewhere in the rotation cycle. Observations in the area indicated that all too often a meadow stand was not secured at its proper place in the rotation and farmers reverted to corn or small grain. This does not give the recognized beneficial effects of turning under a sod before planting to cultivated crops. These two facts led to the study of methods of meadow establishment.

One observation was that the small grain nurse crops were commonly seeded at high rates and consequently offered too much competition for moisture. The period of competition was observed to vary depending on the rainfall distribution. Fifty-five plots 9 feet wide and 150 feet long were laid out early in 1939 for the purpose of studying. the effect of the rate of seeding, and the management of oats as a nurse crop on each of three meadow crops. Eleven replicated treatments were studied in 1939 and 1940. The crops were allowed to go through to the second year for harvest in 1941. The eleven treatments are given below:

Nurse crop	*Meadow crop*
2 bushels oats for hay	Red clover 8 pounds, timothy 7 pounds.
1 bushel oats for hay	Do.
No oats (clip if weeds)	Do.
2 bushels oats for grain	Do.
1 bushel oats for grain	Do.
2 bushels oats for grain	Lespedeza 15 pounds.
1 bushel oats for grain	Do.
2 bushels oats for grain	Alfalfa 15 pounds, timothy 6 pounds.
1 bushel oats for grain	Do.
1 bushel oats for hay	Do.
No oats (clip if weeds)	Do.

The center one-third of all plots was fenced, and the nurse crop on each of these sections was completely grazed out with cattle.

June rainfall was above normal both years the seedings were made, being 9.55 inches in 1939 and 6.48 in 1940, compared with the 51-year average of 4.75. Weed grasses came in on the clover plots where oats were mowed for hay and competed with the meadow seeding for moisture in the middle of the summer, thus offsetting the advantage of removing the competition by the oats. Pasturing reduced the competition from these weed grasses in both years on all plots. Korean lespedeza did not make a fast early growth and the nurse crop seemed to have little effect on the density of stand. It grew well and a very heavy stand was obtained both under oats cut for grain and oats cut for hay. Plant counts of the alfalfa showed very little difference in the stand under oats at different seeding rates, but a somewhat higher stand was obtained where no nurse crop was seeded.

The meadow yield data collected in 1941 substantiated the results of plant counts the previous year. Red clover yields were not significantly different under any of the five nurse crop conditions. The same was true for Korean lespedeza. Seeding alfalfa without a nurse crop gave highly significant increases in yield in comparison to oat seedings, which were removed for grain, and significantly higher yields where oats were removed for hay.

Although this study covers only a limited variety of weather conditions, these meager data indicate that in this area the competition for moisture by the small grain crop and the grass and legume seedings is an adverse factor in the establishment of new meadows.

Cropping systems containing cultivated crops.—Studies were undertaken to show the difference in soil and water losses between continuous cropping and certain rotations commonly practiced in the region. It has been impossible at the station to study all of the possible combinations of crops for rotations. Yield data have been secured to supplement the soil-and water-loss measurements, since it was

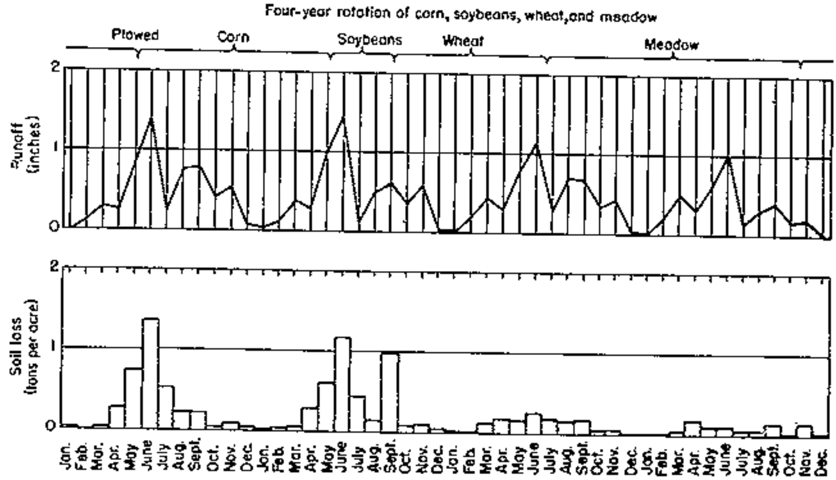


FIGURE 15.—Average runoff and soil loss from a 3-year rotation of corn, wheat and meadow as compared with that from continuous corn. Data from control plot series 1 for the 10-year period 1931–40.

assumed that the preceding crop has an influence on the crop which follows.

In each system of cropping there are critical periods during which crops afford little protection to the soil. During such periods the severity of erosion depends upon the combination and sequence of the crops. With crops that are seeded, cultivated, permitted to mature, and then harvested, there is a rapidly changing cycle that affords minimum protection during the period of establishment, a maximum protection during the period of growth, and a slight reduction in protection at maturity. These factors must be considered in connection with rainfall distribution and intensity when planning rotations for any region where erosion is a problem.

The plots of series 1 have provided a comparison of continuous cropping to corn, alfalfa, and blue grass, with a 3-year rotation of corn, wheat, and meadow.

In order to understand the effect that various crops have on erosion, it is necessary to study the crop through the various stages of its development. Monthly periods were chosen for the time unit in plotting the averages from series 1 shown in figure 15.

The most interesting contrast is between soil loss from corn annually and rotation corn. The plots were spaded the middle of April, and corn was planted about May 10. The rotation corn plot had negligible soil loss until June, whereas the losses from corn following corn were appreciable during April. The value of turning meadow sod under before corn is apparent for the period from April through September. In June, for example, corn following corn lost 18.5 tons soil per acre, compared to 5 tons from corn following meadow. Other months did not show this wide difference, but losses from corn planted annually were larger in each case.

Soil losses from corn in the rotation occurred from June until wheat was seeded the first of October. Wheat permitted significant losses in October and November and again in April, May, and June. Soil loss from this rotation dropped sharply with the development of meadow following wheat harvest and continued low until the plot was spaded for corn. Runoff was highest from corn in June, August, and September and from wheat in May and June.

Soil losses from alfalfa and bluegrass were similar throughout the year, with somewhat higher losses in the fall from bluegrass than from alfalfa. This was due, however, to the losses which occurred from bluegrass in the fall of 1931 before the grass was well established.

A detailed tabulation of data from these plots is given in Appendix, tables 53 and 54.

TABLE 21.—*Average annual rainfall, runoff, and soil losses from rotations on plots A and B of series 8 for the 8-year period 1932–39*

Crop	Rainfall	Surface runoff						Soil loss in runoff per acre	
		Amount		Percent of rain		Density per acre-inch			
		Plot A	Plot B	Plot A	Plot B	Plot A	Plot B	Plot A	Plot B
	Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Tons*	*Tons*	*Tons*	*Tons*
Corn	31.46	5.39	5.46	17.13	17.36	3.3	3.6	17.96	19.44
Soybeans	25.83	4.57	2.83	17.69	10.96	7.0	6.1	32.12	17.31
Oats	26.55	5.36	------	20.19	------	2.1	------	11.20	------
Wheat	26.55	------	3.22	------	12.13	------	.3	------	1.08
Meadow	28.67	3.19	2.37	11.13	8.27	.3	.4	1.01	.97
Rotation average	28.13	4.63	3.47	16.46	12.34	3.4	2.8	15.57	9.70

Soybeans drilled in 8-inch rows for hay lost approximately one-half as much soil and water as those cultivated in 3.5-foot rows. The difference in density of cover accounted for part of these differences in erosion. The cultivation of beans in wide-spaced rows left the soil between the rows loose and unprotected throughout the growing season and made it more susceptible to erosion than when beans were drilled solid. Following soybeans one plot was seeded to wheat while the other was seeded to oats the following spring. Soybeans were observed to leave the soil in a loosened condition. The plot seeded to wheat provided fall, winter, and early spring protection. The other plot was unprotected after the beans were harvested until the oats were seeded in March. This accounts for the greater soil and water losses from the plot seeded to oats.

Other rotations were studied on plot 1 of series 2 and plots A, B, 2, and 3 of series 3. In contrast to the study on the plots of series 1, only one crop of the rotation was represented each year. Thus, they are not directly comparable, and provide a measure only of the climatic conditions which prevailed for the crop represented.

All plots of series 2, with the exception of plot 1, were desurfaced. The surface soil on plot 1 was retained as a check to give a measure of the effect of loss of topsoil on soil and water losses and crop production. This plot was cropped to a 4-year rotation of corn, oats, and 2 years of meadow, and was in corn in 1934 and 1938. Only one crop of the rotation was on the ground each year, hence the rotation is not directly comparable to the 3-year rotation of series 1. It is possible, however, to compare corn following 2 years of meadow on this plot, with corn

FIGURE 16.—Comparison of the exposed soil area with soybeans planted in 42 inch rows with those drilled solid.

following 1 year of meadow on series 1. Soil and water losses from corn in 1938 did not provide a good comparison due to difference in quantity and quality of meadow preceding corn. The meadow on the plot of series 2 was seeded in the spring of 1935. Drought in 1935 led to an inferior type of meadow growth. The average soil loss from corn following 1 year of meadow was 24 tons per acre per annum. Corn following 2 years of meadow lost 20 tons per acre per annum.

Two rotations containing soybeans, shown in figure 16, were studied on plots A and B of series 3. Two rotation cycles of data were collected and are directly comparable on the two plots. Plot A was cropped to corn, soybeans cultivated in rows; oats, and red clover with timothy. Plot B was cropped to corn, soybeans drilled for hay, wheat, and red clover with timothy. Only one crop of the rotation was on the ground each year. Table 21 summarizes the data for the period, and the data by seasons are given in appendix table 56.

Crop rotations on terraced land have been studied on six terrace intervals on field H. Two terraces were in a 2-year rotation of corn and oats with sweetclover turned under as green manure. Four other terraces were in a 4-year rotation of corn, soybeans, wheat, and meadow. All crops of the rotations were thus grown each year.

The purpose of studying crop rotations on terraced land was to determine how intensive the cropping system might be without incurring serious soil and water losses. Cropping on the H terraces is shown in figure 17. A 2-year rotation of corn, oats with sweetclover turned under was grown on terraces 1- and 2-H. Average annual runoff from corn was 4.04 inches and the soil loss 1.35 tons per acre. During the oats' years the average water loss was 3.29 inches and the soil loss 1.21 tons per acre. These losses result in a rotation average of 3.67 inches of runoff and 1.21 tons per acre of soil loss. Detailed soil and water losses by seasons are given in appendix tables. These

FIGURE 17.—Crops on the H terraces; soybeans on the left, corn in the center followed by meadow, wheat, and corn to the right.

losses as measured from the ends of the terraces are not excessive. Observations, however, indicated considerable soil movement to the channels owing to the erodible nature of the soil. Legumes, when seeded without grass, have been observed generally to leave the soil in a loosened condition. This, together with the fact that a close-growing crop, sweetclover, is on the ground only from oat harvest to spring plowing, accounts for this movement to the channel.

The sweetclover was plowed under immediately before corn planting. This large addition of green manure has appreciably depressed corn yields during 3 years of study. These yield depressions were due to a dry soil condition following growth of the sweetclover, which delayed germination and early growth of the corn when moisture was deficient or to midsummer drought following a rapid early growth. Corn yields averaged 18 bushels per acre following sweetclover turned under compared with an average of 23 bushels following timothy and clover meadow in the 4-year rotation of corn, soybeans, wheat, meadow, for an 8-year period. In the 3 years when moisture was deficient, corn following sweetclover averaged only 17 bushels per acre, compared with 28 bushels per acre following clover and timothy. During each of the other years the yields were not materially different.

In order to determine the vulnerable periods in the 4-year rotation of corn, soybeans, wheat, and meadow, the average monthly runoff and soil losses have been plotted in figure 18. Soil loss from corn was appreciable from the time of plowing in April until the amount and

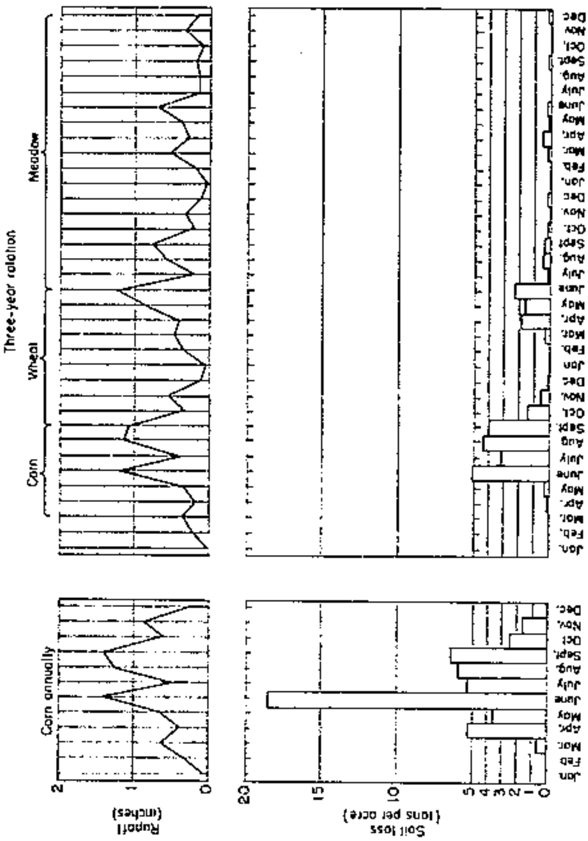


FIGURE 18.—Average monthly runoff and soil losses for a 4-year rotation of corn, soybeans, wheat, and meadow from terraces 3-6-II, for the 10-year period, 1932–41.

intensity of rainfall decreased in October. The soil remains subject to erosion throughout the winter and the following year until soybeans, which were drilled solid on the contour, approach maximum growth in July. On the average, losses have not been excessive from October through March. Soybeans were harvested in late August or early September and the land was seeded to wheat. During the interval from soybean harvest to the establishment of a cover by wheat, erosion was excessive. For example, in 1933 soil loss during September was 6.8 tons per acre, although the rainfall for the month was only slightly more than 5 inches, or approximately 20 percent above normal.

Average soil loss from the rotation has been 2.1 tons per acre per year. While these losses, as measured from the end of the terrace channels, are still low in amount, they are approximately twice as great as those from other terraces on the station. Soil movement to the terrace channels has been large, although much of it has been compensated by uphill plowing which occurs twice in the rotation cycle. The use of this rotation on terraced land of this slope and fertility is questionable even with the plowing method used and could not be recommended with ordinary plowing procedure.

Water losses from the rotation have, in general, paralleled the rainfall and do not show the wide variation common to soil losses.

A point of interest is that the maximum rate of runoff from soybeans, with their large amount of canopy interception in July and August, has been approximately equal to that from the meadow crop. However, the average maximum monthly runoff rates were markedly less from the meadow than from the other crops of the rotation.

Crops grown for continuous hay production.—Measurements of runoff and soil loss from alfalfa have been made on three areas, namely, plot 7 of plot series 1, terrace 2-G, and watershed I-58. The crop has also been studied on an observational basis on strip-cropped field L. The plot, terrace, and watershed were all under measurement during the 5-year period, 1933–37. Annual losses are given in table 22. It will be noted from a study of the table that runoff from alfalfa on the field areas has averaged approximately twice that from plot 7 of the series 1, and that soil loss on the watershed averaged approximately 5 tons per acre per year. Yields of alfalfa on the field areas have averaged only slightly more than 1 ton per acre, or approximately one-third of the yield from the small plot. On terraced area 2-G, the alfalfa failed to grow in the terrace channel because the grade of 4 inches per 100 feet was not sufficient to provide adequate drainage for the alfalfa crop. On watershed I-58 alfalfa died out in the waterways and poorly drained depressions in 1935.

TABLE 22.—*Annual runoff, soil losses, and crop yields, from areas in alfalfa*

Area	Year	Rainfall	Surface runoff		Soil loss in runoff per acre	Alfalfa yield per acre
			Amount	Percent of rainfall		
		Inches	*Inches*	*Percent*	*Tons*	*Tons*
Plot 7 of series 1: Area, 0.01 acre, land slope, 8 percent	1933	31.37	2.35	7.5	0.40	5.41
	1934	31.18	2.84	9.1	.01	2.50
	1935	36.07	6.90	19.1	.26	3.05
	1936	24.29	1.51	6.2	.20	1.85
	1937	21.72	2.36	10.9	.13	2.91
Average		28.93	3.19	11.0	.20	3.14
Terrace 2-G: Area, 0.75 acre, land slope, 12 percent	1933	31.37	7.52	24.0	1.49	0.90
	1934	31.18	7.67	24.6	1.24	.89
	1935	36.07	10.75	29.8	.91	1.48
	1936	24.29	.97	4.0	.00	1.20
	1937	21.72	3.11	14.3	.21	1.00
Average		28.93	6.00	20.7	.77	1.09
Watershed I-58: Area, 2.112 acres, land slope, 9.1 percent	1933	31.37	5.84	18.6	9.89	0.24
	1934	31.18	4.75	15.2	6.40	1.47
	1935	36.07	12.57	34.8	7.63	1.65
	1936	24.29	.87	3.6	.00	1.00
	1937	21.72	2.37	10.9	.29	1.03
Average		28.93	5.28	15.3	4.84	1.08

A survey showed that this area amounted to 16 percent of the water-acreage. The boundaries of the area in which the alfalfa died were found to coincide very closely with the boundaries of soil deposition in the depressions. It is evident that alfalfa should be placed on a well-drained soil to insure good stands and survival and to hold soil losses to a minimum, or that seedings of timothy or brome should accompany alfalfa seedings where portions of the field have poor drainage.

In this region weak points in erosion control occur at the time of seeding alfalfa and again when alfalfa is plowed out for subsequent cropping. This was illustrated on watershed I–58. Soil loss from the watershed in May, following seeding of the crop in April of 1933, was 6.7 tons per acre. This resulted in rill formation which was never entirely eliminated in the 5-year period during which the crop was retained. After plowing out the crop in the fall of 1937, the the watershed was seeded to oats-lespedeza in March of 1938. During May and June the water loss from the area was 1.45 inches and the soil loss 5.85 tons per acre. These losses occurred in the absence of torrential rainfall and appeared to be due to an extremely vulnerable condition of the soil resulting from the preparation of the seedbed and the decay of the alfalfa roots. As an indication of the area's susceptibility to high losses, the measured water and soil losses from watershed D–1, seeded to oats following a corn crop in 1938, were only 0.39 inch and 0.13 ton per acre, respectively, during the same period. On the basis of these losses, it appears advisable to retire alfalfa fields to timothy or grass before plowing out for another crop. This plan is being followed in field trial studies on field L.

Best results in establishing alfalfa were secured when it was seeded on a firm seedbed. This usually involves rolling the ground to produce the desired firmness, sowing the seed, and then covering it lightly by harrowing. The practice of rolling the ground with a corrugated roller is often employed in the spring on previously established stands of alfalfa when the plants have been heaved by freezing and thawing during the winter months. That the practice of rolling the ground is conducive to high water losses was demonstrated on watershed I–58 during the spring of 1935. The plants had heaved during the winter months and the area was rolled on March 20. Water loss from the watershed, following the rolling, during the remainder of March and through April was 1.5 inches, or more than twice as great as from any other measured field area. Relatively highwater losses continued until after the summer months. Total runoff from the watershed for the year was 12.57 inches, or greater than from any other field area at the station, notwithstanding the fact that the yield of alfalfa during the year was 1.65 tons per acre and provided excellent protective cover.

The introduction of Korean lespedeza into the agriculture of the area is comparatively recent. Only a few seedings of the crop were made prior to 1937. In 1942 the acreage of Korean lespedeza in Harrison County comprised approximately 18 percent of the land area. Much of the area on which the crop is grown is eroded to the point where production of other meadow crops is uneconomical. The crop is usually a part of a double-cropping system of oats-lespedeza. The oats are drilled or broadcast in the spring and are grazed out, mowed for hay, or harvested as a grain crop. The lespedeza makes its optimum growth after removal of the oats crop and is used for supplemental pasture during the period when bluegrass pastures are dormant, harvested as a hay or seed crop, or may be utilized for combinations of pasture, hay, and seed production.

Measurements of the erosional behavior of the oats-lespedeza cropping system have been made on subsoil plot 8, series 2, since 1936, and watershed I–58 since 1938. Soil and water losses by years are given in table 23. It will be noted that soil losses are very low after the first or second years of establishment. Dense stands of lespedeza have resulted from natural reseedings of the plant, although dense stands were not secured when originally seeded. The practice followed on both areas has been to leave a considerable growth on the field in the fall. Such litter serves as mulch protection during the spring months and appears to be the key to controlling erosion during this period. Some difficulty has been experienced with a wet soil condition under lespedeza residue in the spring. This tends to delay oats sowing to beyond the recommended dates for seeding.

TABLE 23.—*Annual runoff, soil losses, and crop yields, from oats-Korean lespedeza cropping*

Area	Year	Rainfall	Surface runoff		Soil loss in runoff per acre	Oats yield per acre	Lespedeza hay yield per acre
			Amount	Percent of rainfall			
		Inches	*Inches*	*Percent*	*Tons*	*Bushels*	*Tons*
Subsoil plot 8 of series 2, 0.0193 acres; land slope 9.3 percent; 125 pounds per acre of 20-percent superphosphate applied annually with oats seeding	1936	24.29	0.82	3.4	1.76	39.7	0
	1937	21.72	4.10	19.2	7.29	47.8	0
	1938	26.16	.85	3.2	.80	31.6	1.75
	1939	26.84	4.05	15.1	1.13	2.5	.55
	1940	27.76	.61	2.2	.02	18.9	1.19
	1941	34.62	.77	2.2	.03	15.4	1.19
	1942	33.82	.53	1.6	.13	3.5	2.12
Watershed I–58, 2.112 acres; land slope 9.1 percent; 125 pounds per acre of 20-percent superphosphate applied annually with oats seeding	1938	26.16	2.37	9.1	6.42	44.7	0
	1939	26.84	3.36	12.5	.81	15.8	.88
	1940	27.76	.73	2.6	.06	37.1	.66
	1941	34.02	2.93	8.5	.03	25.1	.99
	1942	33.92	3.39	10.0	.32	27.2	.71

Many farmers in the locality practice burning off lespedeza residues to promote drying of the soil prior to oats seeding. Observations indicate that this practice leads to high soil losses and rill formation when intense rainfall occurs in April or May. The development of a dependable winter barley for the soil area or the use of rye or wheat would possibly be the solution to the problem.

Intensity of grazing on bluegrass pasture.—Bluegrass pastures constitute 40 to 50 percent of the farm acreage of the area. Gully erosion and overgrazing are problems on most of this land. Intensity of grazing has been studied on two pasture areas of series 9. Plot 1 was permitted to obtain a growth of 2 to 3 inches in the early spring before grazing was started. It was grazed moderately during the growing season, and grazing was stopped entirely, in time for the development of a good cover of grass by late fall. Plot 2 was grazed in a manner similar to that often practiced in the problem area. Pasturing was started as soon as the grass began growing in the spring and continued until late fall. Sheep were used for grazing, and records of pasture days and change in live weight were secured. The two bluegrass plots are shown in figure 19.

Below-average rainfall occurred in all years except 1941. This deficiency was reflected in the amount of vegetation, runoff, and soil losses. Table 24 gives annual losses from the two plots by years and an average for the period of study. On the average, runoff was more than three times as great from the intensively grazed area. Soil losses from both were negligible. The records for 1937 were lost because of a leak in the divide between the plots permitting runoff to enter plot 1 from plot 2. Data by individual rains show that runoff from the pasture with controlled grazing was occasionally greater than that from the intensively grazed plot. One such occasion was in 1941, when two rains occurred in close succession. The moderately grazed plot retained 79 percent of the first rain, while plot 2 retained only 32 percent. When the second rain fell, plot 1 was practically saturated and lost 69 percent of the precipitation compared with a runoff of 44 percent for the intensively grazed plot.

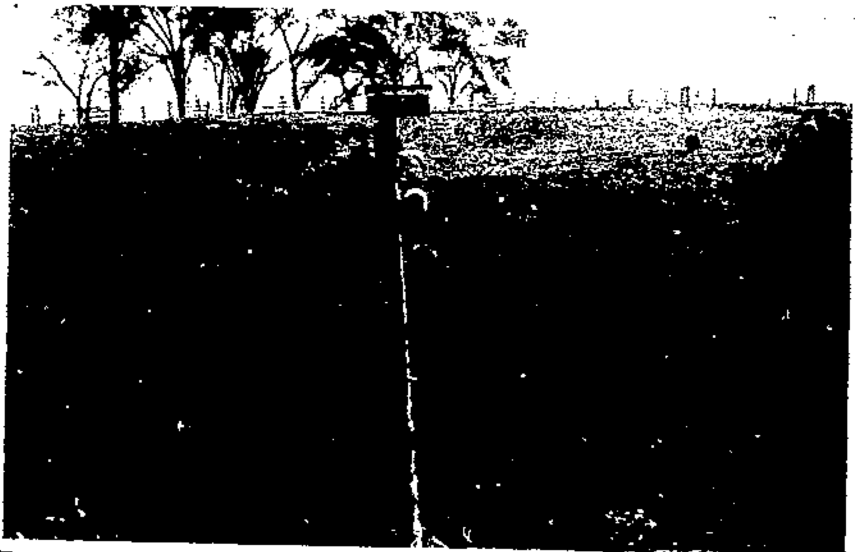


FIGURE 19.—Bluegrass pasture grazing study. Note the dense growth of bluegrass on the moderately grazed plot to the left.

TABLE 24.—*Rainfall, runoff, and soil loss from pasture grazing plots of Series 9, 1936–41*

Year	Rainfall	Surface runoff				Soil loss per acre	
		Amount		Percent of rainfall			
		Controlled grazing	Intensive grazing	Controlled grazing	Intensive grazing	Controlled grazing	Intensive grazing
	Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Pounds*	*Pounds*
1936	24.17	0.88	1.40	3.64	5.70	12	37
1937 [1]	22.08	---	---	---	---	---	---
1938	26.24	.00	.03	0.00	.11	1	3
1939	26.80	.26	2.48	.97	9.25	0	20
1940	27.52	.00	.27	0.00	.98	0	13
1941	35.03	.94	2.53	2.65	7.22	123	224
Average	27.05	.42	1.34	1.50	4.07	27	59

[1] Runoff data lost because of leak in the divider.

A summary of the pasture usage is given in table 25. The intensively grazed area was pastured considerably more days than the area under controlled grazing. The heavy grazing on plot 2, however, has resulted in an average annual loss in live weight of 156 pounds per acre. These data indicate that overgrazing of pastures may result in only small gains, or even losses, of livestock weight. Differences in the growth of grass as a result of rainfall variation must also be considered if the maximum production is to be secured from bluegrass pastures in this region.

Ecological surveys were made on the two pasture areas in 1934, 1936, and 1939. Wide variation in the results between years indicated that a more uniform method of securing the data was needed. On a relative basis, the data from the plots show some general points of interest. The amount of bluegrass on the control grazed plot, when expressed as a percent of the total vegetal cover, showed little variation, and a very few weeds have come in on that plot. The percentage of bluegrass on the intensively grazed area has decreased, but the weeds and annual grasses have increased markedly. In 1939, for example, that plot had 90 times more dryland rush or wire grass than did the moderately grazed plot. Poverty grass (*Aristida oligantha*) and barnyard grass (*Echinochloa crusgalli*) have also increased materially since 1938.

TABLE 25.—*Unit pasture days and change in animal weight on moderately and intensively grazed virgin bluegrass pastures*

Year	Unit pasture-days per acre		Change in animal weight per acre	
	Controlled grazing	Intensive grazing	Controlled grazing	Intensive grazing
			Pounds	*Pounds*
1936	121	95	145	134
1937	154	275	384	51
1938	140	203	141	213
1939	98	157	57	−67
1940	129	218	190	−680
1941	36	89	255	−586
Average	113	173	195	−156

Canopy interception.—A study made on the station in 1937 evaluated the relative merits of crop canopies in intercepting rainfall. Records for one growing season were collected under alfalfa, oats, corn, and soybeans drilled for hay, and for selected periods under timothy, bluegrass, and wheat. Only a summary of the results will be given as the study has been reported by Haynes (*11*) in another publication.

The total interception for the crops studied through the growing season is given in table 26. Measurements of vegetation density and foliage cover, as they increased during the growing season, showed that interception of rainfall increased directly with the increase in vegetative cover. In general, the percentage of storm rainfall intercepted was greater for the smaller storms and decreased as the interception capacity of the plant was exceeded by the larger storms.

The interception by wheat, timothy, and bluegrass was studied for a month previous to wheat harvest. Data for this period showed that wheat intercepted 19.9, timothy 26.1, and bluegrass 16.3 percent of the rainfall, the latter exclusive of litter.

It is obvious that vegetative canopy may influence soil and water losses in four ways, namely, by alteration of the total amount of ground rainfall, the energy of impaction, the pattern of the distribution of the ground rainfall, and the total volume of water available to carry the silt load.

TABLE 26.—*Total canopy interception during the growing season for alfalfa, corn, soybeans, and oats*

Crop	Inclusive dates	Number of storms	Precipitation	Interception of precipitation	
			Inches	*Inches*	*Percent*
Alfalfa	Apr. 27–Sept. 15	46	10.81	3.87	35.8
Corn	May 27–Sept. 15	27	7.12	1.10	15.5
Soybeans	June 2–Aug. 17	24	6.25	.91	14.6
Oats	Apr. 15–June 20	35	6.77	.47	6.9

Of the crops studied, water reached the ground under alfalfa with the least potential energy for moving soil. Reduction of total ground rainfall was greater, intensity of ground rainfall was less, energy of initial impaction was less, and distribution of ground rainfall was fairly uniform, except for increased volumes of water at the stem and the periphery of individual plant canopies. Alfalfas has a large number of stems per unit area, hence the water flowing down the stems is better distributed over the ground surfaces than, for instance, under corn.

A relatively large amount of precipitation reached the ground directly when corn occupied the land, and soil compaction was considerably higher than under alfalfa. Impaction under soybeans was greatly reduced after the crop reached full vegetative development, but rainfall tended to concentrate between the rows. Oats tended to concentrate water between the drill rows and impaction was high until the crop reached an advanced stage of growth. Wheat behavior was similar to oats, except that the interception was effective over a longer season. Measurements of intensity or distribution of rainfall were not made under timothy or bluegrass. Undoubtedly the litter under these two crops plays a major role in interception particularly in preventing the rain from striking the bare ground.

Effect of vegetation density on runoff velocity.—From the standpoint of flood hazard and designing for water disposal, it is desirable to know the relative rates of runoff from various types of vegetation. The rate of runoff from major storms has been appreciably less from areas in dense vegetation than from similar areas less densely vegetated except of course for newly plowed acres.[8]

Table 27 shows ratios of average maximum rates of runoff, secured by dividing the rate for corn areas by the rate for clover and timothy or bluegrass areas. Total runoff from each and the ratio of corn to dense vegetation is also shown in the table. In every case, the close-growing vegetation reduced the maximum rate of runoff. This was true even when the total runoff was the same from the two crops.

[8] NORTON, R. A., and SMITH, D. D. EFFECT OF DENSITY OF VEGETATION ON RATE OF RUNOFF OF SURFACE WATER. Paper read at the symposium on some aspects of vegetative methods of erosion control. Amer. Soc. Agron. Ann Rpt. Dec. 1937.

TABLE 27.—*Maximum rates and total amounts of runoff for different types and densities of cover*

Period	Number of rains	Maximum rate of runoff per hour per rain			Total runoff per rain			Remarks
		Corn	Clover-timothy	Ratio [1]	Corn	Clover-timothy	Ratio [1]	
		Inches	*Inches*		*Inches*	*Inches*		
1932–34	24	0.91	0.37	2.5	0.71	0.43	1.6	Rains severe but well distributed.
1935	19	.52	.23	2.3	.44	.43	1.0	Moderate rains almost continuous during spring.
1936	7	.22	.03	7.3	.28	.04	7.0	Rains light and well distributed.
1932–36	50	.67	.27	2.5	.57	.38	1.5	Average for 5-year period.
1933–34 [2]	36	[3] .79	[4] .20	4.3	[3] .34	[4] .13	2.6	Rains severe but well distributed.
1935	19	[5] 1.23	[4] .53	2.3	[5] .52	[4] .50	1.0	Moderate rains almost continuous during spring.
1933–36 [6]	77	[6] .70	[4] .23	3.0	[6] .33	[4] .20	1.6	Average for 4-year period.

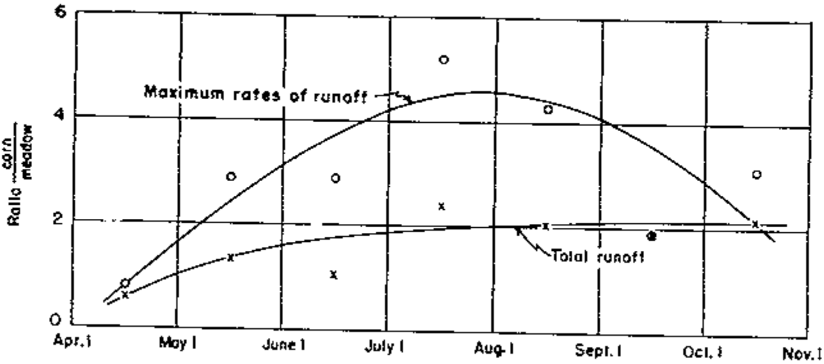
[1] Ratio=corn÷clover and timothy=corn÷bluegrass, etc.
[2] Data for first four periods are from standard design terraces on eroded Shelby soil of 9.4 percent slope.
[3] Corn.
[4] Bluegrass.
[5] Oats.
[6] 4-year rotation corn, corn, oats, clover and timothy, Jan. 1 to Dec. 31. Data for last three periods are from 4.5 acres cultivated watershed on normal Shelby soil of 6.7 percent slope and a pasture watershed of 6.5 acres on normal Shelby soil of 9.5 percent slope.

The 50 rains of line 4, table 27, were averaged by months, and are presented graphically in figure 21. The ratio of maximum rates of runoff increased from near unity in April to a peak in August, and then decreased during the fall. Apparently this decrease was due to the growth of wild grasses in the corn during the late summer, to the reduction in density of meadow by harvesting, and to a lower water requirement of the meadow during the same period. Total runoff ratios from the two conditions of vegetation increased from near unity in April, to a maximum in July, and then remained almost constant. Figure 20 also shows the trends of ratios between oats and bluegrass for the 1935 season. As oats developed, the maximum rate and total runoff ratios approached unity.

A rain of April 3, 1934, having a frequency of occurrence of once in 30 years provided interesting contrasts on watersheds in different crops. This rain of 3.64 inches fell with a 5-minute intensity of 5.76 inches per hour, and a 30-minute intensity of 2.56 inches. The maximum rates of runoff in inches per hour were: Terraced bluegrass pasture 0.32, unterraced bluegrass pasture 2.54, and rough fall-plowed watershed 1.70.

It seems conclusive from these data that on the average the rate of runoff from areas of dense vegetation, such as bluegrass and clover-timothy meadows, on Shelby loam, is materially less than from similar areas of less dense vegetation, such as corn or young oats because of the greater resistance to overland flow offered by denser vegetation. Likewise, the same type of vegetation varies in its ability to reduce the rate of runoff depending on its stage of development at the time the rain occurs.

Effect of vegetation on soil properties.—The vast store of available nutrients found in the virgin Shelby soil reached its maximum under growths of native grasses. Much of this fertility has now been depleted through removals by intertilled crops, over-grazing of pastures, and the actual loss of soil by erosion.



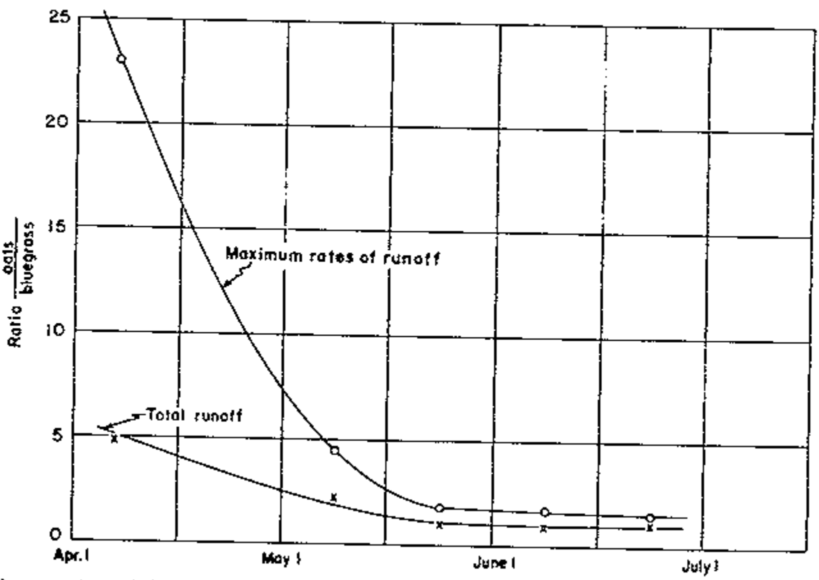


FIGURE 20.—Monthly ratios, corn to meadow, of maximum rates of runoff and total runoff from the H-terraces during the period, 1932–36, and semimonthly ratios of maximum rates of runoff, and total runoff, oats to bluegrass, from watersheds D 3 and Pa–B, for 1935.

Meadow yields.—The role of meadow crops in reducing soil and water losses, either when employed in a rotation or grown continuously, has been shown to be of great importance. Furthermore, the more vigorous the growth of a given type of meadow, the less soil loss and runoff is anticipated, either from the crop itself, or from the rotation in which it is grown.

While experiments were not designed to compare meadow yields, some of the yield differences secured from the plots on surface and subsoil without treatment, and with various soil amendments, are of interest and serve as a guide to the economics of meadow culture in the area.

A limited study of the effects of returning these lands to grass on the increase of available plant nutrients and the rate of such increase was made in 1940 and reported by Whitt (*30*) in 1941. Bluegrass was established on plot 8 of the control plots in 1930. Soil samples from this plot, secured in alternate years from 1931 through 1939, were

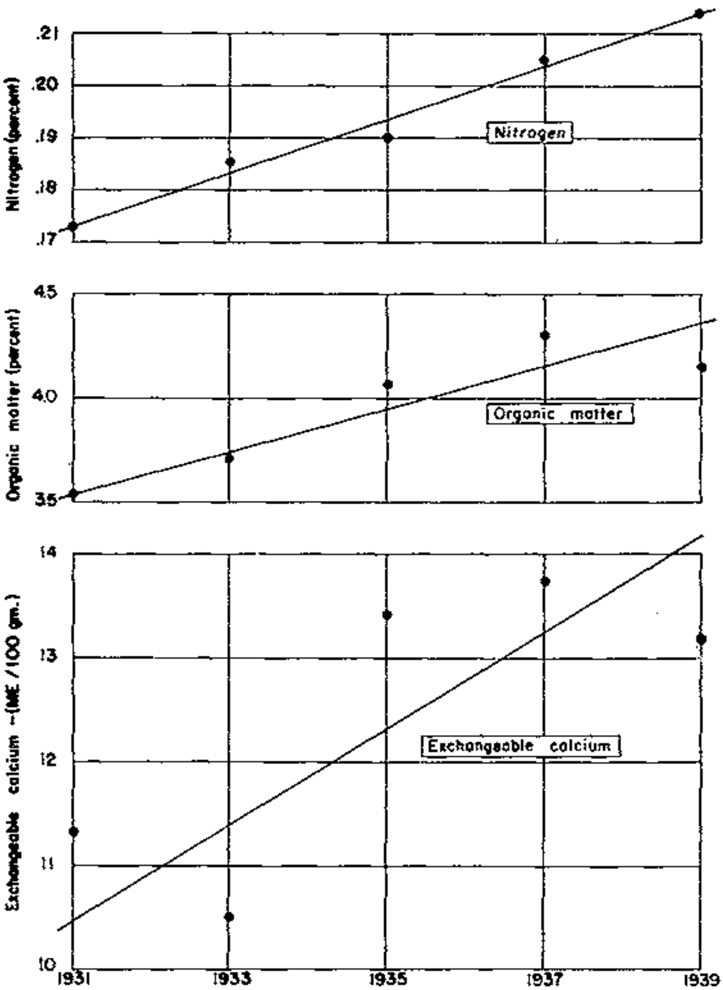


FIGURE 21.—Changes in nitrogen, organic matter, and exchangeable calcium, under bluegrass on plot 8 of series 1 for the period, 1931–39.

analyzed for nitrogen, organic matter, and exchangeable calcium. Results of this analysis are plotted in figure 21. All three of the items studied show increases during the 9-year period. Total available nitrogen increased approximately 3 percent per year from its original level of 0.17 percent; organic matter increased approximately 6 percent per year from its 1931 level of 3.5 percent; and the average increase per year in exchangeable calcium was slightly less than 0.5 per 100 grams of sample. These data indicate that meadows, particularly bluegrass, play a major role in rejuvenating and increasing the available nutrient store of fertility within the soil.

Clover and timothy meadow has been grown without soil treatment each year in a 3-year rotation of corn, wheat, and meadow on plots 3, 4, or 5 of series 1, for the 11-year period 1931–41. The average differences in yield of meadow in tons per acre between data from specific plots and from either plot 3, 4, or 5 of series 1, for the years in which comparisons were possible, were determined and added algebraically to the 11-year average for plots 3, 4, and 5, to secure a comparable yield for each of the plots. These differences and the yields as well as the crops and treatments applied to the different plots, are given in table 28.

The comparisons for clover and timothy meadow are for different soil treatments, type of nurse crop, and age of meadow, on both surface and subsoil. The yield of first-year meadow on surface soil without soil treatment and with oats as a nurse crop has been 0.6 ton per acre per year. An original application of 3 tons of lime per acre, and 180 pounds of 20-percent superphosphate on the preceding oats crop increased the meadow yield to 1.4 tons per acre per year. The further addition of 8 tons of barnyard manure on the corn crop 2 years prior to the time the meadow yields were secured increased the yield to 1.5 tons per acre.

TABLE 28.—*Yields of meadow crops on Shelby surface soil and subsoil for the 11-year period 1931–41*

Year	Shelby surface soil (8 inches deep)						Shelby subsoil			
	Mixed clover and timothy yield per acre				Alfalfa yield per acre	Oats-lespedeza yield per acre	Mixed clover and timothy yield per acre			Oats-lespedeza yield per acre
	Check [1] Series 1	Plot 1 [2] Series 2	Plot 3 [3] Series 3	Plot 2 [4] Series 3	Field [5] L	Watershed [6] I-58	Plot 2 [7] Series 2	Plot 4 [8] Series 2	Plot 3 [9] Series 2	Plot 8 [10] Series 2
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
1931	2.68									
1932	1.63	−0.95	+0.03	+0.06			−0.96	−0.20	−0.16	
1933	1.61	+.15			+1.37		−.87		−.45	
1934	.34				+.81					
1935	1.38		+.18	−.04	+.57			−1.02		
1936	1.72	−.51			−.72		−1.06		−.64	−0.28
1937	.57	+.56			+.59		−.51		−.21	+1.23
1938	1.48		−.45	−.40	−.10	+.29		−.91		+1.35
1939	1.10				+.53	+.63				−.15
1940	.99	−.61			+1.17	+1.21	−.83		−.30	+.95
1941	.56	+.38	+.65	+1.17	+1.39	+1.53	−.36	−.03	−.18	+1.03
Average yield difference 1st-year meadow	0.00	−.69	+.10	+.20	+.62	+.02	−.95	−.54	−.37	+.69
Average yield difference 2d-year meadow		+.36					−.58		−.28	

[1] Plots 3, 4, or 5, rotation of corn-wheat-meadow, no soil treatment.
[2] Rotation of corn-oats-meadow-meadow, no soil treatment.
[3] Rotation of corn-oats-meadow, 3 tons per acre lime and 180 lb. per acre 0-20-0 on oats.
[4] Rotation of corn-oats-meadow, 3 tons per acre lime and 180 lb. per acre 0-20-0 on oats, 8 tons manure on corn.
[5] 3 tons per acre lime and 200 lb. per acre 0-20-0 on small grains before alfalfa was seeded.
[6] Oats-lespedeza annually, soil limed 3 tons per acre and 125 lb. per acre 0-20-0 on oats.
[7] Rotation corn-oats-meadow-meadow, no soil treatments.
[8] Rotation corn-oats-meadow, 3 tons per acre lime and 188 lb. per acre of 4-12-4 on oats.
[9] Rotation corn-oats-meadow-meadow, 3 tons per acre lime and 250 lb. per acre 4-12-4 on oats.
[10] Oats-lespedeza annually, 125 lb. per acre 0-20-0 on oats, 8 tons per acre manure on 3 years of continuous corn prior to oats-lespedeza.

First-year clover and timothy on subsoil without treatment yielded an average of 0.3 ton per acre per year. On limed subsoil plots with 188 pounds of 4–12–4 fertilizer per acre, the yield was 0.7 ton per acre, and with 250 pounds per acre of fertilizer, 0.9 ton per acre. Very little clover was harvested from the untreated subsoil plot. In the main, the growth has consisted of timothy and weeds. The quality of meadow and its nutrient value has undoubtedly been increased along with the total yield.

First-year meadow yields on surface soil, without soil treatment, and with oats as a nurse crop, appeared to be depressed due to the weakness of spring clover and timothy seedings, and their inability to produce an early growth of sufficient vigor to withstand competition with the oats crop for moisture and plant nutrients in May and June. Timothy seeded with oats and clover in the spring frequently required reseeding and thus did not develop to affect the yield until the second year, when the meadow yields were more than double those secured during the first year. A parallel result was common to first- and second-year meadow yields on subsoil, although the differences in yield were proportionately less. When the subsoil received soil treatment, the first-year meadow yields were more than doubled, and were nearly equal to those of untreated second-year meadow.

The yield of first-year meadow following wheat on surface soil without soil treatment was more than double that following oats as a nurse crop, and almost equal to the yield where oats were used as a nurse crop with a soil treatment. Wheat has a more open canopy than oats and does not appear to smother out meadow seedings, nor to offer competition for moisture and plant nutrients during May and June to the extent observed with oats. Also, the timothy growth is materially increased, due to establishment during the previous fall with the wheat.

Alfalfa grown on field L, adjacent to plot series 1, is used in comparing the crop with clover and timothy meadow. Alfalfa grown on plot 7 of series 1 has yielded 3.45 tons per acre per year. This large yield is not typical of field conditions due to the unrestricted feeding zone of the alfalfa roots, which extend beyond the limits of the narrow plot boundaries. The yield of 1.9 tons per acre per year on field L is therefore considered a more representative evaluation of alfalfa yields. During the 9-year period, alfalfa has been cut twice yearly except in 1939–40, when three cuttings were made. Late fall growths have not been cut and the plants are permitted to go into the winter months with appreciable growth remaining on the field.

The largest yield of forage on both surface and subsoil has been secured from an annual rotation of oats-Korean lespedeza. Oats are drilled each spring with 125 pounds of 20 percent superphosphate per acre, and harvested in June. A crop of lespedeza hay has been secured later in the season. Yield figures include the total weight of oats (grain and straw) and lespedeza hay per acre.

The yield of oats-lespedeza on subsoil has been 2.0 tons per acre. The fertility of the subsoil plot was undoubtedly high, as the plot had received 8 tons per acre of barnyard manure annually with 3 continuous corn crops prior to the oats-lespedeza cropping. The yields of oats and of lespedeza from this plot has averaged approximately 1 ton per acre or a total of 2 tons. The yield on the surface soil area was only 10 percent greater than that from the subsoil plot. No lespedeza yield was secured from the initial seeding in 1938, which lowered the average yield for the period. The relatively large yields of oats-lespedeza in comparison with other meadow crops appear to be due to the ability of the double cropping system to permit good utilization of rainfall regardless of its distribution. When above-normal rainfall occurred in the spring the yield of oats was large. Lespedeza practically ceased to grow during dry periods, but usually was not damaged, and made quick responses to rainfall when it occurred.

All meadow yield data from both the surface and subsoil plots are shown on the adjusted 11-year basis in figure 22.

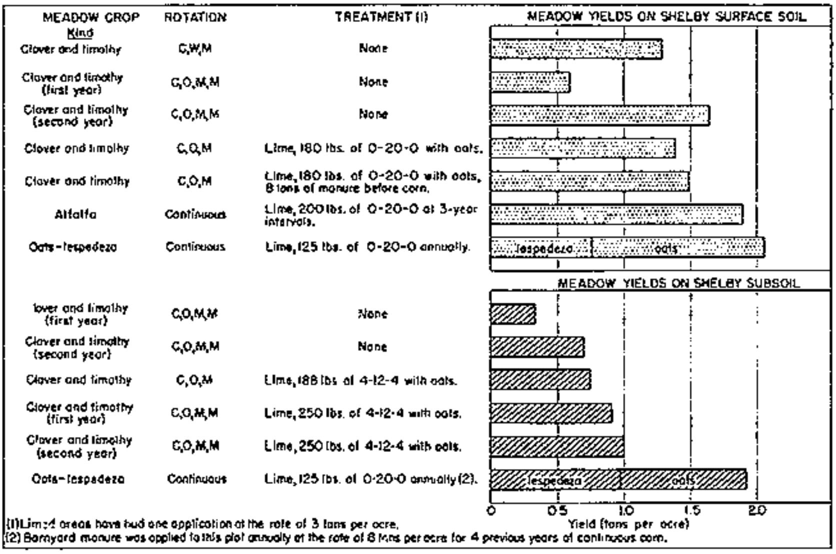


FIGURE 22.—Comparison of meadow yields on surface and subsoil with different treatments, nurse crops, and age of meadow.

TOPOGRAPHY

The slope of productive lands is usually the deciding factor in determining the agricultural uses to which they are adapted. For a specific land use it is necessary to add increasingly effective supporting practices with increases in either the length or steepness of a slope, to attain equally effective protection of the soil on all parts of the slope.

The results of a study of degree and length of slope data, from experiments at Bethany and other locations, have been previously published (*35*) Special studies with a rain simulator were made, as an aid to developing an empirical equation for soil loss. The empirical equation, which seemed best to describe soil loss at this location, was:

$$A=CS^{7/5}L^{3/5}$$

where A=average soil loss from a unit land area in tons per acre; C=a constant of variation; S=land slope in percent; and L=the horizontal length of the land slope in feet.

This derived empirical equation for soil loss was later used for extending plot data to a field basis (*25*). Used in the form

$$L=\left(\frac{A}{C}\right)^{\frac{5}{3}} S^{-\frac{7}{3}}$$

it was possible to evaluate the length of a given slope on which a specific rotation could be grown without exceeding a given maximum allowable average soil loss.

Length of slope.—Studies of the effect of length of slope were conducted on plots 1 and 2 of series 1. The results by months and years for the 10-year period 1931–40 are given in appendix tables. Both plots were in corn annually. Soil and water losses by years from these plots of 145.2 and 72.6 feet are given in table 29.

An average of yearly water loss ratios, long plot to short plot, shows that the longer plot lost 0.97 percent as much rainfall as the short plot. Assuming the short plot to be identical to the upper half of the long plot, the water loss from the lower half of the long plot was 6 percent less than that from the upperhalf of the plot.

The variation in amount of runoff with length of slope appears to bear a relationship to the total amount of runoff during a given period. The surface inches of runoff from the long plot for the 10-year period 1931–40 was 8.4 percent less than that from the short plot where the monthly total runoff was from 0.1 to 3 inches, and when the monthly total runoff exceeded 3 inches that from the long plot was 7.0 percent greater. During prolonged periods of precipitation, these increased lengths appear to reach saturation, or a minimum infiltration capacity, sooner than the shorter portions of the slope above. A reversal in the amounts of runoff coming from different portions of the slope may then occur.

TABLE 29.—*Surface runoff and soil losses from plots of 72.6- and 145.2-foot length* [1]

Plot and year	Rainfall	Surface runoff		Soil loss in runoff per acre	Ratio of long plot to short plot		Ratio of soil loss in runoff from top of slope to loss from bottom of slope
		Amount	Percent of rainfall		Surface runoff	Soil loss per acre	
	Inches	*Inches*	*Percent*	*Tons*			
Series 1, plot 2, 72.6 feet long:							
1931	42.22	13.20	31.3	84.22			
1932	28.79	5.85	20.3	48.93			
1933	32.43	10.09	31.1	49.75			
1934	32.51	11.43	35.2	85.87			
1935	37.99	10.96	28.8	75.12			
1936	24.43	7.86	32.2	18.94			
1937	21.80	4.69	21.5	8.35			
1938	26.65	4.71	17.7	27.69			
1939	27.50	8.75	31.8	88.50			
1940	28.32	4.49	15.9	21.89			
Average	30.26	8.20	27.1	50.93			
Series 1, plot 1, 145.2 feet long:							
1931	42.22	13.30	31.5	105.67	1.01	1.25	1.50
1932	28.79	5.04	17.5	52.68	.86	1.08	1.16
1933	32.43	9.42	29.0	65.18	.93	1.31	1.62
1934	32.51	10.40	32.0	97.76	.91	1.14	1.28
1935	37.90	13.12	34.5	106.10	1.20	1.41	1.82
1936	24.43	7.55	30.9	21.32	.96	1.13	1.26
1937	21.80	4.67	21.4	15.77	1.00	1.89	2.78
1938	26.65	4.64	17.4	42.00	.99	1.52	2.04
1939	27.50	8.34	30.3	122.04	.95	1.38	1.76
1940	28.32	3.85	13.6	27.65	.86	1.26	1.52
Average	30.26	8.03	26.5	65.62	0.97	1.34	1.67

[1] Each plot: 6 feet wide, 8-percent slope, continuous corn, Shelby loam.

The average annual soil loss from the 72.6-foot plot for the 10-year period was 50.9 tons per acre, in comparison with 65.6 from the long plot. Assuming the soil loss on the upper half of the long plot was equal to the loss from the 72.6-foot plot, the average relative amount of soil lost from the lower half of the long plot has been 1.67 times greater than from its upper half. This ratio as determined from individual years' data has ranged from 1.16 to 2.78 as shown in table 29.

Other studies of the effect of length of slope on soil and water losses from continuous corn plots were also carried out during the 6-year period 1934–39. These plots were 90, 180, and 270 feet long, the 90- and 180-foot plots being duplicated. Results by calendar months and years are given in appendix, table 61. A brief annual summary of averages of the duplicated plots is given in table 30. Water losses from this experiment have been inconsistent with the trend indicated by the study on the 145.2- and 72.6-foot plots. While runoff has been less from the 180-foot plots than from the 90-foot plots, that from the 270-foot plot has been the greatest.

TABLE 30.—*Surface runoff and soil losses from plots of 90-, 180-, and 270-foot lengths*

Plot designation	Year	Rainfall	Surface runoff		Soil loss in runoff per acre	Ratio of long plot to short plot		Calculated ratio of soil loss in runoff from different sections of the slope	
			Amount	Percentage of rainfall		Surface runoff	Soil loss per acre	Section	Soil loss ratio
		Inches	*Inches*	*Percent*	*Tons*				
Series 15, plots 1 and 5, 90 feet long, 28 feet wide, 10-percent slope, continuous corn, Shelby loam	1934	31.65	5.30	16.7	9.85	1.00	1.00	Upper 90 feet	1.00
	1935	37.32	7.04	21.3	37.74	1.00	1.00	do	1.00
	1936	24.11	1.70	7.1	5.12	1.00	1.00	do	1.00
	1937	21.84	3.59	16.4	3.92	1.00	1.00	do	1.00
	1938	27.23	2.66	9.8	17.29	1.00	1.00	do	1.00
	1939	27.27	4.93	18.1	42.40	1.00	1.00	do	1.00
Average		28.24	4.35	15.4	19.39	1.00	1.00		1.00
Series 15, plots 2 and 4, 180 feet long, 28 feet wide, 10-percent slope, continuous corn, Shelby loam	1934	31.65	5.30	16.7	16.38	1.00	1.66	Center 90 feet	2.32
	1935	37.32	9.03	24.2	61.96	1.14	2.44	do	3.88
	1936	24.11	1.43	5.9	8.24	.84	1.61	do	2.22
	1937	21.84	3.20	15.1	8.15	.92	2.08	do	3.16
	1938	27.23	2.40	8.8	20.40	.90	1.70	do	2.40
	1939	27.27	4.80	17.6	62.78	.97	2.19	do	3.38
Average		28.24	4.38	15.5	41.15	.96	1.94		2.89
Series 15, plot 3, 270 feet long, 28 feet wide, 10-percent slope, continuous corn, Shelby loam	1934	31.65	7.42	23.4	25.56	1.40	2.59	Lower 90 feet	4.45
	1935	37.32	8.69	23.3	107.33	1.09	2.84	do	3.63
	1936	24.11	1.76	7.3	12.26	1.04	2.40	do	4.01
	1937	21.84	3.60	16.5	11.34	1.00	2.89	do	4.51
	1938	27.23	2.39	8.8	34.77	.90	2.01	do	2.63
	1939	27.27	5.72	21.0	143.29	1.16	3.38	do	5.76
Average		28.24	4.93	17.5	55.76	1.10	2.69		4.17

Measurements of soil loss in runoff from the plots given in table 30 show marked increases with slope length.

Relative amounts of soil loss from 90-foot sections of the plots are shown for each year and as an average for the period. The average progressive increase for 90-foot sections, assuming the upper 90-foot sections of the plots to be unity, is 2.89 and 4.17 for the second and third 90-foot sections, respectively. This rate of increase in soil loss with increased length is greater than the rate of increase experienced on the 72.6- and 145.2-foot plots of series 1.

Elevation surveys of the plot surface, consisting of 12 readings across a plot taken at 10-foot slope distances, have been made yearly on this group.

Elevation readings for 1934 and adjusted elevation readings for 1939 are recorded in table 31. The 1939 readings were adjusted by a constant height vertically to a point where the average elevation difference between the two sets of readings represented the measured soil loss at the end of each plot. Plot profiles thus secured are plotted in figure 23. The depth of soil removed on the 270-foot plot increased to a distance approximately 200 feet from the top of the plot. Correlation of the depth of soil loss with lengths up to 200 feet, from this plot, yielded a coefficient of 0.945 (1 percent point is 0.549). The regression equation of the relationship is

$$y=0.016x^{.57}$$

where y equals depth of soil loss in feet, and x equals slope distance from the top of the plot in feet.

TABLE 31.—*Surface elevation readings for 90-, 180-, and 270-foot plots for the years 1934 and 1939*

Distance from top of plot (feet)	Plot 1 elevation readings			Plot 2 elevation readings			Plot 3 elevation readings			Plot 4 elevation readings			Plot 5 elevation readings		
	1934	1939	Difference	1934	1939	Difference	1934	1939	Difference	1934	1939	Difference	1934	1939	Difference
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
5	100.42	100.44	+0.02	100.14	100.20	+0.06	99.84	99.81	−0.03	91.21	91.22	+0.01	82.56	82.41	−0.15
15	99.52	99.36	−.16	99.30	99.23	−.07	99.08	98.99	−.09	90.41	90.29	−.12	81.49	81.27	−.22
25	98.55	98.38	−.17	98.44	98.30	−.14	98.30	98.16	−.14	89.53	89.42	−.11	80.28	80.17	−.11
35	97.49	97.36	−.13	97.44	97.32	−.12	97.36	97.23	−.13	88.66	88.54	−.12	79.21	79.05	−.16
45	96.43	96.28	−.15	96.48	96.29	−.19	96.41	96.26	−.15	87.80	87.66	−.14	78.12	77.94	−.18
55	95.39	95.20	−.19	95.42	95.29	−.13	95.43	95.30	−.13	86.92	86.76	−.16	77.08	76.90	−.18
65	94.36	94.16	−.20	94.34	94.14	−.20	94.44	94.28	−.16	86.02	85.88	−.14	75.92	75.84	−.08
75	93.37	93.39	+.02	93.34	93.11	−.23	93.43	93.27	−.16	85.13	84.88	−.25	74.76	75.00	+.24
85	92.56	92.82	+.26	92.24	92.07	−.17	92.42	92.20	−.22	84.13	83.96	−.17	73.90	74.19	+.29
95				91.15	90.94	−.21	91.49	91.21	−.28	83.15	82.90	−.25			
105				90.07	89.90	−.17	90.44	90.25	−.19	82.10	81.92	−.35			
115				89.03	88.79	−.24	89.49	89.24	−.25	81.09	80.83	−.26			
125				87.98	87.74	−.24	88.45	88.22	−.23	79.99	79.77	−.22			
135				86.88	86.66	−.22	87.43	87.22	−.21	78.88	78.64	−.21			
145				85.79	85.57	−.22	86.47	86.25	−.22	77.80	77.56	−.24			
155				84.70	84.59	−.11	85.49	85.26	−.23	76.71	76.54	−.17			
165				83.67	83.71	+.04	84.47	84.20	−.27	75.60	75.66	+.06			
175				82.73	82.92	+.19	83.45	83.06	−.39	74.63	74.97	+.34			
185							82.38	82.01	−.37						
195							81.33	81.00	−.33						
205							80.23	79.99	−.24						
215							79.18	78.91	−.27						
225							78.02	77.83	−.19						
235							77.07	76.80	−.27						
245							76.01	75.86	−.15						
255							74.89	75.10	+.21						
265							74.10	74.38	+.28						

Additional investigations with a rainfall simulator on prepared fallow plots were made in 1939. These previously reported investigations (*38*) gave essentially the same results as were attained from the larger field plots. Over-all figures for the study of lengths of 8 and 16 feet on an 8-percent slope showed the soil-depth losses to be proportional to the 0.6 power of the horizontal length of slope.

Degree of slope.—Studies of the effects of degree of slope on soil and water loss have not been made under field conditions at this location, due to the variations in depth of surface soil and slope direction which are characteristic of the Shelby topography. Laboratory studies have been made, however.

The first experiment was carried out in 1934. The equipment used was a galvanized metal trough, 1.6 inches wide, 36 inches long, and 2 inches deep, which was filled with sand to a uniform depth of 1 inch. The slope of the trough was adjustable to any desired degree, and water applied at the upper end. Measurements of the rate of runoff and of

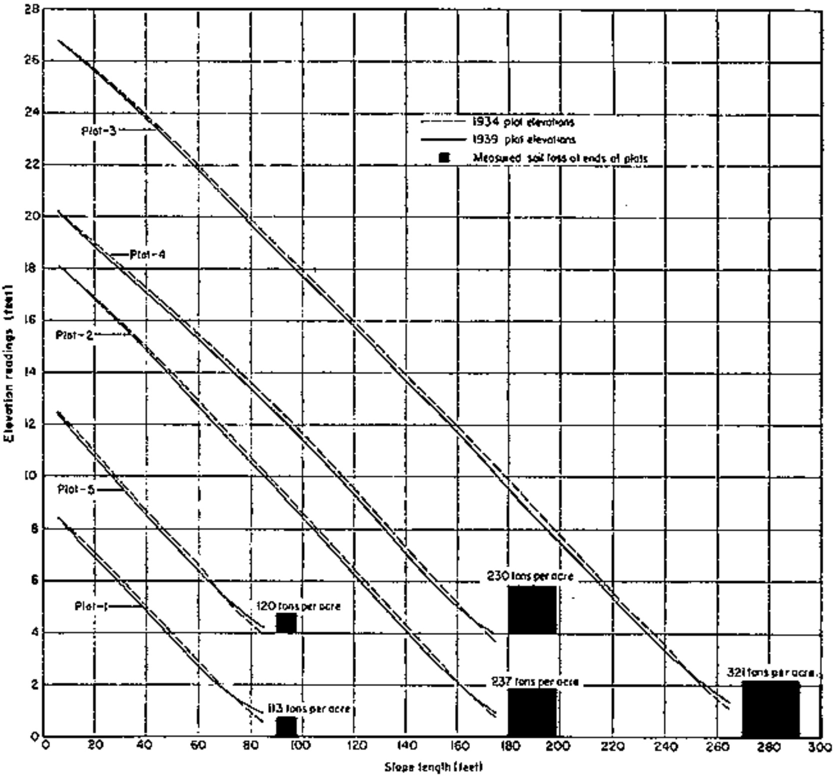


FIGURE 23.—Change in surface profile of length of slope plots, series 15, after 6 years of cropping to continuous corn. The build-up at the lower end of all plots is soil deposition caused by concentration dikes and cultural operations.

the sand transported by runoff were made at the lower edge of the trough. Sand loss was measured for three rates of runoff for slopes of 2, 4, 8, and 12 percent, and for four graduations of sand ranging from very fine to coarse. Losses of sand were found to increase exponentially with the degree of slope and with the rate of runoff.

Another degree of slope experiment was made on a group of prepared field plots, using a rain simulator, in the summer of 1939. Soil and water losses from duplicate plots on 4-, 8-, and 12-percent slopes, having a horizontal length of 8 feet and a width of 3.5 feet, were measured simultaneously. Rainfall was repeatedly applied at rates and amounts anticipated for a storm of 20-year occurrence-frequency. For conditions of the experiment, the amount of runoff was found to increase with the degree of slope. The amount was approximately 14 percent greater from the 12- than from the 4-percent slope. Soil loss was found to increase approximately as the 1.4 power of the degree of slope in percent. A complete report of the experiment has previously been published (35)

Shape of slope.—Uniform slope conditions, similar to those studied on plots, are not usually encountered on the Shelby topography. The characteristic of curvature of the soil surface, both with and across the slope, is common to all but relatively small land areas.

Field studies by Uhland (27), which are being carried out at this and other locations, are yielding data on the factor of slope shape. Physical surveys of the land surface and the depths of surface soil remaining on entire fields have been made. A study of these data indicate that the least surface soil usually remains on a hillside at a point just above where the slope starts to decrease. On cultivated lands the process is complicated by the direction of slope, row direction, vegetated waterways, and by gully formation.

Because slope effects are modified by almost innumerable factors, a simple average of data secured from 6 fields on the Shelby loam soil, near Bethany, Mo. ,and from 7 fields on the Marshall silt loam, near Shenandoah, Iowa, is given. In securing these data, the average depth of soil was ascertained by boring at regular intervals along contour lines in each field. The average horizontal distances between contours were calculated from the areas between contour lines. It was then possible to plot an average profile of each field, and corresponding surface soil depth. Data from groups of fields on each soil type were averaged to more nearly represent the topography and remaining surface soil of each soil type. These data are shown graphically in figure 24. The degree of slope of the fields on the Marshall soil was less than that of the Shelby for horizontal distances up to 185 feet from the ridge top. For distances greater than 185 feet, the degree of slope of the Marshall exceeded that of the Shelby. The slope of the Shelby soil decreased at a point approximately 250 feet from the ridge top, and was accompanied by an increase of surface soil remaining on the hillsides. Decreases in the slope of the Marshall occur at a distance greater than 350 feet, or beyond the scope of the physical data secured for the study.

A marked similarity in depth of surface soil remaining on both the Shelby and Marshall soil types is evidenced when these depths are compared with the total vertical distance from the ridge tops. This is shown in figure 24.

Lack of uniformity across the slope has been observed to be important in relation to the amount and location of surface soil remaining on a field. In general, when a land area is concave across the slope, it is also concave with the slope. A comparable condition exists for areas which are convex across the slope. Runoff will, therefore, tend to concentrate on concave slopes and to spread on convex slopes. The result is temporary deposition in the central and lower portions of the concave-shaped areas. This is often subsequently removed by gully formation. Convex slopes have been observed to erode more uniformly and are less subject to gully formation than concave land areas.

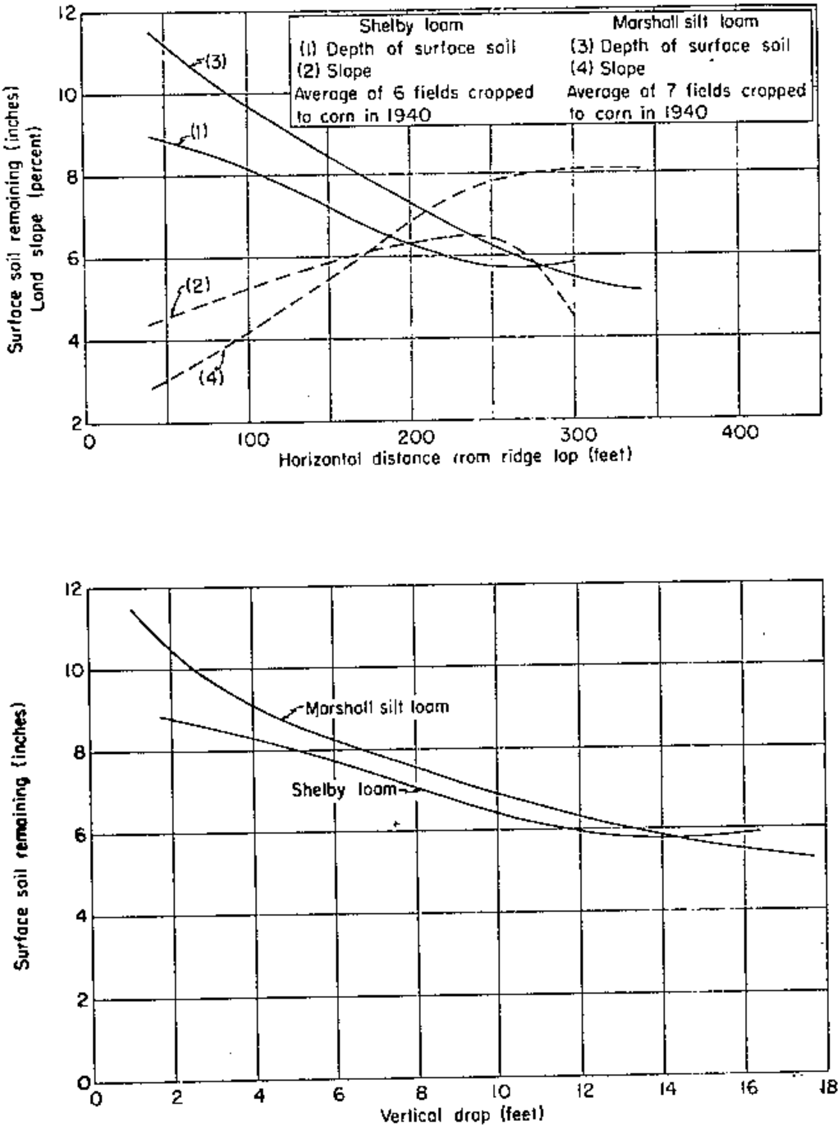


FIGURE 24.—Comparison of slope and surface soil depths on the Shelby loam soil near Bethany, Mo., with the Marshall silt loam soil near Shenandoah, Iowa.

TERRACING

The primary function of terraces is to divide a total slope length, over which runoff would normally flow in increasing volume, into relatively short segments, from which soil loss need not be excessive, during those critical periods when vegetal cover is absent, or affords little protection to the soil surface. Runoff is intercepted by an earth berm, and conducted by a channel of low gradient to a natural or artificial drainage way, where it may be disposed of in an orderly fashion, without damage to cropped land.

Terracing was a comparatively new practice in the region in 1930. Studies were, therefore, designed to determine terrace specifications, their proper use, and their effectiveness, in relation to climate, soils, and the type of agriculture common to the region. Detailed data of results are recorded in appendix tables 62–75.

Publications covering results of terrace studies prior to 1937 have previously been made by Holman (*12*) and by Smith (*24*).[5]

Construction.—During the years 1930 and 1931, 9.15 miles of terraces were constructed at the station. This total mileage comprised 68 individual terraces, with an average length of 700 feet. They were placed on land slopes varying for individual terraces from 4 to 14 percent. The mantle of topsoil varied from 0 to 14 inches, and approximately 80 percent of the terraces crossed gullied areas. The average height of the terraces constructed was 1.2 feet, and the average width of the berm was 19 feet.

The construction equipment, consisting of a small blade and tractor, was in general inadequate for building the terraces, with the exception of those placed on relatively flat upper-slope reaches. Difficulties arose from side slippage, lack of traction, and insufficient power to make uniform cuts on curves or in hard subsoil areas. This resulted in a relatively high construction cost amounting to an average of $13 per acre.

The cost of terracing a 13-percent slope was 2.6 times that of a 7-percent slope. The cost of terracing the upper half of a slope was only one-third of the cost of terracing the lower half, where both portions of the slope had approximately the same grade. The additional cost for the lower half was due largely to the shallow depths of topsoil remaining. The topsoil ranged from 6 to 12 inches in depth on the upper half of the slope, and from 0 to 6 inches on the lower portion of the slope. Making fills where the terrace crossed gullied areas was a very important item in the cost. As an average of all terraces, the cost of making fills constituted 51 percent of the total. This ranged from 0 to a maximum of 63 percent.

Since 1938, emphasis has been placed on developing simple and economical methods of terrace construction. From an economic point of view, the greatest benefit per dollar spent in terracing a slope comes from terracing the upper reaches. Not only is the cost per unit length of terrace less, but since soil loss accelerates with the length of the slope, the benefit to the entire slope length is greatest per unit length of terrace constructed.

It is believed simple methods of terracing upper slope reaches with equipment which a farmer already possesses, or which is readily available to him, would result in wider adoption of terracing programs.

The construction of two terraces on the upper slope reaches of field Q was started in 1938. The slope at this point was from 3 to 5 percent. The method of construction consisted of making two rounds with a small-blade terracer to mark the terrace ridge line, followed by plowing alone. After the first backfurrowing, the field was planted on the contour to corn. The corn was removed in the fall of 1938 and the ridge location again backfurrowed. In 1939 the terrace ridges were

[5] SMITH, D. C. FOUR-YEAR SUMMARY OF ENGINEERING EXPERIMENTS AT THE BETHANY SOIL CONSERVATION EXPERIMENT STATION. Presented at the Amer. Soc. Agron. Corn Belt meeting, Urbana, Ill. June 1936.

backfurrowed before drilling soybeans and in the fall before drilling wheat. These four backfurrowings resulted in a terrace of adequate dimensions. Two of these plowings were a part of the cultural operations. The cost directly chargeable to terrace construction was, therefore, two rounds with a tractor and blade, and two backfurrowings with a plow. The terrace ridges and channels are shown in figure 25.

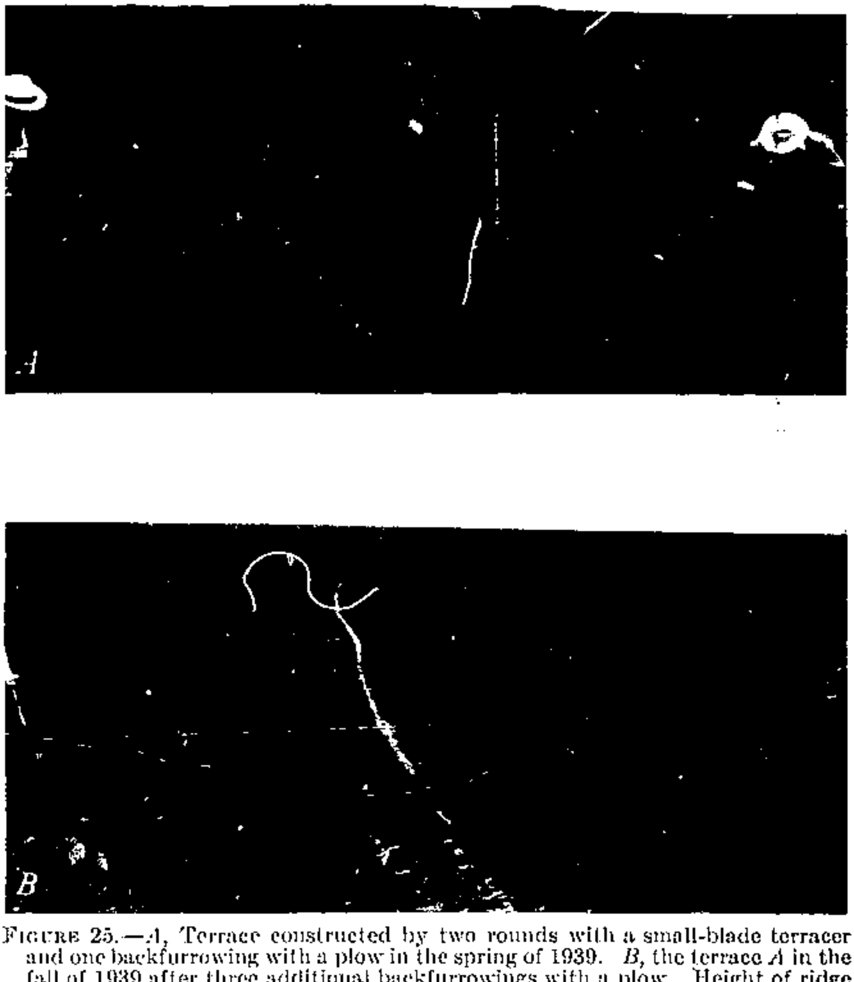


FIGURE 25.—*A*, Terrace constructed by two rounds with a small-blade terracer and one backfurrowing with a plow in the spring of 1939. *B*, the terrace *A* in the fall of 1939 after three additional backfurrowings with a plow. Height of ridge is 14 inches.

Several farmers in the county have adopted this method of construction by plowing. When the soil is moist and the tractor wheels afford compaction, it was sometimes possible to plow repeatedly until a terrace was completed.

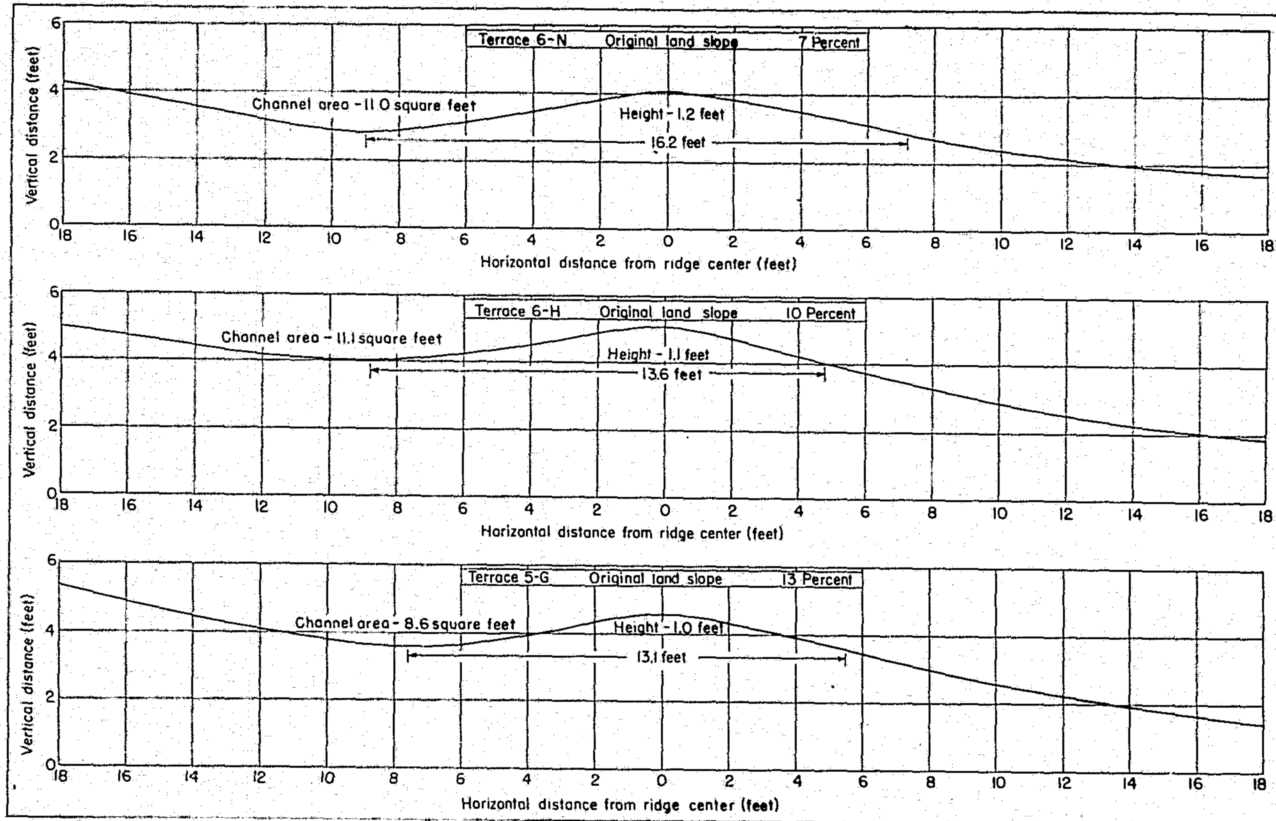


FIGURE 26.—Size and shape of terraces on 7-, 10-, and 13-percent slopes after 10 years of farming.

Size and shape.—The size and shape of terraces has been studied by cross-sectional leveling of the ridges and channels, at regular intervals along the length of the terraces.

Representative cross-section of terraces on 7-, 10-, and 13-percent slopes in 1940, or 10 years after construction, are shown in figure 26. The average height of the terraces is 1.2, 1.1, and 1.0 feet respectively, on these slopes. The distances from ridge to channel centers range from 9 to 7 feet, and the channel cross-sectional areas vary from 11.1 to 8.6 square feet. The horizontal width of the ridges, from the center of a terrace channel to a point of equal elevation on the down-slope side of the berm, varies from 16.2 to 13.1 feet. All dimensions of terraces on the various slopes have tended to retain the same proportion, but to decrease slightly with slope increases.

Abrupt slope changes, common to newly constructed terraces, have disappeared with a decade of farming operations, and the slope between terraces is almost uniform. The slopes on either side of the

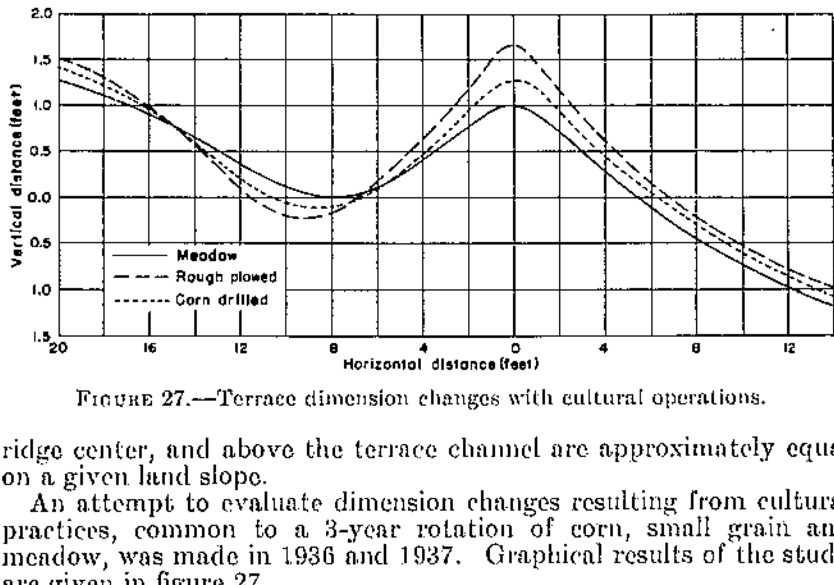


FIGURE 27.—Terrace dimension changes with cultural operations.

ridge center, and above the terrace channel are approximately equal on a given land slope.

An attempt to evaluate dimension changes resulting from cultural practices, common to a 3-year rotation of corn, small grain and meadow, was made in 1936 and 1937. Graphical results of the study are given in figure 27.

The average cross section of the terraces, while in meadow during 1936, is plotted in the figure. The terraces had an average height of 1.0 foot while in the meadow crop. The elevation of the channel bottom represents a datum from which elevation changes may be readily measured.

The terraces were plowed with a two-way plow in the fall of 1936. Cross sections secured after the plowing operation show a ridge height increase of 0.9 foot, owing to backfurrowing on the terrace ridge and leaving the dead furrow in the terrace channel. The procedure of plowing also increased the volume of the furrowslice by approximately 33 percent and resulted in a general elevation change of 0.2 foot.

The rough plowed ground was disked, harrowed, and drilled to corn in the spring of 1937. Cross sections taken after the corn was drilled are also shown on the chart. The ridge height has been reduced from 1.9 feet to 1.4 feet, by preparing a seedbed and drilling corn. It is also apparent that approximately one-half of the soil volume increase due to plowing has been eliminated over the winter and by the seedbed preparation.

Cultivation of the corn crop, soil loss to the channel during the remainder of 1937, and disking and drilling oats in the spring of 1938 resulted in terrace dimensions almost identical to those accompanying the previous meadow crop in 1936.

The study of size and shape of terraces during different periods in the cropping affords a measure of cyclic changes in a vertical plane. The location of the terrace ridge was assumed to remain in the same horizontal location on the slope.

Soil movement on terraced slopes.—Permanent bench marks were established on the upper and lower reaches of three terraced fields in 1932. Their purpose was to establish a line for studying soil movement on the terraced slopes. Precise leveling, at 1-foot slope distances, between the permanent bench marks afforded a basis for evaluation of such soil movement. A previous publication (*37*) deals with this subject in detail.

Soil loss, as measured at the end of the terrace channels, was found to represent only a fraction of the total soil moved to the channels. Soil moved from the interterrace area was found to accumulate on the front slope of the terrace ridge. This caused the channel and ridge location to move up the slope.

Soil moves to the terrace channel from the terrace front slope and from the interterrace area. The movement from the terrace front slope must logically be a very small portion of the total movement to the channel because of the extreme shortness of this slope. One-way plowing, in which the furrow slice is always moved up hill, has only partially compensated for the down-slope movement by runoff and tillage implements on the interterraced area, while it has greatly exceeded similar movement from the relatively short front slope of the terrace berm. Since plowing moves almost equal amounts of soil to the slopes on either side of the channel, the resulting over-all balance logically results in an accumulation on the terrace front slope. While accumulations on the terrace front slope have tended to move the ridge location slightly up the slope, the terraces have not decreased in size or required maintenance for a period of several years.

This unequal distribution of the soil mantle has its effect on crop yields. A station publication (*39*) deals with the distribution of corn yields on terraces in relation to the variation in surface soil depth throughout the terrace interval. Figure 28 shows this relationship in 1940.

An excerpt from this publication (*39* p. 126) is as follows:

In general the yield of corn increased from an average figure on the ridge top to a maximum at a point just off the terrace back slope, or approximately 15 feet down the slope from the ridge center. This area contained point rows, but increase or decrease in yield due to the point rows was not discernible. The yield declines progressively from this point down the slope to the center of the terrace channel. The yield increased from the channel to a point approximately one-half the distance to the ridge top on the front slope of the terrace berm. It again showed a decline on surface soil depths greater than 1 foot on the remainder of the front slope of the terrace.

The yield of corn increased with depth of surface soil, regardless of its location on the terrace, to surface soil depths up to 1 foot. Soil depths above this figure occur on the terrace ridge, and a slight decline in yield was secured for these extra depths of filled in surface soil. Observations during the last few years indicate that a portion of the soil in the terrace ridge, lying above the level of the channel, has received little moisture by infiltration from the surface of the ridge, or by lateral movement from the terrace channel. In securing soil depths on the terrace ridge, for this study, an extremely dry zone of soil was found. It is evident that the moisture content of terrace ridges merits further attention.

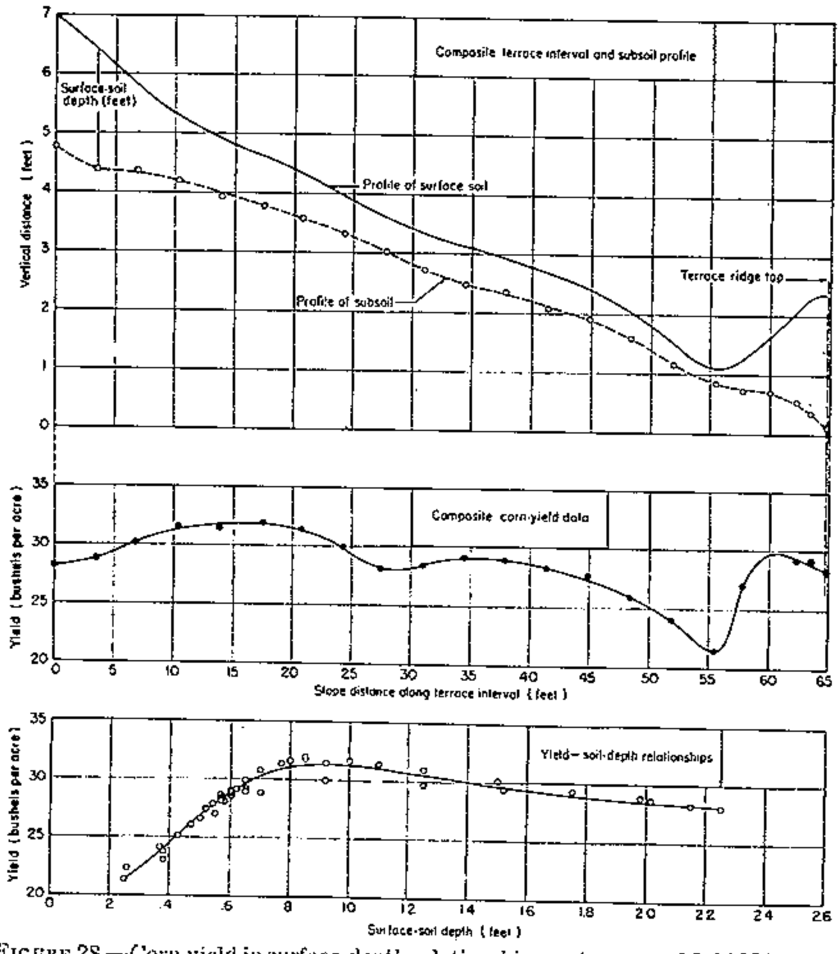


FIGURE 28.—Corn yield in surface-depth relationships on terraces of field N in 1940.

Maintenance and farming.—Maintenance requirements of the 9.15 miles of terraces originally constructed on the station have been very small. During the period 1933–37, a small amount of grading, plowing, and slip work was needed to maintain specific channel grades necessary to research measurements. No special maintenance has been required since 1937.

A two-way plow has been used in farming operations since 1933. When plowing terraced land, the furrow slice is turned up slope, and the dead furrow placed in the terrace channel. It has been found that this method of plowing will maintain terraces in a 3-year rotation of corn, oats, and meadow. Plowing of corn and wheat in a 4-year rotation of corn, oats, wheat, and meadow has also been found to give adequate maintenance.

All farming operations which involve manipulation of the soil body have been carried out on the contour. This includes seedbed preparation with disk and harrow; drilling of corn, small grain, and soybeans; and cultivation of corn. Point rows have been placed in the terrace channel, midway between terraces, and 10 to 15 feet below the ridge center of the terrace berm. When point rows were placed in the terrace channel, rows necessarily sloped to the steeper portion of the area between terraces. This resulted in a concentration of runoff which tended further to erode the steeper portions of the slope, and a tendency to gully formation in old field drainageways. The same condition occurred to a minor extent when point rows were placed midway between terraces. The procedure of starting contour operations on the front slope of the terrace berm, and continuing up slope to within approximately 10 feet of the terrace ridge center above, has been the most satisfactory. The operation is completed by working down slope from the upper terrace berm until overlapping occurs on the point rows. This procedure applied alike to disk, harrow, and drilling operations. When this method is used, runoff is led from the steeper to the flatter portions of the slope, where it proceeds by overland flow, with minimum velocity, to the terrace channel below.

Harvesting of hay and small grain has been accomplished without regard to the terrace direction. Grain binders, mowers, dump rakes, and bull rakes have been operated over terraces. On steep slopes it has been found to be preferable to cross terraces at an angle rather than at a right angle to their direction.

Studies of farm machinery have been confined to using and observing the operation of those types generally used in the soil area. In general, little difficulty has been encountered in using it on terraced land. More flexibility would be desirable for certain types of machinery in certain operations, particularly on steep land. This is particularly true of combines, grain binders, and pick-up hay bailers when operated over terraces. It would often be advantageous to tilt the platforms or pick-up attachments and also to raise or lower them with greater ease.

Larger types of equipment, such as two-row tractor cultivators, have been used satisfactorily on land slopes up to 8 percent. Single row cultivation equipment gave better performance on steeper slopes.

Rigid frame cultivators with difficult side movement of the gangs were not satisfactory. Those with pivot axles gave the desired maneuverability for following curved rows.

The two-way plow used on the station farm for plowing terraces is a trailer type with two sets of 14-inch gangs. The right- and left-hand gangs are mounted adjacently on a wide frame. Each lowers or raises independently from wheel lift mechanisms on either side of the plow. A problem of side draft is common to this type of plow due to its wide carriage.

In plowing with any trailer-type plow, on sharply curving areas, difficulty in securing a cut of even width is encountered. A device for easily shifting the drawbar position, while plowing, is needed.

The only direct tractor mounted equipment used has been a two-row corn planter. The planter is raised and lowered with a power lift.

Direct mounted equipment of this type appears to be a solution to many physical and economic problems encountered in farming terraced or contoured fields.

Terrace spacing.—The problem of terrace spacing has been studied on two slopes, one approximating 7 percent and the other 13 percent. Three terraces, symbol numbers 4–N, 5–N, and 6–N, 1,040 feet long and having vertical intervals of 3, 5, and 7 feet were placed on the moderate slope; and three terraces, symbol numbers 3–G, 4–G, and 5–G, 700 feet long and having vertical intervals of 5, 7, and 9 feet were placed on the steep slope. The channel grade of all terraces was uniform at 4 inches per 100 feet.

Measurements of soil and water losses were made for the 9-year period 1932–40. Data are complete for cropping to three rotation cycles of corn, oats, and meadow and are summarized in appendix, table 65.

Table 32 lists the major variables within the experiment and soil and water losses from each terrace. The terrace of 5-foot vertical interval on the moderate slope, and the terrace of 7-foot spacing on the steep slope, occupy the steepest portions of the hillsides on which they were placed. The surface soil depth on the moderate slope decreases with increased vertical interval, while on the steep slope the surface-soil depth increases with increases of vertical interval. The corn yields of the various terraces also follow surface soil depths very closely. It is evident that these and other variables, besides vertical spacing, are present within the experiment.

TABLE 32.—*Variable factors, and total soil losses and runoff from terrace spacing study, 1932–40*

Terrace number	Vertical spacing	Land slope		Surface soil depth [2]	Corn yield per acre [3]	Total rainfall	Surface runoff		Soil loss in runoff per acre	Density of runoff per acre-inch
		Before terracing	After terracing [1]				Total	Percentage of rainfall		
	Feet	*Percent*	*Percent*	*Percent*	*Bushels*	*Inches*	*Inches*	*Percent*	*Tons*	*Tons*
4N	3	6.3	0.8	97	49.2	255.54	21.97	8.6	4.386	0.200
5N	5	7.4	9.7	83	45.6	255.54	32.06	12.5	6.866	.214
6N	7	6.8	8.2	55	41.0	255.54	26.16	10.2	9.835	.376
3G	5	12.4	18.6	75	36.0	258.74	42.94	16.6	10.172	.237
4G	7	13.9	18.4	89	46.0	258.74	40.15	15.5	10.486	.261
5G	9	13.2	16.0	100	57.0	258.74	30.55	11.8	9.982	.327

[1] The land slopes after terracing were calculated, not measured.
[2] Surface soil depth is 9 inches.
[3] Average of corn yields in 1937 and 1940.

Total runoff for the 9-year period averaged 42 percent greater on the steep slope than on the moderate slope. Inexplicable variations were also found to exist between the individual terraces in each slope group.

The density of total runoff for the period, in tons per acre-inch, was found to increase only slightly with an increase in vertical interval from 3 to 5 feet on the moderate slope, and with an increase from 5 to 7 feet on the steep slope. The 7-foot vertical interval on the moderate slope resulted in a runoff density increase of 88 percent, while the 9-foot vertical interval on the steep slope group resulted in an increase of 42 percent. This fact may indicate that the widest intervals on each slope are excessive. The variation in runoff density is illustrated in figure 29. Increases in density were greatest when the terraces were

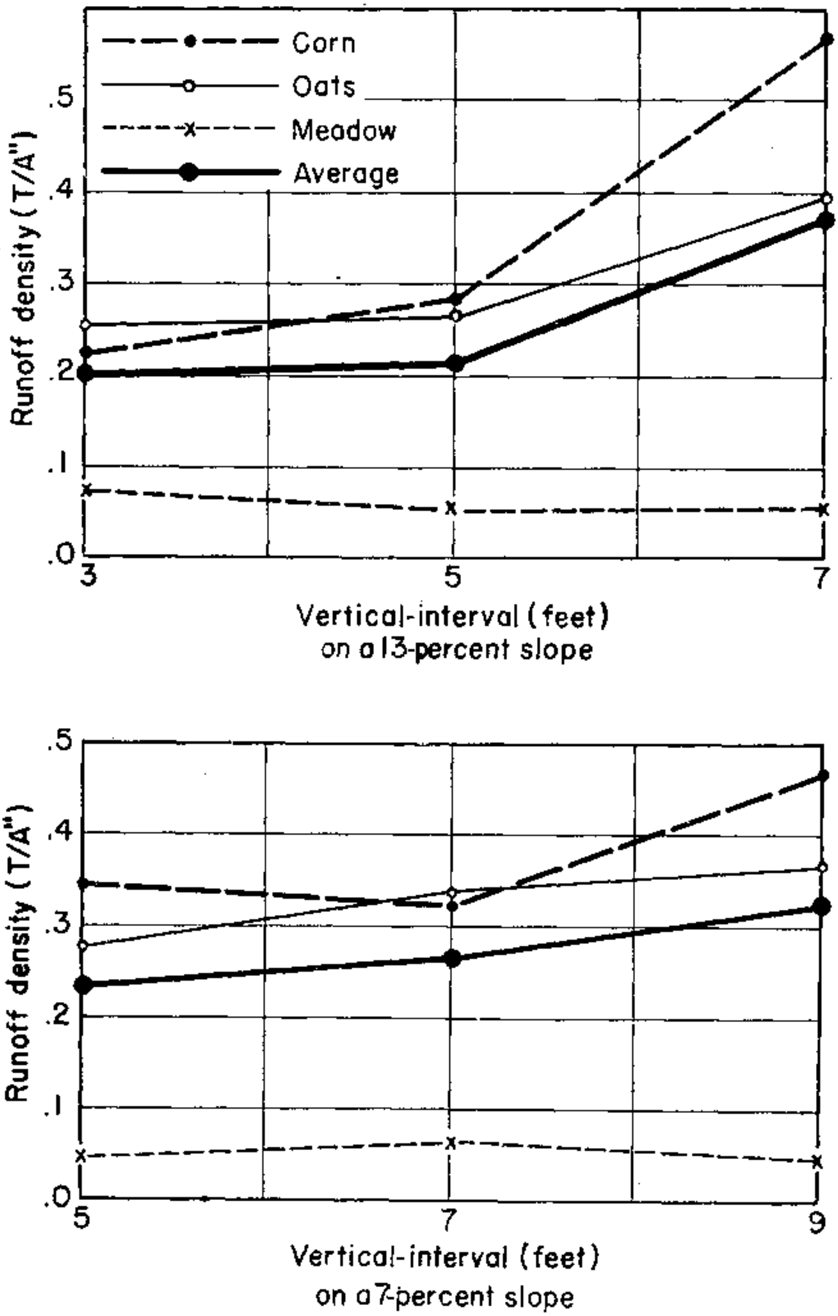


FIGURE 29—Variation in density of runoff from terraces with various vertical intervals on a 13-percent and a 7-percent slope by crops of the rotation and as an average for the 9-year period, 1932–40.

cropped to corn. Appreciable increases also occurred when they were cropped to oats. The density of runoff from all terraces was nearly constant for the meadow crop.

Observations of the vertical intervals on both the moderate and steep-slope groups indicate that the narrower spacings of less than 50 feet horizontally are undesirable, due to the fact that the slopes are greatly increased by the construction of the terraces. Application of the terrace with a 3-foot vertical interval on the moderate slope increased the average slope of the land by 56 percent. Likewise, application of the 5-foot vertical interval to the steep slope increased the land slope by 50 percent. Farming operations are made unnecessarily difficult by these extremely close spacings. The widest spacings studied have not required additional maintenance over the more closely spaced terraces on either slope group. Both fields, however, have a greater than average fertility level and support excellent vegetal growth.

It is believed that the range of spacings on both the moderate and steep slopes, are insufficient to show great differences in soil and water losses. As the horizontal length of the spacings is increased, the grade of the slope is decreased and vice versa. The soil loss from the intervals between the various terraces in each experiment may, therefore, approach a constant.

An approach has been made to the problem of terrace spacing, using soil-loss relationships derived from a study of degree and length of slope data from plots. This material is contained in a previous publication (*36*). The horizontal spacing which will produce a minimum rate of soil loss from the area between adjacent terraces was calculated from an equation for soil loss. The spacing was found to vary with terrace dimensions, and the land slope. A considerable difference in terrace spacing was also shown to produce only a small variation in the average soil loss per unit area between terraces.

Channel grade.—Terrace grade has been studied on six terraces placed on field C in 1930. The terraces were 1, 200 feet long and had grades of 0, 2, 4, 6, 8, and variable 1 to 4 inches per 100 feet. They were placed under measurement on Jan. 1, 1932 with the use of Parshall rate measuring flumes and Ramser silt samplers. Records of runoff and soil loss from the ends of each terrace were continued through three crop-rotation cycles of corn, small grain, and meadow for the 9-year period ended Dec. 31, 1940.

Detailed data pertaining to the specifications of the 6 terraces, and runoff and soil loss are summarized in appendix, table 66.

A publication (*38*) giving an interpretation of the data obtained from the experiment was released in 1942. A graphical summary of soil and water losses taken from this publication is shown in figure 30. A summary of the article is as follows:

> Total runoff and the number of runoff periods increased with terrace channel grade, up to grades of 8 inches per hundred feet, which was the upper limit of the grades under test.

Average maximum rates of runoff for 128 runoff periods increased with channel grade. The average maximum was 5 times greater on the 8-inch grade than on the level terrace.

All amounts of runoff, equal to or greater than selected intensities, as well as total runoff, increased with added increments of terrace grade.

The variable graded terrace was superior to a terrace of uniform grade. It had the capacity to retain a relatively large amount of rainfall, and also to discharge runoff at relatively high rates when hydraulic efficiency was most needed.

There was no significant difference in the total time of runoff from terraces of various grade for the 9-year period.

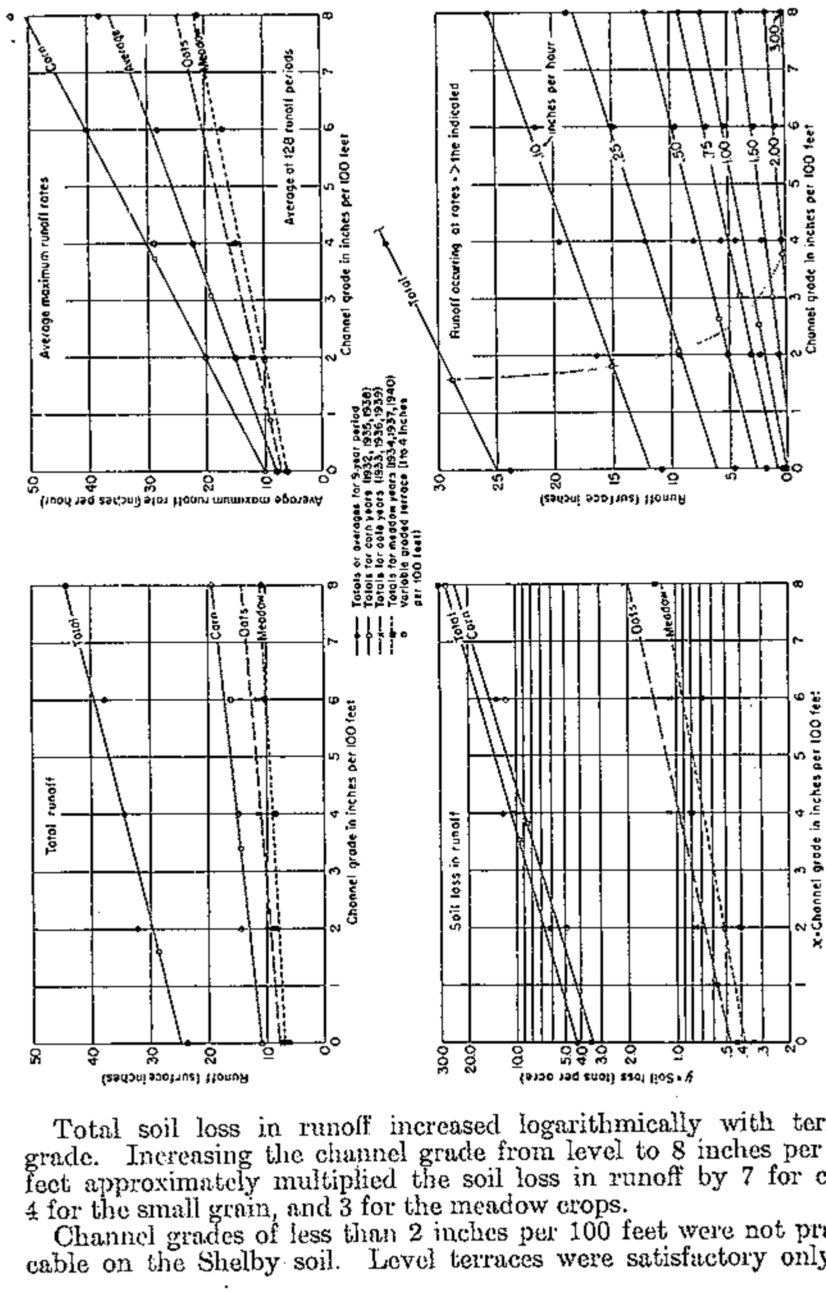


FIGURE 30.—Total runoff, average maximum rates of runoff, soil loss in runoff from terraces on field C, and amounts of runoff occurring at rates equal to or greater than the indicated.

Total soil loss in runoff increased logarithmically with terrace grade. Increasing the channel grade from level to 8 inches per 100 feet approximately multiplied the soil loss in runoff by 7 for corn, 4 for the small grain, and 3 for the meadow crops.

Channel grades of less than 2 inches per 100 feet were not practicable on the Shelby soil. Level terraces were satisfactory only on

Grundy silt loam ridge tops, where the direction and degree of slope were uniform, and the depth of surface soil exceeded 12 inches.

Channel grades up to 6 inches per 100 feet may be safely used on the Shelby soil.

Terrace length.—Two terraces were placed on field I to study terrace length. One was 1,375 and the other 2,450 feet in length. Measurements of soil and water losses were made for the 5-year period 1934–38.

During the period of measurement, both soil and water losses were greater from the longer terrace. It is, however, believed that other variables, in addition to length, account for part of the measured differences.

Considering records from all terraces of different length at the station, it is doubtful if significant change in total runoff can be attributed to terrace length. The longer terraces tend to have higher stages and more prolonged runoff. The soil loss in runoff is also higher due to increased flow velocities.

Terraces less than one-fourth mile long are thought to be more desirable than exceptionally long terraces or those approaching one-half mile in length. More ridge height and channel capacity are needed on the longer terraces.

Terrace overtopping.—Three level terraces were adjacently placed on field C to study the effects of terrace overtopping. The upper two had closed ends, and runoff had to pass over the ridges to the third terrace, located lower on the slope. The terrace occupying the lower slope position had an open end at which measuring equipment was placed. The total length of the 3 terraces was 1,315 feet. Records of soil loss and runoff were secured for the 6-year period, 1933–38.

The upper two terraces overtopped numerous times in the wet seasons of 1934 and 1935, but little damage occurred. Maintenance with a shovel, once yearly has been sufficient to fill in the small rills which occasionally formed from overflow.

Total soil loss from the terrace overtopping study was 10 percent greater, and total water loss was 26 percent less than that measured during the same period from level terrace 9–C of the terrace grade study on the same field.

Conclusions drawn from the study are that occasional overtopping of short terraces by storm runoff will cause only minor damage to a terrace system, if timely maintenance of breaks is made.

Terrace outlets.—Studies of the disposition of storm runoff from terrace systems and diversion dikes have been made at 21 locations on the station.

Three of the systems empty on permanent bluegrass pasture lands. This practice has been highly satisfactory. Grazing of the bluegrass is controlled, and livestock is thus prevented from forming pathways along which runoff will concentrate.

The remaining 18 outlets have been constructed at desired locations. They are also primarily dependent on vegetation for disposition of runoff through their channels.

Bluegrass appears to be the most effective and adaptable grass for outlet control at this location. Once established in an outlet, it has never been severely damaged by storm runoff. Quackgrass was placed in a terrace outlet on field G in 1935. It has remained intact on a 12-percent slope for a 6-year period. While frequently considered a noxious weed, it has spread but little and appears to be adapted to outlet protection in this area.

Six outlets have been completely sodded. Sod has been cut, hauled to the outlet site, and placed at the rate of 1.75 square yards per man-hour. This has been the most satisfactory method of establishing grassed outlets after terraces have been constructed, or where runoff cannot be temporarily diverted from the outlet site.

One outlet on field D–2 was developed while the terraces were in meadow without diverting runoff. It was the first soil treated and seeded. Breaks occuring in the seeding were then repaired by the placement of bluegrass sod. Complete sodding, however, appears to be more desirable than this method, because of the numerous times maintenance must be given.

The remaining outlets have been developed from seedings and subsequent maintenance with sod, where required, has been given. The most practical way to establish terrace outlets from seeding has been to temporarily divert runoff or to establish the outlet before terraces were constructed. The period which has elapsed before adequate protection was secured varied from 1 to 5 years, depending on the soil, slope, area drained, and weather conditions.

Terrace effectiveness.—A terraced area of 8.03 acres, watershed D–2, and an unterraced area of 4.85 acres, watershed D–3, have been used to study terrace effectiveness.

Parts of watershed D–2 were seriously eroded before terracing in 1930. The depth of surface soil ranged from 0 to 12 inches and averaged 8 inches. The average land slope was 7.0. The watershed has a bluegrass terrace outlet, received lime and fertilizer, and is contour-farmed with the terraces.

Watershed D–3 had experienced little cropping prior to 1930. The mantle of topsoil ranged from 4 to 14 inches, and averaged 10 inches. The average slope of the area was 6.7 percent. This watershed has not received soil treatment and is farmed with the field boundaries.

TABLE 33.—*Soil losses, runoff, and crop yields for terraced watershed D–2 and for unterraced watershed D–3* [1]

[D–2 is farmed on the contour and has been limed, and commercial fertilizer is applied on the small grain.]

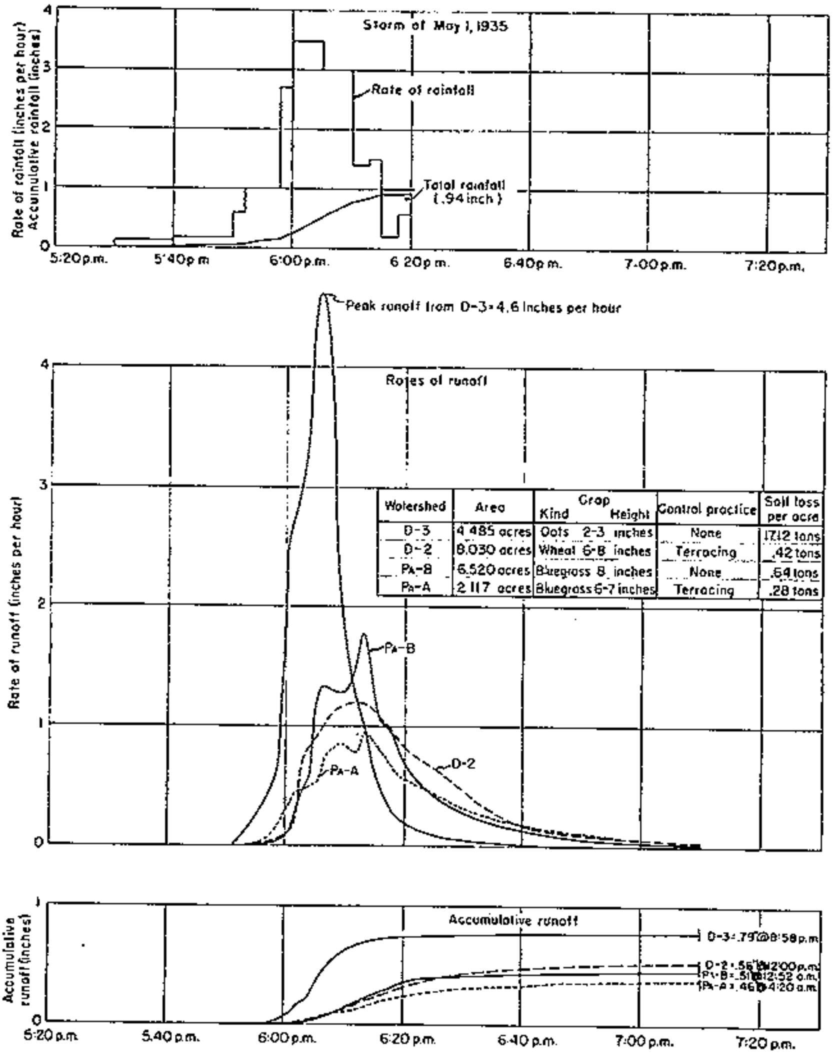
Crop	Rainfall	Runoff				Soil loss per acre		Yield [2] per acre	
		Amount		Percentage of rainfall					
		D–2	D–3	D–2	D–3	D–2	D–3	D–2	D–3
	Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Tons*	*Tons*	*Bushels*	*Bushels*
Corn	28.28	3.84	4.60	13.6	16.3	0.71	41.83	26	21
Oats	29.62	2.00	3.55	6.8	12.0	.32	20.53	[3]36	39
Wheat	31.49	5.75	8.48	18.3	26.9	1.13	36.62	15	14
								Tons	*Tons*
Clover and timothy	26.33	1.52	2.08	5.8	7.9	.03	2.08	1.7	1.6
Rotation average	28.93	3.28	4.68	11.4	16.2	.55	25.26		

[1] D–3 is formed with field boundaries and has not received soil treatments.

[2] Data for each crop are an average for 2 years. Depth of top soil on D–3 in 1930 was 10 inches while that on D–2 averaged only 8 inches. For a more equitable comparison, yields on D–3 should be multiplied by 0.86, an estimated relative production factor for the two original depths of top soil.

[3] Oats on terrace ridge lodged during 1938, resulting in high harvesting losses, while that on D–3 without soil treatment did not lodge and therefore harvesting loss was negligible.

Both watersheds have been cropped to a 4-year rotation of corn, oats, wheat, and meadow since 1935. Soil and water loss data are available for the 8-year period, 1935–42. Data by calendar years are tabulated in Appendix, tables 68–75. An average of data by crops of the rotation is given in table 33. Runoff from the terraced watershed D–2, as an average of the rotation, has been 70 percent of that from the check area. The average soil loss for the different crops from the terraced area has ranged from 1.4 to 3.1 percent of the loss from the unterraced area and has averaged 2.2 percent for all crops.



Watershed	Area	Crop Kind	Crop Height	Control practice	Soil loss per acre
D-3	4.485 acres	Oats	2-3 inches	None	17.12 tons
D-2	8.030 acres	Wheat	6-8 inches	Terracing	.42 tons
PA-B	6.520 acres	Bluegrass	8 inches	None	.64 tons
PA-A	2.117 acres	Bluegrass	6-7 inches	Terracing	.28 tons

FIGURE 31.—Soil loss and runoff data from terraced and unterraced watersheds for the storm of May 1, 1935. Soil moist from previous rainfall.

The average soil loss measured, from the ends of the channels of the terraced area, approximately one-half ton per acre per year, may be considered negligible. It is estimated that soil movement to the terrace channels and deposition on the terrace ridges has been approximately 5 tons per acre per year during the 8-year period. A part of this accumulation on the terrace ridges may be considered as soil lost for crop production, as surface-soil depths above 1 foot have not shown increased crop yields.

Representative hydrographs of runoff from terraced and unterraced areas are shown in figure 31. They are from the storm of May 1, 1935,

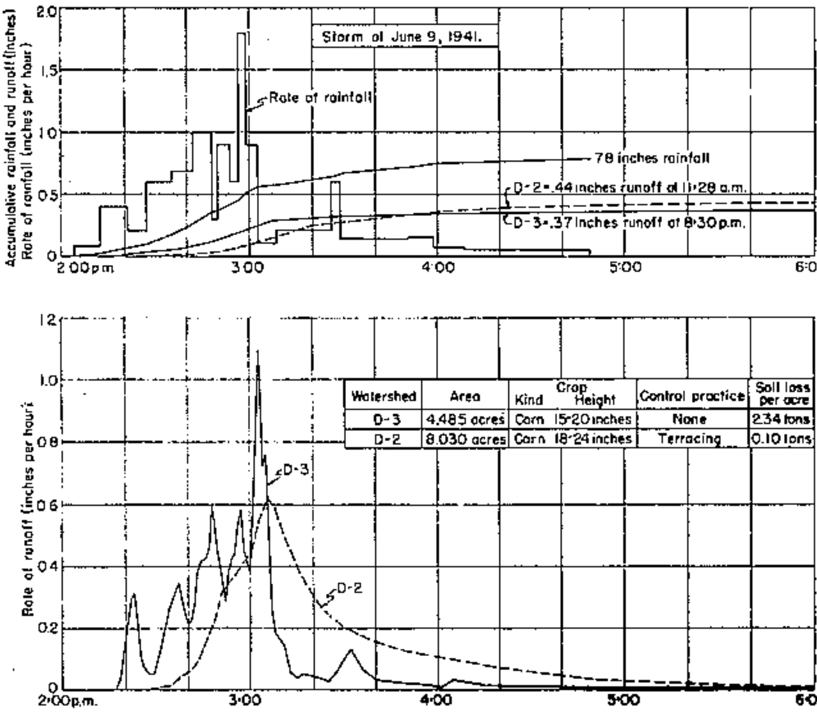


FIGURE 32.—Soil and water loss data from terraced and unterraced watersheds. The hydrograph from the unterraced area follows very closely the changes in rate of rainfall, whereas for the terraced areas the hydrograph peaks are smoothed, depressed, and prolonged. Soil was wet at the time of this rain, from 1.78 inches of rainfall that morning.

and show the rates and amounts of runoff from watersheds D–2 and D–3 cropped to small grain, and similar data from terraced and unterraced bluegrass pastures, Pa–A and Pa–B.

A comparison of hydrographs secured from a storm of June 9, 1941, from watersheds D–2 and D–3 while cropped to corn is shown in figure 32. Runoff from the unprotected watershed is very responsive to slight changes in the rainfall intensity and runoff is detained on the surface only a short time. The ability of terraced areas to retard runoff and to smooth or eliminate runoff peaks from rainfall intensities of short duration is also demonstrated.

A study of maximum rates of runoff from seven major storms during the 6-year period 1935–40 showed the average maximum rate of runoff from the terraced watershed to be 45 percent of the average maximum rate from the unterraced watershed. During each of these storms the maximum rate of runoff was greater from the unterraced watershed.

Strip-Cropping

Six plots, shown in figure 33, designated as plot series 5, 270 feet long and 45 feet wide, have been used to study rotational strip cropping on a 6.6 percent slope. Alternate strips are contour farmed to a 3-year rotation of corn, wheat, and meadow. The remaining three plots are strip-cropped. Each strip-cropped plot is divided into

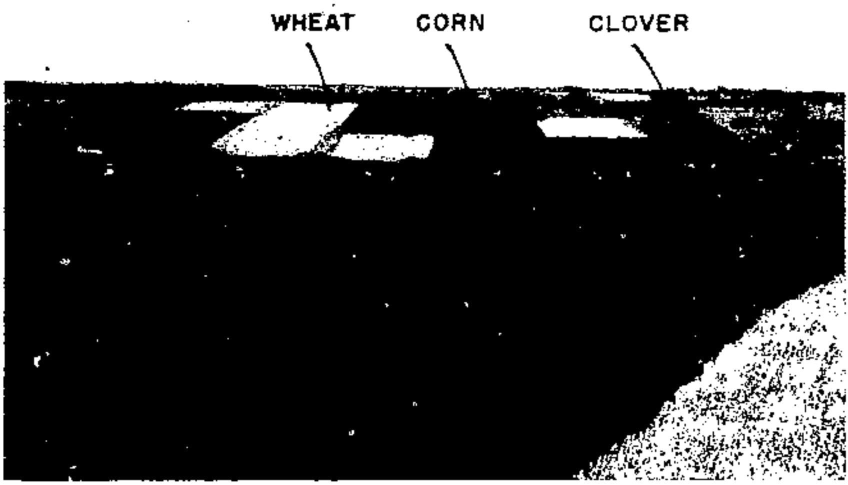


Figure 33.—Rotational strip-cropping plot study on a 6.6 percent slope.

three strips for the growing of each crop of the rotation on each of the three possible locations on the slope. The sequence of crops from the top to the bottom of the slope is such that when corn and small grain are grown adjacently, the wheat is above the corn. Data are complete for the period 1936-41, and are given by seasons in Appendix tables 58 and 59. The data have been arranged according to crops and their positions on the slope.

A brief summary of soil and water losses for the 6-year period is given in table 34. The average annual runoff from the strip-cropped and check plots was almost identical. Soil loss was greatest when corn occupied the entire slope. The position of corn on the strip-cropped plots was also the dominating factor in the amount of soil loss experienced.

TABLE 34.—*Average rainfall, runoff, soil loss, and crop yields from the contour strip-cropped and contoured plots of series 5 for the 6-year period 1936–41*

Plot No.	Crop	Rainfall	Runoff		Soil loss per acre	Crop yields		
			Amount	Percent of rain		Corn per acre	Meadow per acre	Wheat per acre
		Inches	*Inches*	*Percent*	*Tons*	*Bushels*	*Tons*	*Bushels*
1, 3, 5	Corn, clover-timothy, wheat [1]	26.88	2.01	7.5	0.29	25.7	1.30	11.3
1, 3, 5	Wheat, corn, clover-timothy [1]	26.88	2.16	8.0	.63	16.5	1.43	11.8
1, 3, 5	Clover-timothy, wheat, corn [1]	26.88	1.95	7.3	1.62	17.8	1.54	0.8
1, 3, 5	Average strip-cropped plots	26.88	2.04	7.6	.85	20.0	1.42	11.0
2, 4, 6	Wheat	26.88	2.11	7.8	.41			11.3
2, 4, 6	Corn	26.88	2.20	8.5	5.15	21.8		
2, 4, 6	Clover-timothy	26.88	1.79	6.7	.18		1.34	
2, 4, 6	Average contoured plots	26.88	2.06	7.7	1.91	21.8	1.34	11.3

[1] Crops in order from top to bottom of plot.

This loss ranged from 0.29 ton per acre per annum, when corn occupied the upper slope position, to 1.62 tons per acre per year, when it occupied the lower slope position. Average yearly soil loss was reduced 55 percent by strip cropping.

Conclusions based on the soil and water loss measurements are that meadow strips absorb little of the runoff passing over them; they do, however, appear to be effective in filtering soil from heavily silt-laden runoff passing over them.

Crop yields on the strip-cropped plots 1, 3, and 5, and the contoured non-strip-cropped plots 2, 4, and 6 have not been significantly different. Insect damage observed to accompany rotational strip cropping at other locations cannot be gaged by this experiment, due to the fact that the strip width of 90 feet is greater than the plot width. The yield of all crops has been slightly higher when they occupy the upper slope position, which is undoubtedly due to greater depths of fertile topsoil at the upper location.

Observation of the plots have shown that the tendency for water to concentrate and to form gullies increases with slope length. Development of this condition is markedly greater on the plots which are not strip-cropped.

Watershed LJ-1, having an area of 2.13 acres, has been rotation strip-cropped since 1933. During the period 1933–35 it was cropped in four strips on which a rotation of corn, soybeans, wheat, and meadow was grown. Water loss averaged 6.4 inches per year and soil loss 9.1 tons per acre per year during the 3-year period. These losses were excessive due to the large percentage of intertilled crops. In 1936 the number of strips was reduced to three, and cropping changed to a 3-year rotation of corn, oats, and meadow. During the 7-year period 1936–42, water loss from the area has averaged 2.1 surface inches and soil loss only 0.5 of a ton per acre per year.

CONTOUR TILLAGE

Farming of fields with or without terraces on the contour has reduced both soil and water loss and increased crop yields on the station. The Shelby soil, however, with its rather impervious subsoil, has shown a wide variation in the results from one year to another. Observations have shown that grassed waterways are necessary along with contouring.

In 1931 terraced fields N and G were in corn. In field N the corn was planted across the terraces and in field G the corn was planted on the contour with the terraces. Soil on the two fields was approximately the same, but the percent slope of field G was about twice that of field N. During the three years following 1931, the two fields were in corn planted on the contour. Average corrections for slope and other differences were secured from these three years' data for runoff, soil loss, and crop yields, and applied to the original data. Contour planting and tillage based on these adjustments reduced the runoff to 77 percent, and the soil loss to 42 percent, and increased the corn yield 22 percent over planting and cultivating the corn across the terraces. The original and adjusted data are shown in table 35.

TABLE 35.—*Effect of contour tillage on runoff, soil loss, and yield from terraced land in corn*

Period and direction of tillage	Factors	Average for terraces 4, 5, and 6 N	Average for terraces 3, 4, and 5 G	Ratio G/N
1931 contour tillage on G, corrected for slope difference with N terraces.	Rainfall: inches	30.47	30.47	
	Runoff: inches	12.09	9.27	0.77
	Percent	40	30	
	Soil loss: tons per acre	4.27	1.81	.42
Operation across N terraces	Corn yield: bushels per acre	36.6	44.5	1.22

An indirect comparison for the value of contour tillage can be made from the contour or check plots of the strip-crop experiment, plot series 5, and the up-and-down hill operated plot of the same length (270 feet) in plot series 15. Comparative adjusted data are shown in table 36.

TABLE 36.—*Comparison of soil and water losses from contour and up-and-down hill tilled plots*

Year	Crop	Rainfall	Row direction	Runoff amount		Soil loss per acre	Contour, up-and-down hill
		Inches		*Inches*	*Percent*	*Tons*	*Ratio*
1936	Corn	24.16	Up and down	1.02	4.2	1.55	0.03
			Contour	0.13	0.5	0.05	
1937	Corn	21.86	Up and down	2.35	10.8	1.33	.74
			Contour	3.39	15.5	.98	
1938	Corn	26.10	Up and down	2.07	7.9	11.65	.06
			Contour	.53	2.0	.68	
1939	Corn	26.75	Up and down	3.61	13.1	22.60	.86
			Contour	4.19	15.2	19.38	
1940	Wheat	27.67	Up and down	2.60	9.4	7.19	.06
			Contour	.68	2.5	.42	
1941	Meadow	34.62	Up and down	2.25	6.5	.02	2.00
			Contour	1.86	5.4	.04	
1942 [1]	Corn	32.77	Up and down	4.20	12.9	4.83	.43
			Contour	3.76	11.5	2.09	
Total all years		194.02	Up and down	18.10	9.3	49.17	.48
			Contour	14.54	7.5	23.64	

[1] This is a direct comparison from the 3 contour and the 3 up-and-down hill plots of series 5. Adjustments for slope and continuous corn were made for the up-and-down hill plots for the other years.

Soil loss for the 7-year period totaled 23.6 tons from the contoured plot. This is 48 percent of that for the plot operated up-and-down hill. Likewise, runoff from the contour plot was 14.54 inches or 80 percent of that from the up-and-down hill plot. It will be noted that the ratio of soil loss on the contour plot to that on the plot operated up-and-down hill varied from 0.03 in 1936 to 2.0 in 1941. This latter ratio is not of practical value as the soil loss from both plots was insignificant in amount. The ratio of 0.86 in 1939 was largely the result of a 7-year frequency rain of that year. This was the greatest soil-loss year for these plots. Moderate rains of low intensity caused little, if any, soil loss from the contour plot, but long rains of high intensity falling on wet soil caused about equal soil loss for the two conditions.

Contouring has been studied on field-size watersheds on the station in conjunction with other conservation practices. These additional practices consisted of grassed waterways with wire checks, soil treatments of lime and commercial fertilizer, and contour plowing in which the dead furrows and headlands were placed in the same location each time the field was plowed. The contoured area with its additional practices is known as watershed D–1 and the other area as watershed D–3. Farming operations on watershed D–3 were with the field boundaries and therefore all rows were not up and down the slope. The two watersheds have been in the same cropping plan since July 1935. The grassed waterway on D–1 represents 20 percent of the total area of the watershed.

Total soil loss from watershed D–1 for the past 8 years has been 22.1 tons per acre or 10.9 percent of that from watershed D–3, with no control except the crop rotation. Runoff loss from D–1 during the period has totaled 31.3 inches, which is 83.9 percent of that from watershed D–3 and 13.1 percent of the total rainfall for the period. These data are shown in table 37, as well as the yearly losses and crop yields for the two watersheds.

TABLE 37.—*Soil loss, runoff, and crop yields from a watershed with contour tillage and other practices (D–1) and a watershed farmed with field boundaries (D–3)*

Year	Crop	Watershed	Rainfall	Runoff		Soil loss per acre: Amount	Soil loss per acre: Ratio D–1 to D–3	Crop yield per acre: Total yield divided by total area	Crop yield per acre: Total yield divided by area in crops [1]
				Inches	*Percent*	*Tons*		*Bushels or tons*	*Bushels or tons*
1935	Wheat	D–1	36.07	10.31	29	16.07	0.36	20.1	25.0
	Oats	D–3	36.07	11.54	32	47.38		38.0	38.0
1936	Meadow	D–1	24.77	1.94	8	.11	.13	1.83	1.83
		D–3	24.25	2.00	8	.88		1.66	1.66
1937	Corn	D–1	21.63	4.06	19	1.83	.09	35.2	43.7
		D–3	21.68	3.50	16	19.71		33.9	33.9
1938	Oats	D–1	26.13	.71	3	.16	.06	40.9	50.7
		D–3	26.22	1.22	5	2.63		50.0	50.0
1939	Wheat	D–1	26.88	3.65	14	.78	.03	7.0	9.8
		D–3	27.09	5.41	20	25.85		9.0	9.0
1940	Meadow	D–1	27.62	1.03	7	.08	.02	1.03	1.03
		D–3	28.17	2.17	8	3.28		.84	.84
1941	Corn	D–1	35.04	5.03	14	1.38	.02	7.4	9.2
		D–3	34.81	5.69	16	63.94		8.3	8.3
1942	Oats	D–1	32.89	3.65	11	.79	.02	25.7	31.9
		D–3	33.20	5.89	18	38.44		27.8	27.8
1935–42		D–1	230.83	31.28	14	22.10	.11		
		D–3	231.52	37.42	16	202.11			

[1] Waterway not included except for meadow.

Soil loss from D–1 has been calculated as a percentage of that from area D–3 and shown in the table. It is interesting to note that the percentage has been decreasing each year. It is thought that the method of plowing across the slope has contributed to this decrease, and resulted in the area functioning quite similarly to a terraced area. Crop yields calculated on the basis of total area do not show an advantage for the contouring and additional practices, except for the meadow years when the waterways contributed to the yields. Therefore, the yields shown in the table have been calculated on the basis of the actual area seeded to small grain or corn as well as on the basis of total area. On the former basis, average small grain yields were not appreciably different on fields D–1 and D–3; corn yield, however, was 25 percent greater and meadow yield 14 percent greater on the contoured field with the additional practices.

Watershed D–1 contained numerous drainage depressions which have been established as grassed waterways. This left extremely narrow intervening areas to be cultivated and necessarily resulted in numerous short rows. The practicability of farming these small areas is questionable and led to the subsequent establishment of a field trial area in which similar bowl-shaped areas were all seeded to permanent meadow with grassed waterways.

Contour Furrows

Pasture furrows were placed on a virgin bluegrass pasture watershed (Pa–C) of 1.974 acres, in the fall of 1939. The average slope of the watershed was 11 percent, and the furrows were placed at 1-foot vertical intervals.

The furrows were constructed with a contour-furrowing machine developed by the Agricultural Engineering Department of the Missouri Experiment Station. The machine elevates the sod cover with right- and left-hand plow bottoms, and earth is moved to form a ridge by means of a reversible disk. Sod is then dropped back on the excavated channel and earth ridge and packed with a roller. A survey of the furrows made 8 months after their construction showed them to have a storage capacity equivalent to 0.6 inch of a surface runoff from the watershed. Figure 34 shows the furrows in the spring of 1942.

Hydrologic measurements were secured during the 3-year period 1937–39, before placement of the furrows, for calibration purposes with a terraced bluegrass pasture watershed of 2.026 acres (Pa–A), and an undisturbed bluegrass pasture of 5.563 acres (Pa–B). Pastures A and C are on the same hillside, have the same slope aspect, approximately the same percent slope, and similar vegetal cover. Pasture B is on a more moderate and opposing slope across a ravine. During this 3-year period, only traces of runoff occurred, except from one storm of 7-year intensity-frequency on June 21, 1939. All pastures had appreciable amounts and rates of runoff from this storm as shown in table 38. Data from this storm were considered sufficient for calibration purposes, and pasture C was furrowed in the fall of 1939.

Data from the three watersheds, after contour furrowing pasture C, are available for the 2-year period 1940–41. During 1940 no rainfall escaped from the contour furrows while pastures A and B each had 0.4 inch runoff. In 1941 the contour furrows overtopped during three storm periods. Total runoff from these storms was 2.58 inches on the contour furrowed pasture. During the same three storms the

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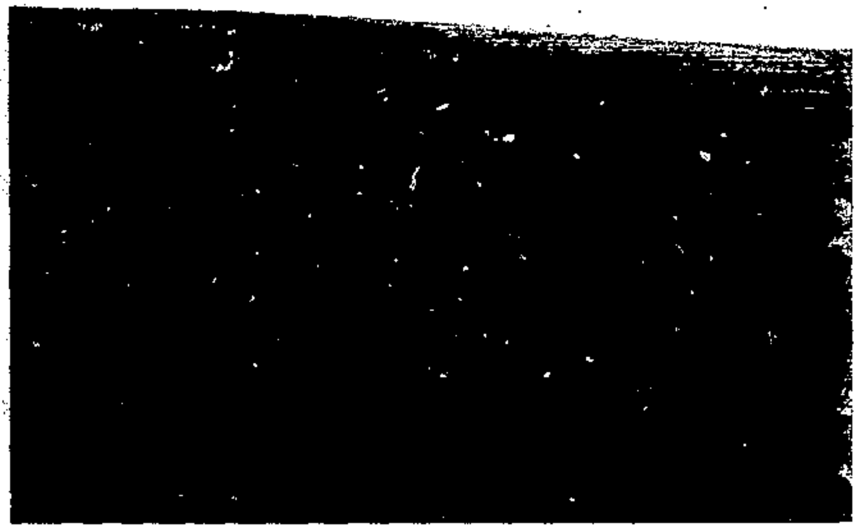

FIGURE 34.—Contour furrows on bluegrass-pasture watershed 3 years after construction.

terraced pasture lost 1.43, and the undisturbed pasture 2.02 inches of runoff. During 1941 there were 16 additional storm periods from which the terraced pasture lost 0.48, and the undisturbed pasture 0.74 inch of runoff while the contour-furrowed pasture did not produce runoff. By retaining all rainfall for the minor storm periods by the contour furrows, the level of soil moisture of that watershed was undoubtedly increased. This apparently resulted in larger amounts of runoff from the furrowed pasture, in comparison to the terraced pasture, for each of the three storms causing runoff on the three watersheds. Total runoff for the year 1941 was 35 percent greater from the contour-furrowed pasture than from the terraced pasture, but 13 percent less than from the undisturbed pasture watershed.

Runoff data from the pasture watersheds for the three major storm periods of 1941 are shown in tabular form, in comparison with data secured from the storm of June 21, 1939, in table 38. It will be noted that for the storm of 1939, pasture C, in its undisturbed state, had total runoff, and an infiltration index, approximately equal to the average of pasture A and pasture B. During each of the three storms in 1941, contour-furrowed pasture C had the largest runoff, and the lowest infiltration index. The fact that runoff from the contour-furrowed pasture was measured as 0.01 inch more than the rainfall of the storm of June 9, p. m., was due to a small amount of residual runoff remaining on the area from the storm of the morning. The contour furrows had been completely filled during the morning storm, and runoff at the rate of 0.005 inch per hour was in progress at the time of the second storm. It is, however, apparent that approximately 100 percent of the rainfall from the latter storm appeared as runoff, and further, that the infiltration rate was negligible.

TABLE 38.—*Comparison of bluegrass watersheds, pasture A,[1] pasture B,[2] and pasture C,[3] before and after contour furrowing pasture C*

Bluegrass pasture watersheds	Date of storm	Rainfall				Runoff					
		Amount	Maximum 5-minute intensity per hour	Maximum 15-minute intensity per hour	Maximum 30-minute intensity per hour	Amount	Maximum intensity per hour	Maximum 5-minute intensity per hour	Maximum 15-minute intensity per hour	Maximum 30-minute intensity per hour	Infiltration index per hour
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Pa-A, terraced	June 21, 1939	2.03	4.20	3.36	2.56	0.82	1.67	1.65	1.43	1.10	1.40
Pa-B, undisturbed	June 21, 1939	2.03	4.20	3.36	2.56	.37	.73	.64	.61	.49	2.25
Pa-C, undisturbed	June 21, 1939	2.03	4.20	3.36	2.56	.55	1.35	1.31	1.08	.80	1.83
Pa-A, terraced	June 9, 1941 a. m.	1.62	4.32	2.80	1.74	.68	.76	.73	.64	.49	.40
Pa-B, undisturbed	June 9, 1941 a. m.	1.62	4.32	2.80	1.74	1.01	1.56	1.50	1.27	.92	.18
Pa-C, contour furrowed [4]	June 9, 1941 a. m.	1.62	4.32	2.80	1.74	1.17	.40	.40	.39	.36	.12
Pa-A, terraced	June 9, 1941 p. m.	.66	1.68	1.13	.85	.33	.27	.27	.25	.23	.30
Pa-B, undisturbed	June 9, 1941 p. m.	.66	1.68	1.13	.85	.39	.50	.49	.43	.35	.23
Pa-C, contour furrowed [4]	June 9, 1941 p. m.	.66	1.68	1.13	.85	.67	.25	.25	.25	.25	.00
Pa-A, terraced	October 30, 1941	1.98	.36	.28	.22	.42	.08	.08	.08	.08	.12
Pa-B, undisturbed	October 30, 1941	1.98	.36	.28	.22	.62	.10	.10	.10	.10	.09
Pa-C, contour furrowed [4]	October 30, 1941	1.98	.36	.28	.22	.74	.09	.09	.09	.09	.08

[1] Terraced bluegrass pasture watershed of 2,026 acres, and 13-percent slope.
[2] Undisturbed bluegrass pasture of 5.563 acres and 9.5-percent slope.
[3] Bluegrass pasture watershed of 1.974 acres, and 11-percent slope before placement of contour furrows.
[4] Bluegrass pasture watershed of footnote [3] after placement of contour furrows.

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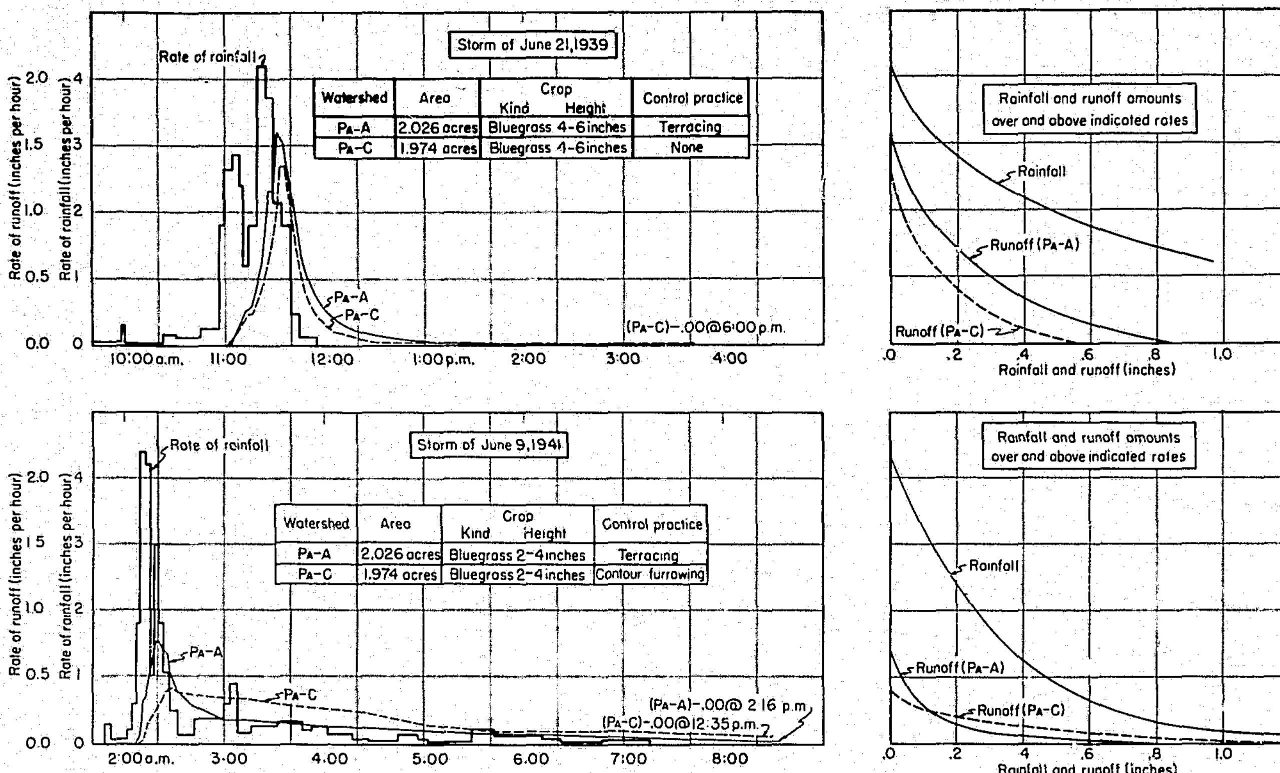

FIGURE 35.—Histograms of rainfall and runoff for two storms on bluegrass-pasture watersheds (Pa-A) and (Pa-C). The storm of 1939 occurred before contour furrows were placed on pasture C, and the storm of 1941 occurred after their placement.

The contour furrows have reduced the peak rates of runoff and the velocity of overland flow as illustrated by the nearly constant values of peak, 5-, 15-, and 30-minute runoff intensities given in table 38. This changed distribution of runoff is further illustrated in figure 35 by plotting the histograms of rainfall and runoff on pastures A and C for the storm of June 21, 1939, and for June 9, 1941. The distribution of runoff over and above indicated rates is illustrated by the curves of the excess series on the right-hand portion of the figure.

A preliminary survey of vegetation and soil moisture was made on the contour-furrowed portion of pasture C, and an adjacent unfurrowed portion of the pasture in 1940. Points for sampling were selected at random. Counts of vegetation were made by the point quadrat method. Moisture determinations were made for soil depths of 0 to 6, 6 to 12, and 12 to 18 inches. Differences in vegetation and moisture between the furrowed and unfurrowed pastures were too small to be significant. Within the contour-furrowed pasture, the strikes of bluegrass and of weeds were significantly greater in the channels than on the ridges of the contour furrows. Moisture differences were not significant. The year 1940 was also deficient in rainfall and only 0.4 inch of runoff occurred from unfurrowed bluegrass pastures on the station. Large differences in vegetation and moisture would, therefore, not be expected.

Bluegrass pasture on the Shelby soil usually occupies lands with slopes in excess of 8 percent. The spacing of furrows must be close to retain surpluses of rainfall on pastures on these slopes. Closely spaced furrows complicate pasture management problems. It was found very difficult to use a mower to clip weed growth on pasture C. The sale of stripped bluegrass seed is a source of considerable revenue to many farms in the Shelby soil region. Contour furrowing, by methods in which numerous ridges are formed, almost precludes the harvesting of bluegrass for seed.

Field Trial of Soil Conservation Practices

The principles of conserving soil and water resources, found to be beneficial by actual measurements on small plot, terrace, and watershed areas have been extended to station fields not otherwise employed in formal experiments. Such field trials constitute a proving ground to test the workability of theoretically sound erosion control practices, and assist in determining the limits of their application to practical farm use. The development of erosion control practices by field trial is the end product of research endeavor.

Studies made of four fields over a period of several years will be discussed. Table 39 lists the field specifications, cropping, and control practices for the areas in 1941.

Rotation strip cropping.—The first problem to receive study by field trial was the application of strip cropping to one of the station fields. A contour map of the area selected for this study (field L) is shown in sketch A of figure 36. The land area has slope variations ranging from 3 to 8 percent, irregular contour direction, and a well developed drainage network, all of which are typical of the Shelby soil. It is located directly east of the major grouping of plot studies.

TABLE 39.—*Areas used to develop field application of erosion-control practices*

Field	Area (acres)	Year started	Rotation (kind)	Soil treatment	Control practices
L	13.1	1932	Corn, small grain, meadow.	2 tons per acre of barnyard manure applied before corn, 200 pounds per acre of 20-percent superphosphate applied with small grain.	Diversion ditch at top of slope. 2.8 acres of permanent alfalfa above diversion ditch and immediately below. 8.7 acres in rotation strip-cropping; 1.6 acres in permanent grass, including small strip to mark boundaries of cultivated strips and correction areas.
F	18.0	1934	Corn, harvested for grain. Small grain, pastured off. Meadow, pastured and residue plowed under in the spring preceding the following corn crop. Crops of the rotation on each field are one year out of phase to provide year around grazing.	4-12-4 fertilizer applied at the rate of 150 pounds per acre with small grain seeding.	Four terraces upon upper reaches of slope. Approximately 9 acres cultivated (including terraces and strips below terraces). 9 acres in permanent buffer strips and grassed waterways.
P	34.0	1938			14 acres cultivated between permanent buffer strips. 20 acres in permanent grass and waterways (all small, severely eroded, concave areas upon which water concentrates have been left in permanent grass).
Q	46.0	1938			Two terraces on the upper reaches of slope. Two diversion dykes at 10-foot vertical intervals. Permanent grass left on irregular areas above diversion dykes. Point rows thus eliminated. 20 acres in rotation. 26 acres in permanent grass.

A diversion terrace was placed on the upper portion of the field in 1931 about 12 feet vertically from the high point of the slope. The first strip-cropping system was installed below the diversion in the spring of 1932.

The purpose of the diversion terrace was to divert runoff from active gullies in the field. The irregular area above the diversion and a contour strip immediately below were seeded to alfalfa. The lower edge of the alfalfa strip followed an exact contour. The reason for placing alfalfa below the diversion terrace was further to reduce runoff from the upper slope region, and thus make an optimum condition for control of the remainder of the slope by rotational strip cropping.

Four strips were laid out below the alfalfa, for the growing of corn, small grain, and meadow. The boundaries of each were placed on the contour. A diagram showing this original installation and the cultivation lines is shown in sketch B, figure 36.

This first application of strip cropping proved inadequate, due to the fact that the strips were extremely narrow at some locations and wide at other points. Point rows were encountered in cultural operations on all strips. Moreover, the field was low in fertility and the growth of meadow too meagre to afford adequate protection to the slope. Strip boundaries became obliterated in the fall by growth of annual grasses and weeds after the removal of the small grain and hay crops.

The system was changed from one of precise contouring in 1932 to one less rigid in 1933. The procedure followed became known at a later date by the term "field-stripping." Strips were of nearly uniform width as shown in sketch C, figure 36. The number of rotated strips, reduced from 4 to 3, were cropped to corn, small grain, and meadow.

This so-called system of field-stripping was retained on the field for

2 years for observation. On some locations on the slope the row direction was perpendicular to the contour of the field. This resulted in poor erosion control. Runoff tended to follow drill and planter marks, depositing topsoil in the drainageways or upon the meadow strip when breaks occurred.

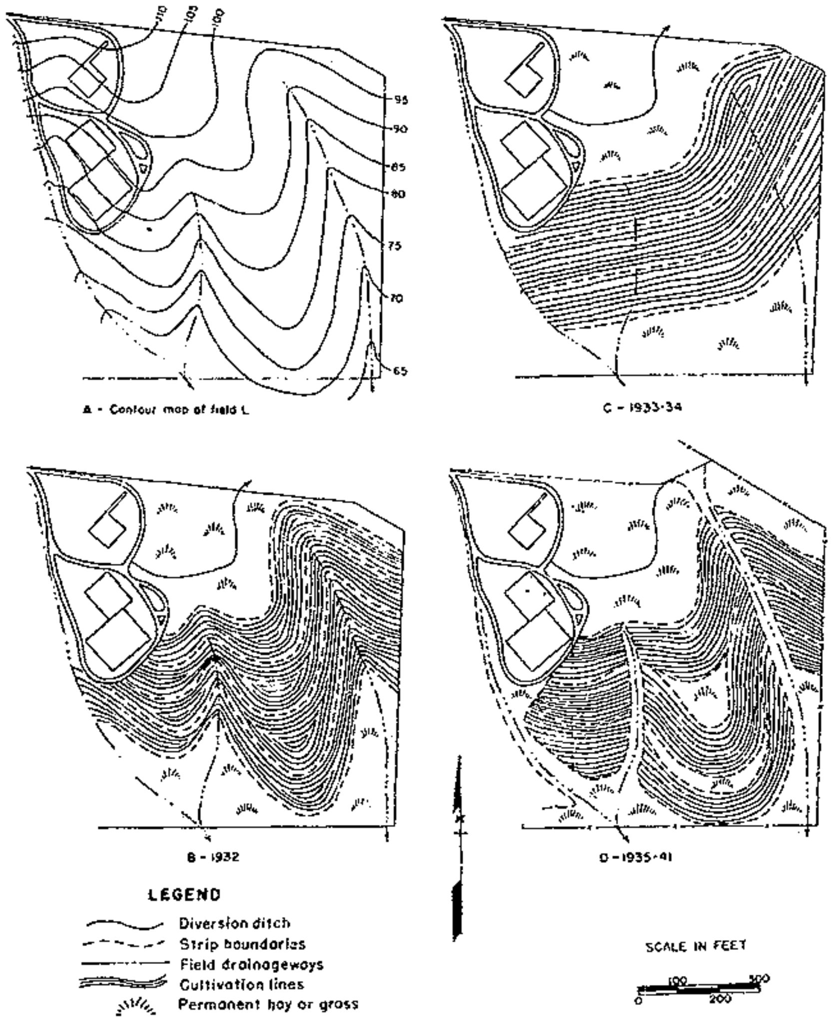

FIGURE 36.—Various systems of rotational strip cropping on field L.

Obviously, when comparing these two early applications of strip-cropping, two extremes in the application of strip-cropping are in evidence, and while the latter method obviated point rows and the sharply curving contour direction, it resulted in inadequate conservation.

Strips were again relocated in 1935, by placing the center of each on the contour. During the preceding years of study, it had been observed that when rounding curves with farm machinery there was a tendency for the implement to crowd the inside of the curve. This factor was taken into consideration by plowing outward from a backfurrow placed on the contour of the strip center. The crowding of a curve on one side of the backfurrow was then balanced by the lag on the opposite side. This procedure resulted in nearly parallel strip boundaries, which varied in distance from the original backfurrow. Irregular areas between the 3 strips of nearly uniform width were seeded to permanent meadow, which has been harvested with an adjacent strip of oats or meadow each year. A map of this strip relocation is shown in sketch D, figure 36.

When laying out the final arrangement of strips, a small land area between them, from 3 to 6 feet wide, was left unplowed. It was retained in grass to define the strip boundaries.

This arrangement of strips has been satisfactory for erosion control. Waterways were under good vegetative control by 1935 and little soil has been eroded from the field. Each year the strip planted to corn has received 2 tons per acre of barnyard manure, and the strip seeded to small grain has received 200 pounds of 20-percent superphosphate. The increases in vegetative growth, accompanying these applications of manure and fertilizer, are undoubtedly one of the major factors contributing to the successful erosion control of the field. The strips have been plowed outward from a backfurrow, and from the outer boundaries to the dead furrow, on alternate plowings, in an effort to prevent benching and to retain a smooth land surface.

The only change in the system from 1935 to 1941 has been the elimination of the narrow buffer or guidelines between each rotated strip, as the lines of cultivation became visibly defined.

Two major difficulties with this method of strip cropping have been encountered. The first was the occasional damage to the corn crop by insect migrations from the small-grain strip. Insect damage, primarily by chinch bugs, is illustrated by yield comparisons with other areas in 1932 and 1940. In 1932 the yield of corn was 4.6 bushels per acre on the strip of field L, while it was 27.5 bushels per acre on field C, where corn occupied the entire slope. A comparable condition occurred in 1940 when the yield was 6.1 bushels per acre, as compared to 51.1 bushels on adjoining field N. The other difficulty encountered was the impracticability of grazing the field with livestock.

Further study of rotational strip cropping, in addition to the field trials on field L, was initiated on field F in 1934. This provided for a study of rotations other than the 3-year one of corn, oats, and meadow.

Four small terraces were placed on the upper slope reaches, and the remainder of the slope divided into five strips. The field was seriously eroded, and had a low fertility level when the control practice was applied. The rotation used on the strips was corn, oats, wheat, and meadow. The strips were of uniform width, with intervening correction areas which were cropped to oats and meadow with adjacent contour strips. This rotation was retained on the slope until 1936.

Experience with the system gave negative results. The rotation of corn, oats, wheat, and meadow, coupled with a low fertility level and irregular eroded topography, resulted in rill formation, which extended across all strips, and excessive soil movement down the slope. Insect damage to the corn crop was also severe due to the amount and location of small grain.

In 1936 the field was divided laterally into two units. The purpose of this division was to segregate the growing of corn from small grain.

The rotation was changed to one of corn, small grain, and two years of meadow. By the use of the two field units, it was then possible to have one unit in alternate strips of corn and first-year meadow while the other was in small grain and second-year meadow.

This system permitted grazing out of the field unit in small grain and meadow, and also alleviated insect damage. Soil fertility was improved by application of 6 tons per acre of barnyard manure preceding the corn crop and of 200 pounds per acre of superphosphate fertilizer with small-grain seeding.

Successful erosion control was dependent upon establishment of a good crop of meadow each year to spread runoff from the strips planted to corn. When the seedings failed the system was disrupted.

In plowing the strips from 1936 to 1938, the plan was to ridge or bench the field by backfurrowing the strip boundaries and leaving the dead furrow in the center of the strip. In practice this resulted in leading runoff along the edge or center of a strip, until it broke through at a low point in the field. An attempt was made to control soil wash at these points by the placement of sod. This proved to be impractical on the lower slope reaches where relatively large volumes of water passed over the field or where runoff concentrated at many points on concave land areas.

Trials of rotational strip cropping were discontinued on this field in the fall of 1938, at which time it was given over to the study of permanent buffer strip cropping.

Rotational strip cropping proved effective in controlling erosion on convex land areas, where the slope length did not exceed approximately 300 feet and the soil fertility was maintained at a high level. It was not effective on eroded concave-shaped land areas, where water tended to concentrate, or where the fertility level was low.

On irregular topography the most satisfactory method of laying out strips has been to place the center of each strip on the contour, determining the outer boundaries of the strip by plowing outward from the strip center, and to retain irregular areas between strips in small grain and meadow. Inasmuch as correction areas are located on the flatter portions of the slope, where the horizontal distance between contours is greatest, the practice does not permit maximum utilization of these areas for cropping. Where the topography was fairly uniform, the practice of placing both of the strip boundaries on the contour was feasible.

Attempts to maintain systems of rotational strip cropping on more than one field for the purpose of separating intertilled and small-grain crops to minimize insect damage and to facilitate grazing with livestock, are easily deranged by the failure of meadow seedings.

The several difficulties encountered with rotational strip-cropping at this location gave rise to the development of permanent buffer-type strip cropping as discussed in the following section.

Buffer strip cropping in field unit systems.—An 80-acre addition, adjoining the west boundary of the original station site, was leased in 1936. The area proved to be irregularly eroded to the extent that comparable areas of sufficient size for plot studies did not exist. It was therefore utilized for field trials of erosion-control practices.

Livestock play an important role in the conservation and economical utilization of soils in the region. Since little of the methodology of conservation had been developed with adequate consideration for this type of agriculture, it was decided to study measures which would be adapted to livestock farming.

Plans for practices to be applied to the area for trial and development were originated in 1938. They were designed to permit study of grazing, fencing, cropping, machinery use, and other factors which arise in the application of various conservation measures to practical and economical farm use, in conjunction with a system of livestock farming.

A minimum requirement for the study was determined to be three separate fields, on which each crop of a 3-year rotation could be

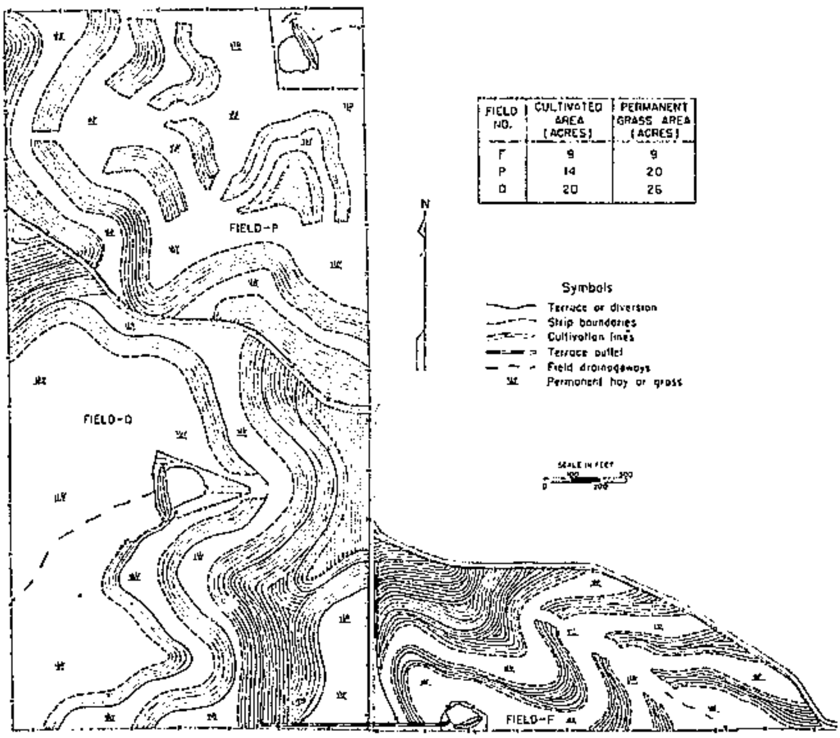

FIGURE 37.—Field trial of conservation systems on fields F, P, and Q.

grown, and each of which could be grazed by livestock. The 80 acres was accordingly divided into two fields, comprising natural watersheds by a curved fence, which was placed on a ridge running diagonally across the area. The resulting fields were designated as P. and Q. Field F, which had formerly been used to study rotational strip cropping, comprised the third field of the system (fig. 37).

A rotation of corn, small grain, and meadow, 1 year out of phase on each of the three fields, has been grown on the field units since 1938. Permanent buffer-type strip cropping, in conjunction with varying degrees of support by terraces and diversion dikes, is employed on the units. Permanent vegetation, consisting of mixtures of grasses and legumes, occupies all land areas not employed in growing crops of the rotation. It is utilized primarily for grazing with beef cattle.

The small grain is drilled between corn rows in the early fall before corn is mature. After husking the corn crop, the stalk residue and small grain are utilized for pasture in the fall. The small grain provides a winter cover crop and is again utilized for early spring grazing. It is grazed completely out, or a grain crop harvested, dependent on the need of the crop for pasture purposes. The rotation meadow is grazed, or cut for hay, also dependent upon the need for pasture. Meadow seedings have consisted of mixtures containing sweetclover. Growth, which is not removed by grazing, is plowed under preceding the drilling of corn. The system has been found to have flexibility commensurate with feed requirements of livestock during seasons of varying rainfall and plant growth. The portions of each field which are in permanent meadow are thus available for grazing for all of the 3-year period of the rotation, excepting the 5.5-month period when

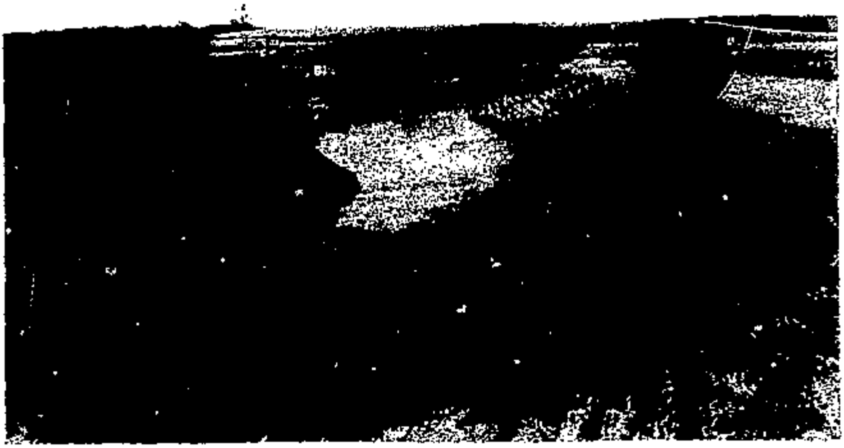

FIGURE 38.—Field F. The upper reaches of the field are terraced and the remainder of the slope utilized under a system of permanent buffer-strip cropping.

corn occupies the rotated ground. A hay crop may be cut from them during this period.

Erosion-control practices were established on each field in the fall of 1938 as shown on the land-use maps of figure 37. A detailed account of the installations is given in the following discussion of each field.

The first of these areas to be discussed is field F. Four terraces on the upper portion of the field support the growing of crops of the rotation on the land area where surface soil depth and fertility are greatest. Runoff from the terraced area is led to a fenced pond which provides a supply of water for livestock, in addition to controlling a former gully header at the pond site. Since the headwater to the normal drainage network of the field was removed, the problem of developing waterways was fairly simple. It will be noted in figure 37 that the waterway through the central portion of the area is approximately 100 feet in width.

The area below the terrace system is divided into alternate permanent meadow and rotated strips, as shown in figure 38. Boundaries of all strips are on the contour at 5-foot vertical intervals. While it is planned to retain the noncultivated strips in permanent grass over a long period of years, it would also be possible to utilize all of the area equally, by use of a 6-year rotation of corn, small grain, and 4 years of meadow. At the same time the upper terraced portion of the slope could be cropped continuously to the 3-year rotation of corn, small grain, and meadow. This plan would possibly more equitably utilize the field according to its capabilities.

In plowing the field, soil of both terraces and the rotated strips has been thrown to the outer boundaries of the terrace interval or strip. This leaves the dead furrow in the center each time plowing occurs.

FIGURE 39.—Small grain on the rotational strips of field P. Note that these strips do not extend through eroded concave-shaped areas.

The purpose of this practice is to get further data regarding the effects of benching.

The second field was placed under a system of permanent buffer strip cropping. It is identified as field P. This field was seriously eroded and clay subsoil exposed at many points, when acquired for conservation studies. It was seeded to meadow and a pond of the retention reservoir type was constructed at the location of a large gully header in the fall of 1936. Gullies were converted to vegetated waterways in the fall of 1938 and the spring of 1939 and the use of cultivated crops was deferred until grassed waterways and a meadow cover suitable for sod buffer strips were established on the field.

Cultivated strips, in most cases with a uniform width of approximately 100 feet, were plowed in the spring of 1940 for cropping to corn. The lower boundaries of the two strips which lay adjacent to the upper field borders were placed on the contour. These two strips were consequently quite irregular. The upper boundaries of the remaining strips were placed on the contour. Their lower boundaries were determined by plowing with a two-way plow, by which the furrow slice is thrown up the slope.

The location of the strips was determined by the topography and soils of the field. The minimum distance between cultivated strips was arbitrarily chosen to be 50 feet. Strips were not extended through seriously eroded concave-shaped areas where a network of fan-shaped gullies had developed in the field, as past experience had shown that they may be better utilized in perennial grasses. Cultivated strips are thus largely confined to convex land areas where runoff tends to spread as it progresses down the slope. Deviation of rows from the contour, by progressive planting down the slope, has tended to lead runoff to the grassed waterways. A view of the field while cropped to small grain is shown in figure 39.

In laying out the rotation strips of uniform width, the objective of securing protection where it is most needed was attained by use of a crescent-shaped strip laid out toward the end of a relatively flat ridge. This was done in order to crop a soil area which could not have been utilized by a strip of uniform width.

In planning the third area, field Q, a combination of terraces, diversion dikes, and permanent buffer strips was used. The measures were applied in the fall of 1938.

Two terraces made possible the use of all the deeper surface soils in the field for crop rotation purposes. They were developed as economically as possible by the plowing method explained under the section on "Terracing." Proceeding down the slope from the second terrace, diversion dikes were placed at intervals double that of the regular terrace spacing. A combination of rotated strips of even width and permanent meadow was used to control soil movement to the diversion dikes. The remainder of the field was seriously eroded and contained numerous gullied areas. After construction of the diversion dikes, these gullies were plowed in, soil treated, and seeded to permanent meadow.

The water-disposal system of this field is of interest. The two terraces on the upper portion of the slope divert water from its normal drainage course across a ridge, where, due to the moderate slope of the land, it is readily disposed of in seeded terrace outlets, along out-of-the-way fence lines. The remainder of the field drains via diversion dikes to a centrally located pond. The pond is fenced and piped to a tank to serve as a livestock watering system.

An even-width strip, extending from the center of the terrace channel above to a point approximately two-thirds of the distance to the diversion channel below, as shown in figure 40, is cropped to the 3-year rotation of corn, small grain, and meadow. Permanent meadow covers the remaining interval to the center of the channel. Thus, in addition to service as a filter strip for runoff, it occupies irregular areas and simplifies farming when row crops are grown. The purpose of placing the crop division in the center of the channel is to provide for maintenance of the diversion by plowing in the normal course of the rotation. A two-way plow is used, placing a headland on the ridge center, and leaving a furrow in the center of the diversion channel. This also insures hydraulic efficiency of the channel compatible with rates and quantities of runoff anticipated from the crop of the rotation which is occupying the field.

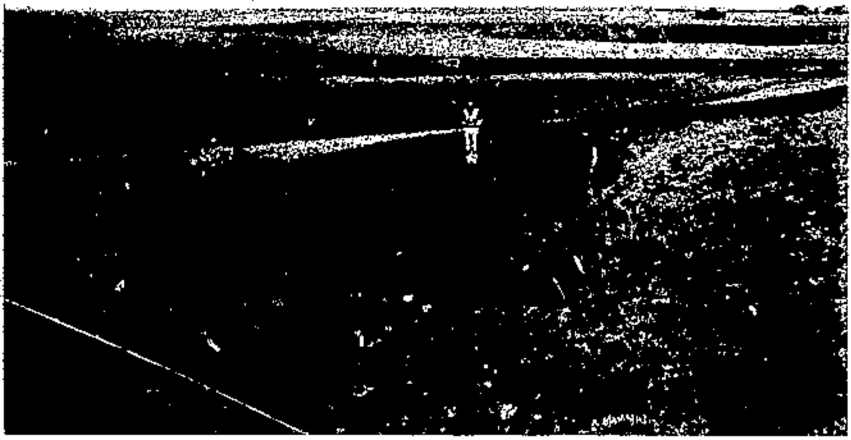

FIGURE 40.—Even width rotated strips in conjunction with diversion dikes and permanent buffer strips.

Operation of the field has been very satisfactory both as to farm management and erosion control.

RECLAMATION OF SEVERELY ERODED LAND

Reference to the reconnaissance erosion survey data for that portion of the Shelby and associated soils' region lying in Missouri shows that by 1934 subsoil was being mixed with the remaining surface soil in the plowing operation on approximately half the area. This had reached the severe erosion stage with less than 40 percent of the surface soil remaining, accompanied by severe gullying on 8 percent of the Shelby-Grundy group of soils. Thirty-six percent of the Shelby-Lindley area was so affected by 1934. In such a state these areas are not only low in value, but present a hazard to lower-lying fertile soils, particularly bottom lands. It was in an effort to study land use for the subsoil of Shelby loam that several plots were artificially eroded down to the subsoil in 1930. The plots of series 2 comprise the detail study, and a naturally eroded area on the station has provided observational data.

Soil treatment.—Plots 2 and 3 were cropped in a 4-year rotation of corn, oats, and 2 years of meadow consisting of clover and timothy. Plot 2 was untreated, while plot 3 was limed at the rate of 3 tons per acre in 1930 and received 250 pounds of 4–12–4 fertilizer with the oats. The results for the 9-year period ending in 1940 are given in table 40. The superior crop cover obtained with the treatment is reflected in the yields from the two plots. The yield of oats was increased fourfold and the yield of meadow doubled. In addition to reducing soil and water losses while these crops were on the ground, the larger amount of meadow stubble and roots turned under before corn reduced the soil loss from corn by one-half.

The effect of incorporating organic matter with exposed subsoil has received study on plots 4, 5, and 6 of series 2. All three plots were limed with 3 tons per acre in 1930 and have been cropped in a 3-year rotation of corn, oats, and meadow. Plots 4 and 5 received 188 pounds per acre of 4–12–4 fertilizer with the oats. In addition to this treatment, plot 6 received 8 tons per acre of barnyard manure which was spaded under before corn. Red clover with timothy was sown as a meadow on plot 4 and was removed for hay. Sweetclover was seeded for meadow on plots 5 and 6 and was turned under before corn in the fall preceding corn planting. Sweetclover growing on the plots is shown in figure 41. This system of management permits comparison of a plot having all crops removed, with one having sweetclover turned under, and with one having sweetclover plus barnyard manure turned under, before corn.

FIGURE 41.—Sweetclover on treated subsoil plots.

TABLE 40.—*Average rainfall, surface runoff, soil loss, and crop yields from treated*[1] *and untreated subsoil plots, 1932–40*

Crop	Number years	Rainfall	Surface runoff				Soil loss in runoff per acre		Crop yield per acre	
			Amount		Percent of rainfall					
			Untreated plot	Treated plot	Untreated plot	Treated plot	Untreated plot	Treated plot	Untreated plot	Treated plot
		Inches	*Inches*	*Inches*	*Percent*	*Percent*	*Tons*	*Tons*	*Bushels or tons*	*Bushels or tons*
Corn	2	20.46	6.02	4.87	20.4	16.5	28.54	14.69	1.1	0.8
Oats	2	32.79	8.61	6.42	26.3	10.6	39.32	13.59	3.9	16.6
First-year meadow	3	27.27	1.92	.36	7.0	1.3	.69	.08	.50	1.08
Second-year meadow	2	27.18	6.02	2.95	25.5	10.9	1.03	.65	.40	.76
Rotation average		29.18	5.87	3.65	20.1	12.5	17.40	7.25		

[1] Treatment consisted of liming at the rate of 3 tons per acre in 1930 and applying 4–12–4 fertilizer at the rate of 250 pounds per acre with each oats seeding.

The soil- and water- loss data for the years through 1934 do not follow the trend of the subsequent period. Corn on plot 5, following sweetclover had the highest soil loss in 1933. This early loss could not be satisfactorily explained by observation at the time. These data affect the averages given in table 41. Nevertheless an increase in crop yields and a decrease in soil and water loss has, as an average for the 9 years, accompanied an increase in the amount of organic matter added to these plots.

Very satisfactory responses to soil treatment, particularly phosphate and manure, were secured on the eroded field area used for observational study. This would indicate that soil treatment is an essential in reclaiming severely eroded areas in this soil region.

TABLE 41.—*Average rainfall, surface runoff, soil loss, and crop yields from organic matter treatments on subsoil plots, 1932–40* [1]

Plot	Crop	Years (number)	Rainfall	Runoff		Soil loss in runoff per acre	Crop yield per acre
				Amount	Percent of rainfall		
			Inches	*Inches*	*Percent*	*Tons*	*Bushels or tons*
4	Corn	3	28.15	5.16	19.9	17.13	12.5
	Oats	3	27.67	4.77	17.2	9.23	20.6
	Clover-timothy	3	31.06	3.76	12.1	2.39	0.79
	Rotation average	9	28.96	4.71	16.3	9.58	
5	Corn	3	28.15	4.49	16.0	19.53	15.8
	Oats	3	27.67	4.02	14.5	7.26	23.5
	Sweet clover	3	31.06	2.16	7.0	.75	Under
	Rotation average	9	28.96	3.56	12.3	9.18	
6	Corn	3	28.15	4.86	17.3	15.93	17.3
	Oats	3	27.67	4.17	15.1	7.48	28.0
	Sweet clover	3	31.06	2.45	7.9	.40	Under
	Rotation average	9	28.96	3.83	13.2	7.94	

[1] All plots were limed at the rate of 3 tons per acre in 1930 and received 188 pounds per acre of 4–12–4 fertilizer with each small grain seeding; in addition, plot 6 received 8 tons of barnyard manure per acre before corn. Clover-timothy meadow on plot 4 is removed for hay, while sweetclover on plots 5 and 6 is turned under before corn.

Tillage Practices.—The structure and texture of eroded soil is such as to make proper tillage practices essential for successful management. Time and depth of plowing are particularly important considerations. After plowing, a rough, cloddy condition usually results, due to the high clay content of the subsoil. The soil that is turned up often has a gummy consistency, which upon drying develops into hard clods. Observational study has shown that late fall plowing is helpful to soil structure. The large clods are broken into small aggregates by freezing and thawing over the winter, and in this condition are more easily worked into a good seedbed in the spring.

The effect of depth of plowing was studied for 8 years on two subsoil plots A and B of series two. The surface soil was removed from the plots in 1930; they were fallowed through 1932, and from 1933 through 1939 they were cropped to corn annually. Both plots were treated with 250 pounds of 4–12–4 fertilizer at corn planting time. Measurements of soil- and water-loss data covered the 8-year period 1932–39. During that period plot A, spaded 3 inches deep, lost an annual average of 31.5 percent of the rainfall and 58.28 tons of soil per acre, and plot B, spaded 6 inches deep, lost 24.8 percent of the rainfall and 43.83 tons of soil. Droughts and insects damaged the corn 4 years out of 7, but for the other 3 years the deep-spaded plot yielded 25.1 bushels of corn per acre compared with 19.6 bushels from the shallow-spaded plot. Plowing to the normal depth, compared with raising the plow when subsoil points are encountered, and plowing becomes more difficult, provides a more receptive condition for rainfall and a zone more conducive to root development. The presence of more moisture, the better tilth in the surface, and the release of more plant food through increased weathering make plowing subsoil to the normal depth desirable.

Cropping Systems.—The plots used in the foregoing discussion of subsoil management together with plots 7 and 8 in series 2, provide a comparison of several cropping systems on subsoil. Table 42 shows the systems together with the soil and water loss for various periods during which they were in operation. As might be expected, corn annually with commercial fertilizer had the largest soil and water loss of any system studied and the continuous grass-legume mixture had the lowest. It is significant that the soil and water losses decrease with increases in organic matter added by the different cropping systems. The second year of meadow on plot 3 accounts for some decrease in losses over those from plot 4 having one year of meadow. Oats-Korean lespedeza has given exceptionally good control for the period of study. No periods of precipitation suitable to test the control in the late fall and early spring have occurred and for that reason these data may not be within the range to be expected from this rotation over a long period of years.

Many different rotations may be used on subsoil, but those studied serve to indicate that reclamation of eroded land can be accomplished more quickly with systems in which organic-matter additions are made. For best returns commercial fertilizers are necessary, except in those instances where an abundance of barnyard manure is available. These severely eroded lands have produced the best returns when utilized for meadow crops or pasture.

TABLE 42.—*Average rainfall, surface runoff, and soil loss from various cropping systems on subsoil*

Plot	Cropping system	Soil treatment	Years incl.	Rainfall	Runoff		Soil loss in runoff
					Amount	Percent of rainfall	
				Inches	*Inches*	*Percent*	*Tons*
B	Corn, annually	250 pounds per acre, 4-12-4	32-39	29.01	7.10	24.8	43.83
8	Corn, annually	8 tons per acre, manure annually.	33-35	[1]29.01	[1]5.41	[1]18.6	[1]30.36
4	Corn, oats, meadow	Lime, 188 pounds per acre, 4-12-4 on oats.	32-40	28.96	4.71	16.3	9.58
3	Corn, oats, meadow, meadow.	Lime, 250 pounds per acre, 4-12-4 on oats.	32-40	29.18	3.65	12.5	7.25
8	Oats-Korean lespedeza	125 pounds per acre, 0-20-0 annually.	36-40	[2]25.79	[2]2.10	[2]8.1	[2]2.24
7	Grass-legume mixture	Lime, 188 pounds per acre, 4-12-4 in 1931.	32-40	28.96	1.40	4.8	.09

[1] Adjusted to be comparable with Plot B, on the basis of a straight-line relationship for the 3 years plot 8 was in this system.
[2] Previous treatment of 8 tons of manure annually during the 3-year period, 1933-35, when the plot was in continous corn.

Seeding of waterways and terrace outlets.—More than two dozen grassed waterways and 18 terrace outlets were established in the fields of the station. Various methodology has been employed in their establishment. Early work of seeding waterways for field drainage was in conjunction with wire or brush check dams and with sod bag or sod strip checks. In the terrace outlets cresosoted board checks, set in the soil with their upper edge flush with the surface of the outlet, were used to supplement the seeding. Sod strips were also used in place of the board checks. No early attempts were made to establish the waterways by seedings without supplementary devices.

The necessity for a fertile seedbed and a channel cross section, which would tend to spread runoff, was early recognized. The ditch banks were plowed, and the soil disked and harrowed until a desirable seedbed was secured. When the fill was appreciable, wire checks were installed. In the field drainageways the final cross section was elliptical shaped and in the terrace outlets the channels were shaped like modified drainage ditches with a flat bottom and side slopes of about 1½ to 1.

Most of the grassed waterways were developed at the time the fields were seeded to small grain and meadow. The drainage channels were prepared, fertilized, and seeded, broadcast with a selected seed mixture, then when drilling the field to small grain, the drainageway channels were also drilled. Satisfactory stands of grass were secured except in years of drought or when high runoff-producing rains occurred in the spring and early summer. This latter hazard was largely eliminated by establishing the waterways 1 year later or during the year when the field was in second-year meadow, although this deferment would not always have been desirable or practicable.

During later years, the use of supplementary control measures with the seedings has been discontinued except for diversion dikes or terracing, since early advantages have been largely offset by later disadvantages and increased costs. These supplementary measures will be discussed in the following section of the report.

As an outgrowth of early experience, somewhat modified methods of establishing grassed waterways were devised and used with exceptional success. This success was attributable to the methods used, and to favorable weather conditions. Establishment was started when at least a part of the drainage area was in sod and the remainder was to be seeded to small grain. The drainageways were first covered with straw and manure. The banks were next plowed in and shaped with a small grader to form a desirable cross section, which was wider and flatter than the earlier ones on the station. This cross section, in addition to having more desirable hydraulic characteristics, was designed to prevent smothering of grass, which had formerly occurred in deep V-shaped drainageways when excess amounts of snow and ice lodged in them during the winter months. The plowing and shaping operations incorporated the straw and manure in the disturbed area, thus assisting in binding and protecting the soil from subsequent rainfall and increasing its water-holding capacity and productivity. Another layer of straw and manure was next applied and disked into the surface of the soil. Care was exercised to apply only amounts which could be disked into the immediate soil surface.

Productivity changes by treatments.—Plots 1 to 7 of series II were all spaded in the fall of 1941 and planted to corn the following spring, to determine how the producing ability of the subsoil had been changed by the soil treatments during the past 11-year period. The 1942 corn yields per acre for the different rotations and treatments are as follows:

	Bushels
Rotation of corn, wheat, meadow 2 years—	
Surface soil without treatment	43.0
Subsoil without treatment	20.5
Subsoil with lime and 4–12–4 fertilizer with the oats	34.6
Rotation of corn, oats, meadow 1 year—	
Subsoil with lime and 4–12–4 fertilizer with the oats	32.2
Rotation of corn, oats and sweetclover, sweetclover—	
Subsoil limed, 4–12–4 fertilizer with the oats and the 2nd year sweetclover plowed under	44.0
Subsoil limed, 0–20–0 fertilizer with the oats, 2nd year sweetclover and 8 tons per acre barnyard manure plowed under before all previous corn crops	64.6
Continuous grass and legume meadow for 11 years without crop removal, but with an original treatment of lime and 4–12–4 fertilizer	44.2

These data show that the addition of organic matter, in addition to lime and commercial fertilizer, is necessary to bring the producing ability of the subsoil to a par with that of untreated surface soil. Sufficient addition of organic matter in the form of manure even resulted in the subsoil outyielding untreated surface soil. This treatment, however, could hardly be considered practical on a farm except for limited areas. Lime and commercial fertilizer without the manure or sweetclover plowed under resulted in a yield increase of about 60 percent over untreated subsoil but nearly 25 percent less than untreated surface soil. That a subsoil plot with only an original treatment of lime and fertilizer but without crop removal for 11 years could equal the yield of the untreated surface soil plot is further evidence of the necessity for organic-matter addition to the severely eroded soil for its rejuvenation.

Seed mixtures were varied with the apparent fertility of the soil and the degree of wetness of the location. The mixture consisted of alsike, Dutch white clover, redtop, meadow foxtail, reed canary grass and timothy, for the seepy but fertile field drainageways. For drainageways in severely eroded fields with low fertility, the mixture consisted of lespedeza, alsike clover, redtop and timothy. For terrace outlets a different seed mixture was used, as in general the outlets were located on hillsides free from seepage. Thus, bluegrass was included in the mixture in place of reed canary grass; also rye-grass was included because of its quick, early growth. Commercial fertilizers were applied with seeding. The rate of seeding varied from 20 to 30 pounds per acre.

Weather conditions played an important part in determining successful establishment of the vegetation. Near normal rainfall during 1930–33 was accompanied by fairly satisfactory results, as shown by the waterway of figure 42, whereas from the middle of 1935 through 1937 the severe drought prevented successful development of grassed waterways regardless of the method used.

Mechanical control practices.—In the fall of 1930, a severely eroded field, G–1, with slopes of 12 to 15 percent, was terraced and plowed. A small type of terrace, placed at vertical intervals of 5 feet and with a

Figure 42.—Grassed waterway developed by seeding.

channel grade of 8 inches per 100 feet was used. A section of the hillside was left unterraced to serve as a check. Portions of the field were then given various treatments similar to those formally studied on the subsoil plots and the entire field seeded to small grain in the spring of 1931.

From this seeding the soil-treated portions of the field yielded 42 bushels of oats per acre, compared to 19 bushels per acre from that receiving no treatment, and thus more than returned the cost of an original application of 150 pounds of 20-percent superphosphate per acre.

In 1932 the field was in meadow. Seedings of red clover, alsike, and sweetclover, as well as lespedeza and timothy, had been made with the oats seedings of 1931. Yields of hay were 1.25 tons per acre on the phosphated areas, 1.75 tons per acre where both lime and phosphate had been used, and where no treatment had been given the weak growth of lespedeza was too small to harvest. The field has since been retained in meadow with an occasional crop of small grain.

The small terraces were effective in holding the soil treatments on the field and in checking gully and rill formation already in progress at the time of their application. However, by 1935 they were almost filled with eroded materials and were overtopping at many locations, although vegetal cover was sufficient to prevent damage from the overtopping. In 1937 the terraces were extended across the portion of the slope which was formerly left unterraced, to alleviate rill formation at that location, and all terraces were plowed for maintenance purposes.

An indication of the increase in productivity and value of this severely eroded area after 10 years of good management is provided by the income received from the field in 1941. Hay, composed of a mixture of oats, lespedeza, and sweetclover, was sold locally and gave a gross income of $13 per acre. When fields similar to this area must be plowed and soil treatments renewed at intervals, terraces appear to safeguard the progress already made in reclaiming them. Suitable locations for terrace outlets appear to be the limiting factor in their use.

Vegetation in Drainageways

Methods of reducing soil and water loss have been discussed as they relate to the area occupied by the crop and practices. These methods are also the most important means of reducing or eliminating gully formation, as they operate to alleviate the causes of gully formation and erosion. Practices such as crop rotations, soil treatments, mulching, contour tillage, strip-cropping, and terracing, reduce the amount and rate of runoff from the fields. Furthermore, in terracing a field the gullies themselves may be eliminated, depending on the completeness with which the field is terraced.

In many cases the native perennial grasses, which originally protected field drainageways, have been destroyed either by plowing of the drainageway with the fields for crop production, excessive siltation from the land above, or by overgrazing and trampling by livestock. For successful operation of contour-tilled and strip-cropped fields, these waterways must be reestablished in vegetation. Advancing overfalls in the larger drainageways, however, are a problem to be solved by structures or dams.

Broadcast seedings were then made along with a generous application of a complete commercial fertilizer, followed by a light harrowing to cover the seed. Seed mixtures containing a rather large proportion of legumes and grasses were used. Observations of the stands and types of cover secured from these seedings reaffirmed the original theory that different mixtures were desirable for different types of drainageways. For the more fertile drainageway without seeps a mixture of timothy, bluegrass and red clover proved to be desirable, whereas for those with seeps, the red clover and bluegrass were inferior, and redtop, reed canary grass and alsike were more desirable. On the poor, eroded hillside drainageways, timothy, redtop, and Korean lespedeza appeared better suited.

After the vegetative growths were established on the drainageways, proper care resulted in improvement of the stands. Mowing helped to control and eventually eliminate weed growth. Certain areas were occasionally reseeded, and places severely damaged by runoff were repaired by placing sod immediately following the rain when the soil was wet. Livestock has been excluded from the newly established drainageways, and this undoubtedly has been a factor in their rapid development.

In 1940, brome grass was seeded in the drainageways of watersheds D–1 and I–58. The growth of the grass was hardly noticeable during 1940 and 1941, but by the summer of 1942 it was the predominating species in both waterways. There also was an appreciable amount of redtop, but very little timothy. As these drainageways are seepy, bluegrass has not become established, and stands of timothy have been short-lived. Under the conditions described, brome grass appears to offer excellent possibilities as waterway protection.

On two large drainageways on the station, drop inlet dams were constructed. The gullies above the first dam soon filled to the level of the riser by bank sloping and erosion. A tile line was subsequently installed throughout most of its length. Bluegrass has become very well established in this one whereas on the other, which remains wet, only sloughgrasses have been increasing.

Sod structures.—Bluegrass sod has been transferred from pasture lands to stabilize gullies or drainageways. In most cases the sod has been used a a supplement to the seeding of the entire drainageway, although in others it has been used in the form of flumes for overfall stabilization without application of additional treatment. The different uses have included complete sodding, sod flumes, sod-hump dams, sod checks or barriers, and sod-bag checks.

The sod was first cut with spades, which was not only slow and laborious, but resulted in poor quality sodding, due to the small size of the pieces and their uneven thickness. This method was replaced by a sled-type sod cutting machine (*27*) which was pulled by horses, truck or tractor, and which cut the sod into strips 15 inches wide and to a uniform thickness ranging, as desired, from 1½ to 4 inches.

Complete sodding on the station has been confined to terrace outlets where runoff could not be diverted from the outlet for a sufficient time for a sod to develop from seeding. Satisfactory results were secured when the sod was cut and placed over a treated and cultivated soil. The sod was handled in strips of 4 or 5 feet in length with a thickness of 2 to 3 inches. These strips were placed crosswise of the channel with the joints alternated as in laying brick. The placed strips were well tamped and loose soil placed in any cracks between the strips. Both wire staples and stakes have been used to hold the sod in place the first season. Their use was apparently not necessary in most cases, although they were considered a safeguard against high runoff velocities occurring shortly after laying of the sod. Experience indicated that thin sod strips placed on productive topsoil soon became permanently stabilized. Thicker sod (3 to 4 inches) appeared better suited for replacement on poor, eroded soil where little if any topsoil remained. This type of sodding required 1 to 2 man-hours per square yard for cutting, hauling, and placing.

Sod check barriers as first constructed were not satisfactory, as a result of the development of overfalls below the strips. This was somewhat alleviated by the use of a stepped check, although the waterways thus controlled were not ideally stabilized. The extra turbulence of the runoff at the overfall of each check has continued to be a hazard requiring attention after heavy runoff rains. Sod hump dams and sod flumes have been used to advantage by the Missouri State Highway Department in the control of roadside drainage ditches, as shown in figure 43.

Sod-bag checks were used in the early years of the station, but due to their cost they were replaced by the sod-strip barriers. The only apparent advantages of the sod bags over the sod strips was in those cases where only extremely poor quality sod was available. They had, however, the same disadvantage as the strip check in that when they did produce a dense stand of sod in the waterway, the waterway was a series of steps, each becoming a hazard for future overfall erosion, instead of a channel of uniform or gently changing grade as produced by complete sodding or seeding.

From experience on the station, certain points common to all bluegrass sod checks were evident. Sod of this grass will not live when placed in wet, seepy locations; it will withstand fairly high runoff velocities provided the direction of velocity is not changed on the sod itself; bluegrass sod as well as other crops cannot be expected to thrive and give satisfactory protection when placed on soil devoid of available plant nutrients or without capacity for absorbing rainfall for future plant use; protection against tramping of livestock during wet periods is necessary if excessive maintenance is to be eliminated;

FIGURE 43.—Sod-hump dams in highway ditch adjoining the station.

and sod is the only practical repair material for small damaged places in waterways and outlets.

Trees.—A study to test the control of drainageways and gullies by use of trees was started in 1931. Plantings of black locust (*Robina pseudoacacia*) were made in gullies of fields H and L. Other plantings were made on sites in Harrison County for a more extensive test.

The spacing used was 2 to 3 feet between and within rows. All tests were spot or localized plantings, confined to the bottom, sides, and banks of the gullies. All but a few of the locations received runoff from cultivated lands. The trees made excellent growth and survival in 1931 and 1932, except on wet locations in the bottom of the gullies. Plantations became infested with the locust borer in 1933. Drought periods in 1933–36, in combination with the extremely close spacings of trees, borer infestation, and repeated denudation of leaves by grasshoppers, resulted in almost complete loss of the trees. The dead top growth was removed in 1937.

A few of the root growths of the plantations were not killed and formed new shoots in 1937 and 1938. In 1941 a few scattered trees are present on the gully banks. Some are 15 to 20 feet tall and are producing seed pods.

The plantings of locust on the station have not evolved into gully control. They tended to hold the banks of the gully and to prevent their caving in, but relatively deep washes occurred in the bottom of the gullies between the trees on the banks.

Plantings made in two large hillside gullies of the Dale Harvey farm about 30 miles from the station were more successful. The gullies were on an approximate 10-percent slope and extended close to the top of the hill. The drainage areas at the heads of the gullies were less than 0.5 acre and the fields had been retired from cultivation. These plantings were made in the spring of 1932. One gully received 20-percent superphosphate fertilizer and the other was planted without treatment.

An inspection of the plantings was made in 1939 and good control of the hillside gullies was in evidence. The gullies apparently had good drainage as the trees were present over the entire area. Comparisons of the tree growth in the fertilized and unfertilized showed that the fertilized plantings exceeded the unfertilized plantings by 23 percent in stand, by 14 percent in height, and by 40 percent in diameter.

Willow (*Salix nigra*) plantings were made on the ravine of field L, below the site where locusts were planted. The initial plantings were also made in 1931. Good growth of the willows took place until 1934, when they were killed by drought. They assisted in stabilizing the gully to the extent that a grass cover developed before they were killed. Observations of willow growth in many ravine and branch drainageways in the vicinity indicate that they are effective in providing stabilization in these locations. They tend to die out with extreme temperatures and drought, but once established make recurring growth from natural seedings.

Structures for Water Disposal

Temporary check dams.—Check dams of posts, wire, and brush were originally designed to stabilize gullies until vegetation became established. Many structures of this type were installed in ravines A and B of the station, and in field drainageways entering the ravines.

The first brush structures were usually piles of brush placed longitudinally in gullies with the butts upstream and held down by rows of stakes driven through them. Sometimes woven wire was placed over the brush and fastened to the stakes to hold the brush in place. Later installation consisted of single or double rows of posts across the gully approximately 2 to 3 feet apart. Brush was packed between the posts and held in place with wire. Brush aprons were usually placed below the post and brush dams and held in place by driven willow stakes. All of the brush structures required maintenance each year as holes developed in the rotting brush. New brush had to be added frequently.

The first wire checks installed were essentially fences of woven wire. The wire was set in the ground a few inches and from time to time straw was placed on the upper side of the wire. The checks rapidly filled with silt, and cut around the ends, usually moving the gully a short distance to the side. New installations were then made in which the centers of the wire checks were lowered to provide sufficient weir-notch capacity to confine the runoff. Again they filled with soil until such time as straw rotted and holes formed in the barrier. Almost constant maintenance to keep the fills from washing out was required. Water falling over the checks also cut holes immediately below the structures. Only a few checks on small drainageways of 5 acres or less have become stabilized with vegetation both above and below.

One essential principle of gully control has been secured from the installations, namely, that water cannot be lowered over temporary structures without constant and costly maintenance and that methods of temporary gully control, which tend to develop a series of drops, are undesirable.

Wood structures.—In 1932, a dam built of 3-inch creosoted fir planks was installed on a drainage area of 17 acres. The 8-foot planks were placed vertically and bolted together with cross members. The lower 2.5 feet of the planks were anchored in the bottom of the gully. A trapezoidal weir notch was provided, and an apron of concrete and rubble masonry was placed below the dam. The life of the structure as originally installed is estimated to be approximately 18 years. This type structure appears to give good service, and is easily installed, although its economy is questionable unless the lumber may be obtained at costs lower than those prevailing in the locality of the station.

Creosoted boards 2 x 12 inches, placed at right angles to the direction of water travel and flush with the ground surface, were installed in several terrace outlets and one field drainageway on the station. Their purpose was to assist in stabilizing the channel until a grass sod could be developed from seeding. Each board developed an overfall below. They appeared to be a hindrance rather than an aid, in developing the grassed channels.

Asphalt structures.—Several asphalt structures have been installed in gullies with drainage areas ranging from 4 to 30 acres. Mixtures of dry sand and asphalt in the proportion of 1 cubic yard of sand to 1 gallon of asphalt were used in the structures. The materials were heated, mixed and applied as flume or channel linings. Reinforcing of diamond-shaped wire chicken netting and burlap was used in the larger structures. The body of the linings was 3 to 4 inches thick, with the reinforcing material in the center. The surfaces of one of the structures was lined with burlap previously soaked in hot asphalt. All structures were given a seal coat of fluid asphalt.

A seal coat of asphalt was required each year to prevent deterioration of the surface by weathering. The materials became soft and rather unstable in hot weather, necessitating protection from livestock. Vegetal growth was also found to penetrate the linings, and to lead to disintegration of the materials. The protective covering of burlap and asphalt did not maintain a satisfactory bond with the sand-asphalt mixture. The materials failed to withstand the force of changing flow direction at the structure apron, on all such structures installed. Aprons of concrete are at present used on the two remaining structures.

The use of asphalt as a gully control material cannot be recommended on the basis of its performance in these trials.

Rock-masonry dams.—Two rock-masonry dams were constructed in 1935. The smaller structure is the straight wall type and the larger is the arched wall type. They have not required maintenance and after 7 years they are in excellent condition. Their service life is estimated to be a minimum of from 30 to 35 years. They appear to be a durable and desirable structure for locations where it is necessary to maintain a permanent drop of 3 to 5 feet in the drainage system. This type of structure is particularly adapted to those localities where rock is available on the farm site.

Concrete spillways.—An unformed reinforced concrete spillway 4 to 6 inches thick was installed in 1932 to protect a drop of 5 feet below

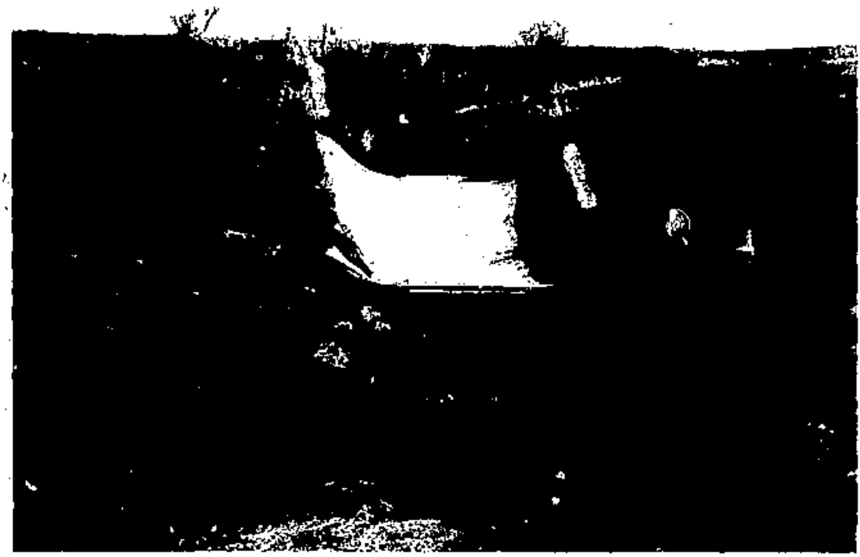

FIGURE 44.—Unformed reinforced-concrete spillway in a drainage-way of 20 acres after 10 years of service. The structure controls a drop of 5 feet.

a drainage area of 19.6 acres. It has now been in place for 12 years, and with minor repair, is estimated to have a life of over 20 years. Maintenance to date has consisted of placing a cut-off wall at the lower edge of the apron. A few minor checks have developed in the concrete, but they do not appear to be of a serious nature. This spillway, shown in figure 44, is the original of the present "Missouri-type unformed flume (*88*)." Spillways of this type appear well adapted to control of drops up to 5 or 6 feet. They have the further advantages of economy of materials and are easily and quickly installed.

A drop inlet type overshot flume was constructed over an earth dam in 1937, in place of the side spillway unformed concrete flume which had failed. The flume was designed to give a large discharge with a relatively low head, and to eliminate the use of all materials not used in conveyance of runoff without sacrificing durability. Reinforced concrete 3 to 4 inches thick was selected as the construction material. The structure was divided into several independent units for installation, to eliminate the danger of breaks from freezing and thawing which would normally accompany the thin section to be used. The shape was such that the structure would blend easily with the soil and vegetation and could be troweled into place with a minimum of forming. The lower section was to be a small but efficient energy dissipator.

Scale models of the proposed flume were made of sheet metal, tested, and changed until the desired performance was secured. The resulting structure is shown in figure 45.

The flume was constructed in seven independent units. The inlet section was installed first. The only concrete form required for this section was for the square part of the drop. The velocity dissipator

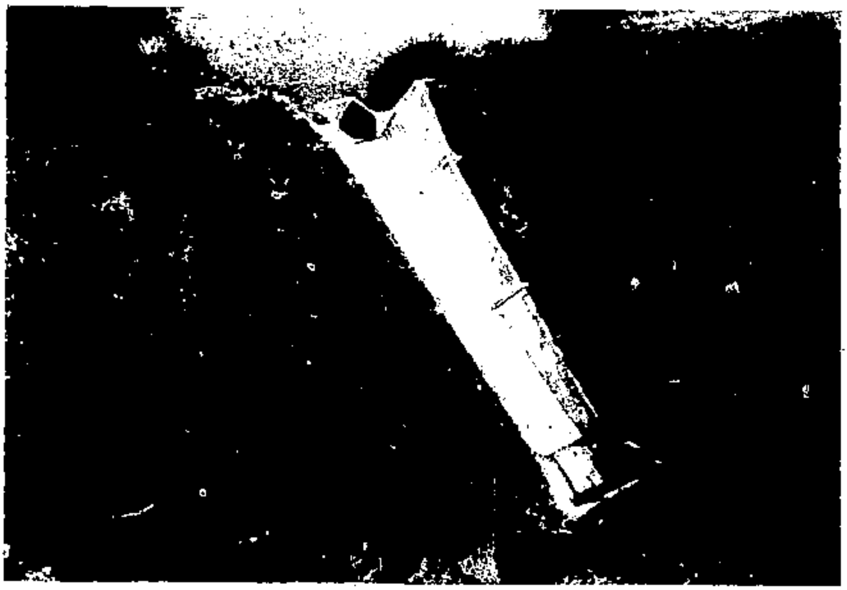

FIGURE 45.—Drop-inlet type overshot flume developed and installed at the station.

or lower section was installed next. It was shaped to throw the water upward and outward instead of backward as with the "turn-back type."

Upper and lower cut-off walls were next installed. The upper one was located on a 2-to-1 slope above the velocity check at the point of tangency with a 10-foot radius curve from the inlet section. The lower cut-off wall was placed midway between the upper cut-off wall and the velocity check. The middle spillway section was installed before the upper and lower sections, so as to help in lining the other two sections. The concrete was placed on the side wall before placing on the bottom of the spillway section. Construction joints were left between the spillway sections and the cut-off walls. These were later filled with asphalt.

Both woven-wire and steel-bar reinforcements were used in the spillway sections. The woven wire served to hold the concrete in place on the slope before setting. Only steel bar reinforcing was used in the other parts of the structure. The flume remains intact after 7 years of service.

Farm ponds.—Five farm ponds have been located on the station. They all drain cultivated areas ranging from 10 to 30 acres and are used as aids to gully control, as well as a source of water for livestock. Their drainage areas, while under cultivation, are well protected by supporting practices, such as terracing, contouring, and strip cropping, and siltation is not excessive.

The general practice in the locality of the station is to place the ponds on grassed drainage areas of from 2 to 5 acres. This has been highly satisfactory, because a large volume of the storm runoff from this type area is stored in the ponds. Little or no spillway protection, beyond diverting a small amount of runoff from the earth fill has been necessary. These small ponds are usually located well up on the hillside.

Observations of ponds on the station indicate that with the aid of conservation practices, ponds may be successfully used on larger drainage areas. This procedure does not replace building of small ponds higher on the slope reaches, but extends their range of usefulness to larger areas, particularly for gully control. Ponds located on the larger drainage areas have been placed on relatively flat portions of the drainageway to afford protection and assist in stabilizing ravine gullies below. Large quantities of water are stored at these locations, with relatively low dams. They have made excellent habitats for fish and waterfowl. Those with the larger drainage areas have been protected by mechanical outlets. Sewer tile with the detention reservoir-type dam or concrete and sheet metal flumes with the more conventional pond dams have been used successfully for this purpose on the station.

Farm ponds have been one of the most popular conservation practices on the Shelby soil. In the 5-year period from 1935 to 1940, the building of ponds in Harrison County has increased rapidly. The construction of 300 ponds was reported to the county agent in 1940. Sixty of these were fenced and piped to livestock watering tanks. In 1941 the number of new ponds constructed was 400. Four professional pond diggers have residence in the county. Other ponds are built with farm and county-owned equipment.

Drop-inlet dams.—The first large gully-control structure on the station was constructed in the spring of 1930. This was a drop-inlet dam, placed at the lower end of ravine B, which drains an area of 65 acres. A 4-foot corrugated pipe was so placed on the side of the gully that a concrete riser of only 4.5 feet was necessary. Four concrete seep collars were also placed along the length of the tube. An earth fill, with a top width of 12 feet, and a maximum height of 15.5 feet completed the structure. The earth fill had side slopes of 2 to 1 and a volume of approximately 650 cubic yards. An emergency side spillway was located 2 feet above the top of the riser. The top of the earth dam serves as a farm roadway. The portion of the gully above the dam was sloped by grading operations in the fall of 1932 and the spring of 1933. A line of 4-inch drain tile was also installed.

Cross-section and profile views of the gully are shown for the original condition in 1930, after grading operations in 1933, and again in 1939 after the fill materials have been stabilized by vegetation, in figure 46. It is of interest that the fill materials have assumed an almost uniform grade of 0.007 foot per foot for a distance of approximately 750 feet above the inlet of the soil-saving structure. The remainder of the gully, where the slope is in excess of this figure is at

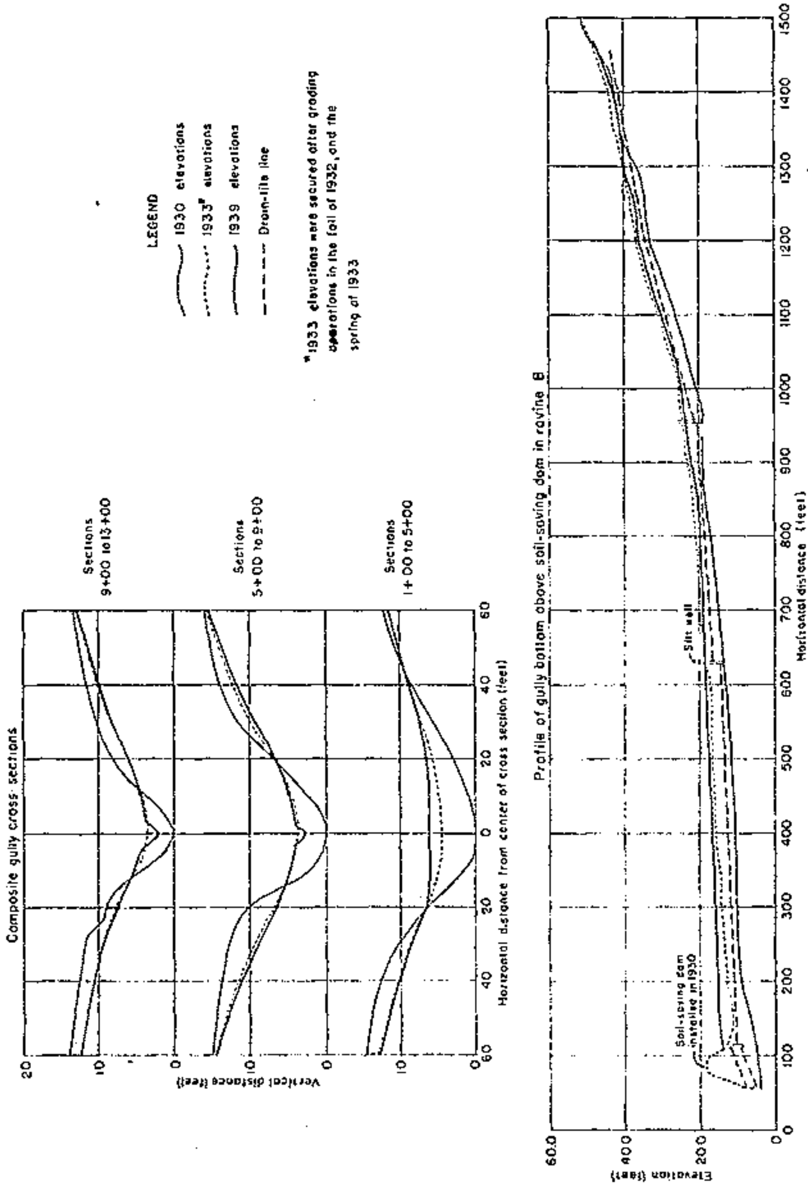

FIGURE 46.—Gully cross sections and profiles above drop-inlet dam in ravine B.

present subject to channel formation. The gully in 1930 and the reclaimed gully in 1942 are shown in figure 47.

A drop-inlet dam in ravine C, completed in 1934, serves a drainage area of 100 acres. The dam is 12 feet high, 125 feet long, 60 feet

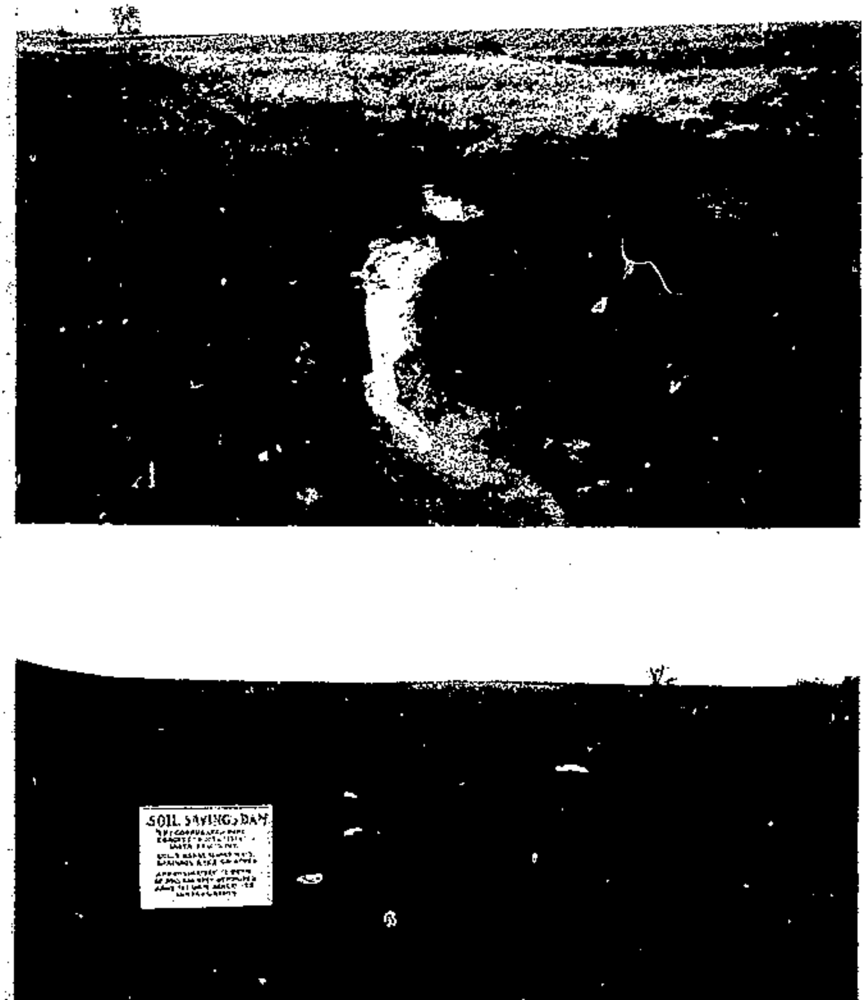

FIGURE 47.—*A*, Ravine B before control work was started in 1930; *B*, the same gully in 1942.

wide at the base, and 5 feet wide at the top. The drop-inlet culvert is 4 x 4 feet and has an 8-foot riser.

The drainage area of the structure is well protected by vegetation and terrace systems, consequently, little soil has been deposited in the reservoir above the dam. The water surface of the reservoir has formed a stable point in the ravine, and vegetal cover at present covers the remainder of the gully bottom. This vegetal cover is predominantly sloughgrass. Profile readings in 1941 show the gully to be stable at a slope of 1 foot per 100 feet.

The use of drop-inlet dams, if strategically placed, affords a method of stabilizing many active ravine gullies. Such structures, while high in initial cost, will often protect several overfalls entering a large gully, and consequently, are more economical than several smaller structures which may accomplish the same purpose. Their present use is largely limited to highway systems, where they are gully-control measures, in addition to being a part of transportation systems.

Comparative cost of structures.—The original cost, actual maintenance cost, the life expectancy, and future anticipated maintenance cost, of various type gully control structures located on the station are given in table 43. It is to be noted that drop-inlet culverts, a detention reservoir, and unformed flume ¾ inches thick have been the most economical. The basis of comparison is the cost in dollars of protecting a 1-foot vertical drop on a drainage area of 1 acre for a period of 1 year.

TABLE 43.—*Cost of various structures, Soil Conservation Experiment Station, Bethany, Mo.*

Structures: Kind	Structures: Description	Structures: Installation date	Drainage: Number	Drainage: Area	Drainage: Vertical drop	Cost[1]: Original	Cost[1]: Maintenance: To date	Cost[1]: Maintenance: Anticipated	Life, years	Protection, feet-acres-years	Cost, dollars, feet-acres-years
				Acres		*Dollars*	*Dollars*	*Dollars*			
Temporary checks	Discarded oak posts, wire, and brush	1931	6	8	17	11.25	30.37	10.00	12	1,632	0.032
	Hedge posts, wire, and brush	1935	6	15	15	136.10	13.75	25.00	20	4,500	.039
	Double hedge posts, wire, and brush	1932	1	30	2½	31.00	8.75	10.00	25	1,875	.027
Permanent and semi-permanent	Creosote dipped 3-in. plank dam	1932	1	17	6	70.23	0	0	18	1,836	.038
	Rubble-masonry dam	1935	1	26	4½	97.58	0	5.00	30	3,510	.029
	Rubble-masonry dam	1935	1	6	4	31.70	0	2.00	35	840	.040
	Asphalt and sand flume (3-4 in. thick)	1936	1	11	8	29.00	13.00	10.00	10	880	.059
	Asphalt and sand flume (3-4 in. thick)	1936	1	28	6½	97.97	45.55	10.00	12	2,184	.070
	Unformed concrete flume (4-6 in. thick)	1932	1	19.6	5	33.15	15.25	15.00	20	1,960	.032
	Unformed concrete side spillway (1½-2 in. thick)	1932	1	19	13	99.00	15.00	...	5	1,235	.092
	Concrete drop-inlet flume (3-4 in. thick)	1937	1	19	14	126.00	0	15.00	25	6,650	.021
	Corrugated sheet-metal flume (wooden framework)	1930	1	19.6	7	22.00	0		3	412	.053
	Sheet-metal flume	1939	1	15	6	25.00	0	12.00	12	1,080	.034
	Detention reservoir (1-foot sewer tile)	1936	1	29	14	153.67	5.00	15.00	25	10,150	.017
	Drop-inlet culvert (corrugated)	1930	1	65	12	251.65	50.00	10.00	30	23,400	.013
	Drop-inlet culvert (concrete)	1934	1	100	8	625.02	0	50.00	50	40,000	.017

[1] Costs shown do not include placing of earth fills.

Tile lines for drainage of silt deposits.—A line of 4-inch drain tile was placed in the fill material above a drop inlet culvert on ravine B in 1933, as shown in figure 46. Its purpose was to give drainage which would encourage desirable types of vegetal growth, and possibly cause the fill material to assume an increased gradient from the dam below. Bluegrass is the predominating plant growth on this soil deposit of low gradient, while the fill material in ravine C without a tile line and above a similar drop-inlet dam has a vegetal cover in which sloughgrass predominates.

Tile and sod channel lining.—In the winter of 1938, concrete half tile were precast in the station shop. The tile were 4 feet in length, had an inside diameter of 1 foot, and a wall thickness ranging from

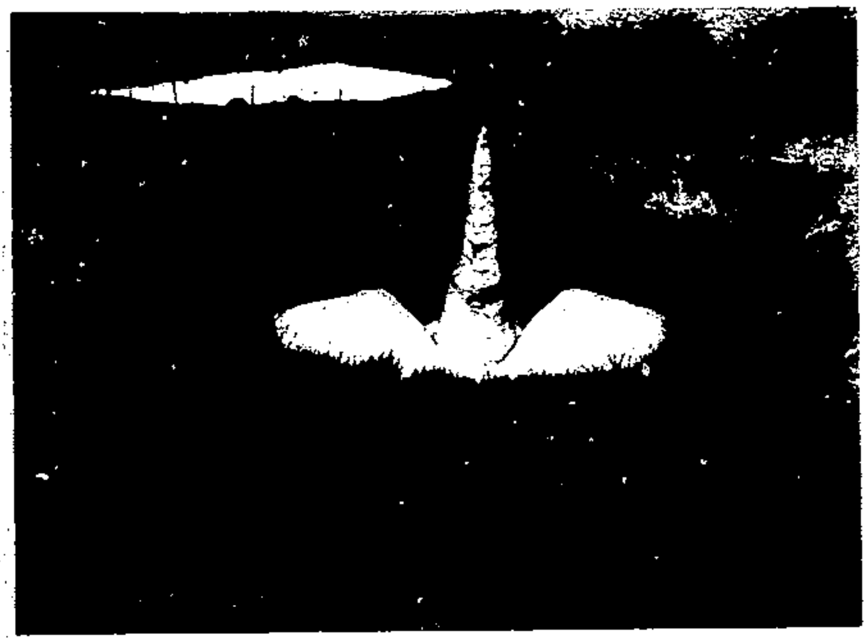

FIGURE 48.—Half-tile and sod-channel lining for diversion-dike outlet.

3 inches at the bottom to 2 inches at the edges of the half section. They were reinforced with woven wire and had flanges at the ends for overlapping sections of adjoining tile during installation.

The half tile were installed as a diversion-dike outlet in 1939 on a 7.5-acre drainage area of field F to convey runoff to a farm pond. The tile will carry runoff from the drainage area at the approximate rate of 0.8 inch per hour. On the basis of runoff from terraced areas on the station, the size of the tile would have been sufficient to carry 90 percent of the total runoff occurring during the last 10 years.

The plan was to install sod strips along the edges of the tile to provide for added capacity. Before these strips were installed a 7-year intensity-frequency storm occurred. The tile were overtopped and earth washed from along their sides, but they retained their position on the slope. This soil was replaced and the sod lining installed as originally planned. The capacity of the tile has been exceeded, and the sod has successfully carried a portion of runoff during four subsequent storm periods. The sod growth has been found to lap over the edges and to make a good bond with the tile. The installation as it stood in 1942 is shown in figure 48.

Diversion dikes.—The term "diversion dikes" is usually applied to large terrace-like channels draining land areas greater than normally drained by an individual terrace. The seven diversion dikes installed on the station have been used to divert runoff of small areas on neighboring farms, to divert runoff of the station barn lots, and in conjunction with experimental conservation practices on field-sized areas. Table 44 gives the specifications of the different dikes, the areas they drain, and the type of outlet used.

TABLE 44.—*Station diversion dikes*

Location	Drainage area	Total length	Specifications, lower 200 feet		Type of outlet
			Cross-section area	Grade per foot	
	Acres	*Feet*	*Square feet*	*Foot*	
Pa-B	2.8	950	5	0.017	Bluegrass pasture.
Pa-C	2.1	410	7	.010	Do.
Field F	7.5	325	10	.008	Combination concrete and sod.
Field L	1.6	530	9	.002	Grassed waterway.
Field Q:					
3 north	5.4	1,350	18	.005	Sod channel.
3 south	4.0	1,340	15	.004	Do.
4 south	4.1	1,350	13	.005	Do.

The Pa-B dike receives runoff from the station barn lots and driveway. The channel has been scouring toward the outlet end, due to excessive grade and lack of a satisfactory stand of vegetation in the channel. This part of the dike passes through a sparsely timbered pasture. Cattle seeking the shade of the trees have trampled out the grass each summer. Cutting is also taking place to a limited extent in the pasture sod below the outlet of the channel. Prior to 1937 a section directly above the dike was devoid of vegetation due to improper location of a stock tank. This made necessary the frequent removal of silt from the channel to prevent overtopping of the ridge. Moving the tank and vegetating this area eliminated the difficulty.

The pasture C dike channel has become well established with grass. There is no evidence of erosion in the channel itself or directly below the outlet on the sod of the pasture. The drainage area is permanently vegetated.

The channel of field F has scoured to a limited extent. The runoff carried by this dike has been high as it has been from eroded land across the property line, from about 600 feet of one of the station roads, and from four cultivated terraces. A cover of grass has not been secured in the channel. Some scouring has resulted from the high velocity of the runoff water in the channel.

The dike on field L receives runoff from a pasture and meadow slope. Its purpose has been to divert runoff of this upper part of the slope from the waterway and strip-crop area below. This dike was located about 12 feet vertically below the ridge top. It has performed satisfactorily without scouring or silting of the channel and without erosion in the outlet.

The diversion dikes of field Q are terraces at double the recommended vertical spacing. They are cultivated with the remainder of this field except for a permanent meadow buffer strip directly above the channel. There has not been visible scouring or excessive silting in the channels.

The diversion dikes of fields, F, L, and Q, and of pasture B have been of material assistance in revegetating the drainageways directly below. They have provided supplementary protection at low cost in the experimental application of conservation practices on fields L and Q.

From this experience with diversion dikes, it is apparent that their operation, without excessive maintenance, requires an area of grass above the channel or some other method of preventing the formation of silt deposits in the channels. Grades in excess of 0.005 foot per foot are not desirable if the channel is to be cultivated or if it cannot be satisfactorily vegetated with grasses. The outlet problem is practically the same as for terraces.

Hydraulic Studies

Studies of the retarding influence of vegetation on the flow of water have been made on terrace outlets and channels. Such studies have all been made in the field from storm runoff. The retardance coefficient n in the Manning formula,

$$V=\frac{1.486}{n}R^{2/3}S^{1/2}$$

in which V equals velocity in feet per second, R equals hydraulic radius in feet, S equals energy gradient in feet per foot, and n equals retardance coefficient has been used as a gage of channel roughness.

Retardance of bluegrass terrace outlets.—Data secured prior to 1938 on bluegrass terrace outlets on slopes ranging from 7 to 12 percent, consisted of peak discharge rates and maximum depth of flow readings in the channels. The slope of the channel was assumed to coincide with the energy gradient and substitution of these data in the Manning formula was made for 34 channel flows. The average value of n was found to be 0.075 with variations from 0.024 to 0.24. In general, the smaller values were secured from new outlets having only a thin young stand of vegetation.

Two bluegrass outlets, one on field G having a 12 percent slope, and the other on terraced watershed D–2 with a 5.9 percent slope, were each equipped with a Friez float recorder in 1938. The recorders were placed at the side of the channels to give a continuous depth reading of channel flow, while Parshall rate-measuring flumes at the end of the outlets gave a continuous record of the discharge.

A storm of 7-year frequency occurred on June 21, 1939, when bluegrass was at its maximum growth stage. For shallow flows the grass remained erect and created excessive turbulence. Values of n both channels approximated 0.55 for this condition. Bluegrass was flattened out on the 12-percent slope when the flow depth reached 0.5 foot. A flow depth of 0.33 foot subsequently resulted in a minimum value of n of 0.65. Bluegrass flattened out on the 5.9 percent outlet at a flow depth of 0.6 foot. The minimum value of n was 0.095 at a flow depth of 0.62 foot. The values of n during recession flow increased uniformly with decreases in flow depth, again reaching 0.55 at low stages, when the entire body of the bluegrass was incorporated throughout the flow. Data for this particular rain were calculated by using the outlet slope as the value of S in the Manning formula, as only one recorder was located in each outlet.

In 1940 another Friez water stage recorder was added to each of the two outlets to form a test section from which the slope of the

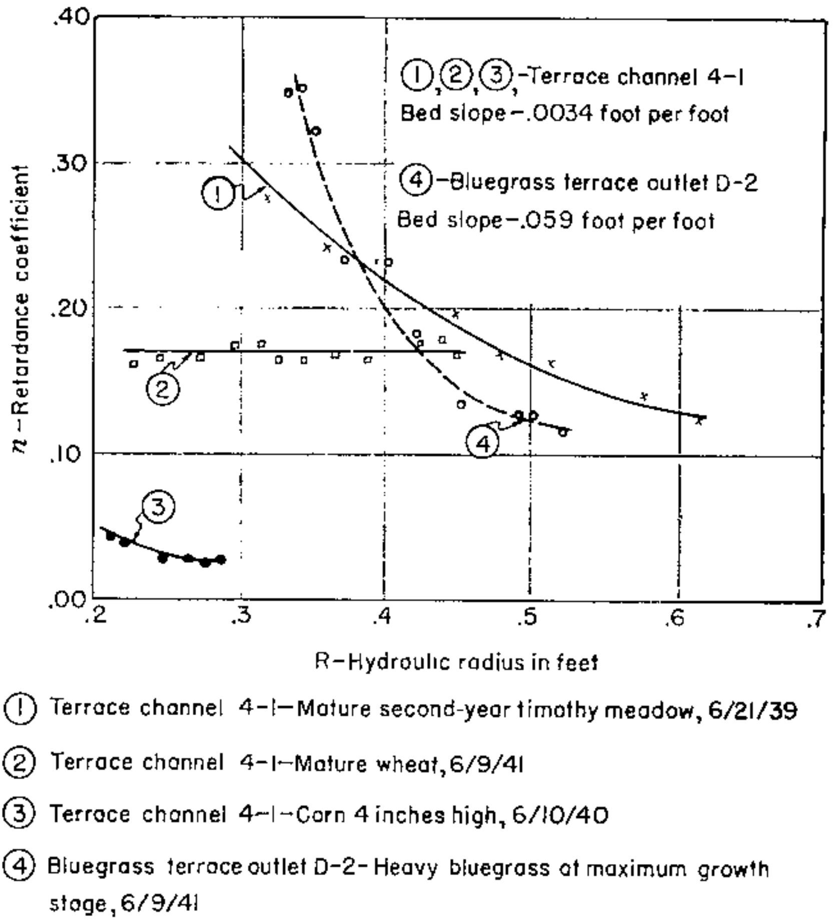

FIGURE 49.—Retardance coefficients of vegetal channel linings.

water surface and energy gradient could be calculated. Flow occurred on the 5.9 percent outlet from a rain of June 9, 1941. Bluegrass was again heavy and at a maximum growth stage. Values of n during the gradual varying flow of hydrograph recession yielded a minimum value for n of 0.118 for a hydraulic radius of 0.52 foot. The range of values for this runoff period is shown in figure 49. They are believed to approach the maximum retardance which heavy bluegrass will afford, in the Shelby soil region. Values of n were slightly higher when the energy gradient determined by the Manning formula during recession flow was used for S instead of the channel grade.

Retardance of vegetation in terrace channels.—Terrace channel 4–I, having a length of 2,450 feet and a drainage area of 3.34 acres, was equipped with two channel water stage recorders and a 3-foot type H flume, in 1938. The test section is 150 feet in length and its average slope 0.034 foot per foot. Hydraulic data for the Manning formula are secured by reconstructing the runoff hydrograph to compensate for the time lag in measurement between the test section and the rate measuring flume at the end of the terrace. Only values for the gradually varied flow during hydrograph recession are presented. This eliminates the overland flow entering the test section from the interterrace area during the storm. Values of n have been secured on 2-year-old timothy meadow, mature wheat, and corn 4 inches high. All values are shown in relation to the hydraulic radius by the curves of figure 49.

The values of n for the mature 2-year-old timothy meadow approach the maximum retardance which vegetation will produce in the terrace channel. The flow on corn ground approaches the minimum value of n which will be experienced in a terrace channel. The corn height of 4 inches produced little, if any, retardance when this record was secured in 1940. The flow on mature wheat in 1941 resulted in a constant value for n of 0.17 for values of the hydraulic radius up to 0.45 foot, which was the maximum secured from the runoff period. A fundamental difference in the retardance of wheat and timothy is noted. This is attributed to the fact that mature wheat is an open, uniform type of vegetative growth in which the ratio of the vegetative surface retarding runoff to the hydraulic radius remains almost constant with increases in the value of the hydraulic radius. Mature timothy has graduations of density of vegetative growth from a maximum at the ground surface. The density of vegetation in the across section of the flow area decreases with increases of the hydraulic radius.

From the studies conducted in terrace channels and outlets, it is apparent that the retardance coefficient n in the Manning formula is a function of plant growth characteristics, the effects of which vary with changes of S, R, and V.

Watershed Studies

Eight small agricultural watersheds, varying in size from 2 to 8 acres, comprise a study of the effect of land use and conservation practices on runoff and erosion.

Plans for establishment of the watersheds were developed and seven of them were laid out during the period, 1930–34. They were equipped with Parshall rate measuring flumes and Ramser silt samplers as funds permitted. Two of the watersheds were under measurement in 1932. By 1934, seven were under measurement. A contour-furrowed bluegrass pasture watershed was added in 1936. This latter watershed will not be discussed in this section as the relatively short period of records is covered in another section of this report. Typical measuring equipment installations are shown in figure 50.

Characteristics of the watersheds, hydrologic data, the cropping practices, soil treatments, and the period of records for each are shown in appendix, tables 52 and 68–75.

FIGURE 50.—The type of measuring-equipment installations used in the watershed studies; contoured watershed D-1 to the left and terraced watershed D-2 on the right. The silt box on watershed D-1 is 80 feet in length.

Discussion of annual data.—Average annual data from the watersheds over a period of years afford some interesting contrasts, although they do not permit a precise evaluation of the various major control practices alone, due to the presence of other variables. These data are included in table 45.

Referring to the table of average annual data it will be noted that for the 9-year period 1934–42, terraced pasture (Pa–A) had slightly less runoff and greater soil loss than the undisturbed pasture (Pa–B). A study of amounts for individual years shows that both water and soil loss were appreciably greater from the terraced pasture during 1934, or the year following terrace construction. During the following 8-year period runoff from the terraced pasture averaged 82, and soil loss 36 percent of that from the undisturbed pasture. During the period 1932–35, pasture (Pa–B) had soil losses averaging 1.85 tons per acre per year. During the period 1936–42 they averaged only 0.06 ton per acre due to the elimination of gully erosion which occurred on the lower portion of the watershed during the early period of measurement.

A marked contract is also afforded by comparing losses from watersheds D–3, I–58, and Pa–B, during the period 1933–42. The straight-row farming practiced on watershed D–3 has produced appreciably more runoff than either the watershed cropped to alfalfa or retained in bluegrass. The soil loss is also many times greater and approximately equivalent to a loss of 0.2 inch per year.

TABLE 45.—*Averages of annual data from watersheds in various land use and with different conservation practices for specified periods of years*

Watershed designation	Major practice [1]	Period of records	Rainfall	Runoff		Soil loss per acre
				Amount	Percent of rainfall	
		Years	*Inches*	*Inches*	*Percent*	*Tons*
Pa-A	Bluegrass, terraced	1934–42	29.45	2.36	8.0	[2] 0.94
Pa-B	Bluegrass, undisturbed	1934–42	29.26	2.58	8.8	[3] .62
D-3	Rotation, no supplemental practices	1933–42	29.41	4.96	16.9	26.98
I-58	Alfalfa 1st, 5 years, Oats-lespedeza 2d 5 years.[4]	1933–42	29.71	3.82	12.9	3.18
Pa-B	Bluegrass, undisturbed	1933–42	29.47	2.59	8.8	[3] .60
D-3	Rotation, no supplemental practices	1935–42	28.95	4.67	16.1	25.26
D-1	Rotation, contoured	1935–42	28.86	3.91	13.7	2.76
H-1	Rotation, strip-cropped	1935–42	29.32	3.17	10.8	1.69
D-2	Rotation, terraced	1935–42	28.77	3.27	11.4	.55

[1] Refer to appendix table 52 for additional variables and specifications of the watersheds and to appendix tables 68–75 for cropping, yield, and annual data.
[2] Losses were relatively high during revegetating of area disturbed in terracing.
[3] Includes gully erosion prior to 1936.
[4] Runoff and soil loss were appreciably less during last 5-year period. (See table 23.)

The four watersheds in rotations containing intertilled crops, and various supplementary practices, show reductions in average annual runoff and marked reductions in soil loss during the period 1935–42, with increasingly rigid supporting practices.

Correlation of maximum runoff rates with other variables.—The maximum rate of runoff for a given watershed is a function of cover and soil moisture condition in addition to rainfall intensity and amount. Rainfall intensity and antecedent rainfall are variables which can be expressed numerically, and which are available from weather records. These data were correlated with the maximum rate of runoff to determine the extent to which they have determined the maximum rate of runoff from the bluegrass pasture watershed Pa–B and the up-and-down-hill cultivated watershed D–3. This study demonstrates the effect of extreme differences in land use on these several interrelated factors.

Seventy-nine rains during the 8-year period 1933–40, with a 15-minute intensity of 1 inch per hour or greater, were included in the comparison. They are classified as excessive rainstorms by the Weather Bureau. Sixteen of the storms did not cause runoff on the cultivated watershed, while 45 did not result in runoff from the pasture watershed. Distribution of maximum rates of runoff from the two areas is shown in table 46.

TABLE 46.—*Distribution of maximum rates of runoff from 79 storms*[1] *from a cultivated and a pasture watershed during the 7-year period, 1933–40*

Range of runoff in inches per hour	Cultivated watershed D-3	Pasture watershed Pa-B	Range of runoff in inches per hour	Cultivated watershed D-3	Pasture watershed Pa-B
	Number	*Number*		*Number*	*Number*
0-0.49	45	69	2.00-2.49	5	0
0.50-.99	11	3	2.50-2.99	4	1
1.00-1.49	3	4	3.00-4.99	2	0
1.50-1.99	9	2			

[1] All storms during the period with a 15-minute intensity equal to or greater than 1 inch per hour.

The period of concentration for each of the watersheds was assumed to be within the limits of 5 to 30 minutes. Antecedent rainfall was used to express soil moisture. It was numerically equal to the sum of the 20 days' previous daily rainfall amounts, after each was divided by the number of days the rain preceded the storm in question. In the multiple correlation the maximum rate of runoff was taken as the dependent variable, and the 5-, 15-, and 30-minute rainfall intensities and the antecedent rainfall as the independent variables.

The average values for the different independent variables common to both watersheds were:

	Inches per hour
5-minute intensity	2.82
15-minute intensity	1.76
30-minute intensity	1.18
Antecedent rainfall index	.51

Estimating equation showing the linear relationship between the different independent variables and the maximum rate of runoff were determined by the method of least squares. They were:

Pasture (Pa–B) watershed:

$$X^1 = -.58 + .16X^2 - .49X^3 + .79X^4 + .14X^5$$

Cultivated watershed D–3:

$$X^1 = -1.11 + .29X^2 - .15X^3 + .85X^4 + .73X^5$$

in which

X^1 = maximum rate of runoff in inches per hour.
X^2 = 5-minute rainfall intensity in inches per hour.
X^3 = 15-minute rainfall intensity in inches per hour.
X^4 = 30-minute rainfall intensity in inches per hour.
X^5 = antecedent rainfall index.

For both watersheds the 30-minute rainfall intensity had the greatest effect on the maximum rate of runoff, and for both, the maximum rate of runoff decreased as the 15-minute rainfall increased. The antecedent rainfall factor was of materially more importance in increasing the maximum rate of runoff for the cultivated watershed than on the pasture.

The standard estimates of error and coefficients of multiple correlation were as follows:

Bluegrass Pasture B	$S = \pm 0.39$	$R = 0.60$
Cultivated watershed D–3	$S = \pm 0.66$	$R = 0.73$

As the 1-percent level of significance is 0.40, both coefficients may be considered as highly significant. As area D–3 was in a rotation with different type crops grown in the different years, a correlation coefficient of lesser significance than that of the pasture area was anticipated. The reverse was true, however. Plotting of the individual points showed a wide scatter but a tendency toward leveling off at the higher intensities, thus suggesting that a curvilinear relationsip would probably have yielded for the two watersheds an index of correlation of higher value.

Solving of the estimating equations with maximum 2-, 5-, 10-, and 25-year-frequency rates of rainfall for 5-, 15-, and 30-minute periods, from Yarnell's intensity-frequency curves, and the average value of antecedent rainfall, showed that the maximum rates of runoff from the two watersheds came closer together as the occurrence frequency of rainfall rates increased. For the 2-year frequency intensities the maximum rate for the cultivated watershed was 5 times greater than from the pasture watershed, whereas for the 25-year frequency it was only 3 times greater. The two curves are shown in figure 51. These curves are not used for estimating purposes for any given condition, as they are based on average cover and soil condition, and the average value of antecedent rainfall at the time of the 79 storms.

Topographic, soil, and land use maps, and a detailed description of each watershed are contained in a previous report.[6] This publication

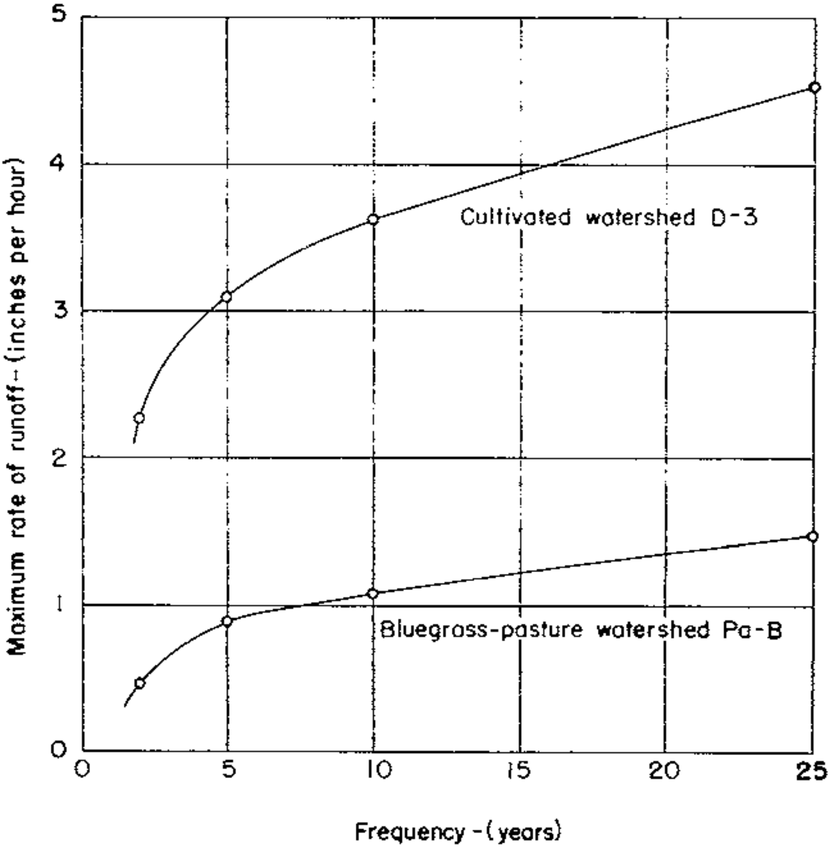

FIGURE 51.—Maximum rate of runoff from a cultivated and a bluegrass-pasture watershed for different frequencies of 5-, 15-, and 30-minute rainfall intensities. Data show average relationships for 79 excessive rainstorms in the 8-year period, 1933–40.

also includes complete runoff, soil loss, cultural operation, observation, and crop yield data for each watershed through the year 1940. Histograms of rainfall, and runoff hydrographs are included for each major storm period.

Data from the watersheds have been used in other sections of this report where they are directly related or closely allied to other studies.

This section presents certain aspects of the hydrologic data secured on the station under the following subjects: Discussion of annual

[6] ZINGG, A. W. 1941 HYDROLOGIC STUDIES. COMPILATION OF RAINFALL AND RUNOFF FROM WATERSHEDS OF SHELBY LOAM AND RELATED SOILS, CONSERVATION EXPERIMENT STATION, BETHANY, MO. SCS-TP-30 Supplements 1 and 2. [Mimeographed.]

data; correlation of rainfall intensity and previous rainfall with the maximum rate of runoff, for 79 storms selected by use of the Weather Bureau formula for excessive rain storms; a comparison of data from the watersheds for 9 major storm runoff periods; and the density of soil loss in runoff and its relation to the rate of runoff. These discussions of data are on the basis of watersheds which are homogeneous in soils, size, and topography. All of the watersheds, excepting pasture A, are natural watersheds which are concave both with and across the slope. Variations in soils, size, and topography do, however, exist.

Comparison of hydrologic data from watersheds for 9 major storms.— A group of major storm runoff periods were used to study hydrologic data from the various watersheds for torrential storm conditions. Only those storms meeting the following arbitrary conditions were chosen: The average rate of rainfall for a 30-minute period, equal to or greater than 1.5 inches per hour; the maximum rate of runoff on any one of the watersheds, not less than 1.5 inches per hour; and total runoff from each watershed exceeding 2 percent of the total rainfall. Nine storm runoff periods fulfilling these requirements occurred during the period July 1, 1934 to December 31, 1940.

Hydrologic data relative to the storm runoff phenomena for the 9 storms are recorded in table 47.

TABLE 47.—*Study of 9 intense storms occurring from July 1, 1934, to December 31, 1940, inclusive, Soil Conservation Experiment Station, Bethany, Mo.*

TERRACED BLUEGRASS PASTURE WATERSHED (Pa-A)

Date of storm	Rainfall, total amount	Amount of rainfall during rise of hydrograph	Time of hydrograph rise	Average rainfall intensity during time of hydrograph rise (I)	Maximum rate of runoff (Q)	Coefficient of runoff (C)	Total amount of runoff	Retention rate index (R)	Effective rainfall (I-R)	Crop and soil condition factors influencing runoff: Crop kind	Crop growth (height)	Soil condition
	Inches	*Inches*	*Minutes*	*Inches per hr.*	*Inches per hr.*		*Inches*	*Inches per hr.*	*Inches per hr.*		*Inches*	
9-13-34	1.95	0.95	13	4.41	1.59	0.36	0.69	1.96	2.45	Bluegrass	4 to 6 in.	Surface soil moist, subsoil dry.
10-19-34	1.22	.64	13	2.94	.71	.21	.22	2.15	.79	Bluegrass	5 to 7 in.	Soil moist.
5-1-35	.94	.68	14	2.90	.95	.33	.45	1.05	1.85	Bluegrass	6 to 7 in.	Soil wet.
5-31-35	1.05	.44	12	2.22	1.00	.45	.87	.10	2.12	Bluegrass	9 to 12 in.	Soil saturated.
6-1-35	.93	.42	11	2.29	.93	.41	.57	.40	1.89	Bluegrass	9 to 12 in.	Soil saturated.
6-17-35	2.37	.79	15	3.16	1.23	.39	1.38	.75	2.41	Bluegrass	Mature	Soil wet.
6-26-35	1.26	.52	13	2.39	.59	.25	.48	1.08	1.31	Bluegrass	Mowed on 6/25	Soil wet.
6-20, 21-39	2.19	.50	8	3.75	1.67	.45	.82	1.60	2.15	Bluegrass	4 to 6 in.	Surface soil moist
6-23-40	1.02	.49	12	2.45	.31	.13	.23	1.87	.58	Bluegrass	5 to 8 in.	Surface soil moist.
Average	1.54	.60	12	2.95	1.00	.33	.63	1.22	1.73			

NORMAL BLUEGRASS PASTURE WATERSHED (Pa-B)

Date of storm	Rainfall, total amount	Amount of rainfall during rise of hydrograph	Time of hydrograph rise	Average rainfall intensity during time of hydrograph rise (I)	Maximum rate of runoff (Q)	Coefficient of runoff (C)	Total amount of runoff	Retention rate index (R)	Effective rainfall (I-R)	Crop kind	Crop growth (height)	Soil condition
9-13-34	1.95	0.82	11	4.45	0.21	0.05	0.07	4.10	0.35	Bluegrass	4 to 6 in.	Surface soil moist; subsoil dry.
10-19-34	1.22	.46	8	3.46	.09	.03	.03	3.36	.10	Bluegrass	5 to 7 in.	Soil moist.
5-1-35	.94	.65	13	3.02	1.55	.51	.50	.90	2.12	Bluegrass	8 inches	Soil wet.
5-31-35	1.05	.46	13	2.11	1.43	.68	.93	.06	2.05	Bluegrass	9 to 12 in.	Soil saturated.
6-1-35	.93	.62	21	1.77	1.70	.96	.76	.14	1.63	Bluegrass	9 to 12 in.	Soil saturated.
6-17-35	2.37	.66	12	3.28	1.75	.53	1.48	.64	2.64	Bluegrass	Mature	Soil wet.
6-26-35	1.26	.48	12	2.39	1.20	.50	.61	.67	1.72	Bluegrass	Mowed on 6/25	Soil wet.
6-20, 21-39	2.19	.79	13	3.65	.73	.20	.37	2.40	1.25	Bluegrass	4 to 6 in.	Surface soil moist.
6-23-40	1.02	.44	10	2.66	.18	.07	.10	2.46	.20	Bluegrass	5 to 8 in.	Surface soil moist.
Average	1.54	.60	13	2.98	.98	.39	.54	1.64	1.34			

CONTOUR CROPPED WATERSHED (D-1)

9-13-34	1.95	0.39	5	4.73	2.38	0.50	0.73	1.87	2.86	Plowed on 8/20; disc on 9/11.		Surface soil moist; subsoil dry.
10-19-34	1.22	.37	6	3.68	1.34	.36	.26	2.03	1.65	Drill wheat 10/5	Coming up	Soil moist.
5-1-35	.94	.49	9	3.27	3.18	.97	.70	.40	2.87	Wheat	6 to 8 in.	Soil wet.
5-31-35	1.05	.29	5	3.52	2.14	.61	.84	.12	3.40	Wheat	30 inches	Soil saturated.
6-1-35	.93	.32	7	2.74	3.05	1.11	.89	.02	2.72	Wheat	30 inches	Soil saturated.
6-17-35	2.37	.54	9	3.60	2.68	.74	1.63	.51	3.09	Wheat	36 inches	Soil wet.
6-26-35	1.26	.23	5	2.73	1.61	.59	.54	.91	1.82	Wheat	Mature	Soil wet.
6-20, 21-39	2.19	.35	5	4.20	3.18	.76	1.72	.42	3.78	Wheat	Mature	Surface wet.
6-23-40	1.92	.30	7	2.57	1.44	.56	.73	1.08	1.49	Clover	Cut and shocked	Soil moist.
Average	1.54	.36	6	3.45	2.33	.69	.89	.82	2.63			

TERRACED CROPPED WATERSHED (D-2)

9-13-34	1.95	0.75	10	4.48	2.20	0.49	0.96	1.37	3.11	Plowed 8/20; disc on 9/11		Surface soil moist; subsoil dry.
10-19-34	1.22	.42	7	3.64	.38	.10	.21	2.26	1.38	Drill Wheat 10/5	Coming up	Soil moist.
5-1-35	.94	.73	16	2.72	1.21	.44	.55	.77	1.95	Wheat	6 to 8 in.	Soil wet.
5-31-35	1.05	.50	16	1.87	.94	.50	.81	.16	1.71	Wheat	30 inches	Soil saturated.
6-1-35	.93	.62	21	1.77	1.34	.76	.73	.17	1.60	Wheat	30 inches	Soil saturated.
6-17-35	2.37	.70	13	3.23	1.48	.46	1.49	.51	2.72	Wheat	36 inches	Soil wet.
6-26-35	1.26	.65	18	2.17	.51	.24	.43	1.27	.90	Wheat	Mature	Soil wet.
6-20, 21-39	2.19	.84	15	3.34	2.36	.71	1.56	.60	2.74	Wheat	Mature	Surface wet.
6-23-40	1.92	.56	15	2.23	.53	.24	.59	1.25	.98	Clover	Cut and shocked	Soil moist.
Average	1.54	.64	15	2.83	1.22	.44	.81	.93	1.90			

CROPPED WATERSHED (D-3)

9-13-34	1.95	.02	14	4.36	2.48	.57	1.01	1.27	3.09	Corn	5 feet	Surface soil moist; subsoil dry.
10-19-34	1.22	.61	12	3.03	2.03	.67	.47	1.27	1.76	Corn	Poor crop mature	Soil moist.
5-1-35	.94	.34	6	3.40	4.62	1.36	.79	.20	3.20	Drill oats 3/20	2 inches	Soil wet.
5-31-35	1.05	.29	5	3.52	2.50	.71	.72	.27	3.25	Oats	12 inches	Soil saturated.
6-1-35	.95	.29	6	2.90	2.72	.94	.78	.12	2.78	Oats	12 inches	Soil saturated.
6-17-35	2.37	.52	8	3.89	2.48	.64	1.42	.70	3.19	Oats	30 inches	Soil wet.
6-26-35	1.26	.16	4	2.44	1.45	.59	.45	1.18	1.26	Oats	Mature	Soil wet.
6-20, 21-39	2.19	.30	4	4.50	3.36	.75	1.73	.40	4.10	Wheat	Mature	Soil wet.
6-23-40	1.92	.28	6	2.75	1.53	.56	.83	.97	1.78	Clover	Cut and shocked	Soil moist.
Average	1.54	.42	7	3.42	2.57	.75	.91	.71	2.71			

TABLE 47.—*Study of 9 intense storms occurring from July 1, 1934, to December 31, 1940, inclusive, Soil Conservation Experiment Station, Bethany, Mo.*—Continued

CONTINUOUS ALFALFA WATERSHED (I-58)

Date of storm	Rainfall, total amount	Amount of rainfall during rise of hydrograph	Time of hydrograph rise	Average rainfall intensity during time of hydrograph rise (I)	Maximum rate of runoff (Q)	Coefficient of runoff (C)	Total amount of runoff	Retention rate index (R)	Effective rainfall (I-R)	Crop and soil condition factors influencing runoff: Crop kind	Crop growth (height)	Soil condition
	Inches	*Inches*	*Minutes*	*Inches per hr.*	*Inches per hr.*		*Inches*	*Inches per hr.*	*Inches per hr.*		*Inches*	
9-13-34	1.95	0.82	11	4.45	0.67	0.15	0.26	3.40	1.05	Alfalfa	12 inches	Surface soil moist; subsoil dry.
10-19-34	1.22	.57	11	3.13	1.74	.56	.37	1.57	1.56	Cut alfalfa 9/19	Stubble	Soil moist.
5-1-35	.94	.49	9	3.27	3.52	1.08	.75	.28	2.99	Alfalfa	6 to 8 in	Soil wet.
5-31-35	1.05	.35	7	3.04	1.93	.63	.90	.08	2.96	Alfalfa	18 inches	Soil saturated.
6-1-35	.93	.40	10	2.40	2.53	1.05	.90	.02	2.38	Alfalfa	18 inches	Soil saturated.
6-17-35	2.37	.52	8	3.89	2.30	.59	1.46	.67	3.22	Cut alfalfa 6/8	4 inches	Soil wet.
6-26-35	1.26	.23	5	2.73	1.57	.58	.62	.65	2.08	Alfalfa	10 inches	Soil wet.
6-20, 21-39	2.19	.40	6	4.00	3.99	1.00	1.60	.55	3.45	Oats lespedeza	Mature 4 to 6 in.	Soil wet and packed.
6-23-40	1.92	.42	9	2.80	1.05	.38	.44	1.47	1.33	Oats lespedeza	Shocked. Heavy young growth.	Soil moist.
Average	1.54	.47	8	3.30	2.14	.67	.81	.97	2.34			

ROTATION STRIP-CROPPED WATERSHED (IJ-1)

Date of storm	Rainfall, total amount	Amount of rainfall during rise of hydrograph	Time of hydrograph rise	Average rainfall intensity during time of hydrograph rise (I)	Maximum rate of runoff (Q)	Coefficient of runoff (C)	Total amount of runoff	Retention rate index (R)	Effective rainfall (I-R)	Crop kind and crop growth	Soil condition
9-13-34	1.95	0.89	12	4.43	1.49	0.34	0.42	2.82	1.61	Strip-cropped with corn, soybeans, wheat and meadow.	Surface soil moist; subsoil moist.
10-19-34	1.22	.37	6	3.68	.73	.20	.13	2.66	1.02	Strip-cropped with corn, soybeans, wheat and meadow.	Soil moist.
5-1-35	.94	.58	11	3.19	3.00	.94	.61	.61	2.58	Strip-cropped with corn, soybeans, wheat and meadow.	Soil wet.
5-31-35	1.05	.33	6	3.29	2.54	.77	.93	.07	3.22	Strip-cropped with corn, soybeans, wheat and meadow.	Soil saturated.
6-1-35	.93	.40	10	2.40	2.64	1.10	.81	.08	2.32	Strip-cropped with corn, soybeans, wheat and meadow.	Soil saturated.
6-17-35	2.37	.52	8	3.89	2.24	.58	1.16	1.02	2.87	Strip-cropped with corn, soybeans, wheat and meadow.	Soil wet.
6-26-35	1.26	.22	4	3.31	1.73	.52	.66	.55	2.76	Strip-cropped with corn, soybeans, wheat and meadow.	Soil wet.
6-20, 21-39	2.19	.40	6	4.00	3.12	.78	1.72	.41	3.59	Strip-cropped with corn, oats, and meadow	Soil wet.
6-23-40	1.92	.44	10	2.66	1.12	.42	.42	1.50	1.16	Strip-cropped with corn, oats, and meadow	Soil moist.
Average	1.54	.46	8	3.43	2.07	.63	.76	1.08	2.35		

The table also contains observations pertinent to crop and soil conditions at the time of the storms on each watershed.

The retention rate index *R* is used as a gage of the capacity of a watershed to absorb rainfall by all processes during a storm period. It is defined as the rainfall intensity, in inches per hour, over and above which an amount of rainfall, equaling the total runoff from the terrain, occurs from a given storm.

Values of *R* show that the undisturbed bluegrass pasture (Pa–B) retained rainfall for the 9 individual storms at rates varying from 0.06 to 4.10 inches per hour, while the average was 1.64 inches per hour. The cropped watershed with the least control (D–3) retained rainfall at the average rate of 0.71 inches per hour with a variation from 0.12 to 1.27 inches per hour. Greater variability, and the highest as well as the lowest retention rate indices have, therefore, occurred on the watershed having the greatest average retention The variability of the retention rate index is illustrated in table 48 by summarizing the frequency of occurrence of the relative rank of the watersheds in their ability to retain rainfall for the 9 different storms.

TABLE 48.—*Frequency of occurrence of relative rank in retention capacity of watersheds for 9 storms*

Watershed	Relative rank in retention capacity (high to low)							Average ranking for 9 storms
	1	2	3	4	5	6	7	
Pa–A	2	3	1	3				2
Pa–B	4	1	1		2		1	1
D–1			1	1	4	2	1	5
D–2	1	2	3		1	1	1	3
D–3	1	1	1	1			5	7
I–58		1		3	1	4		6
H–1	1	1	2	1	1	2	1	4

Five of the seven watersheds have had the highest retention index for some one of the nine storms. Five of the areas have similarly had the lowest retention index. The average ranking of the practices on these particular watersheds in their capacity to retain rainfall is in the order: (1) undisturbed bluegrass pasture, (2) terraced bluegrass pasture, (3) terraced cropped land, (4) strip cropping, (5) contour cropping, (6) permanent alfalfa, and (7) cropping with no control practices. The failure of the terraced pasture (Pa–A) to retain as much as the normal pasture (Pa–B) is believed to be, in part, due to channel and vegetative conditions associated with terrace construction. In addition, the terraced pasture also has a steeper terrain, is convex shaped, and does not have a central drainageway. The low ranking of the permanent alfalfa watershed (I–58) is associated with the fact that several of the storms prior to 1939 occurred shortly after an alfalfa hay crop was removed, and the change from alfalfa to annual oats-lespedeza cropping. When the soil was in a saturated condition, May 31 and June 1, 1935, all watersheds had extremely low retention capacities. Small differences shown between a few of the watersheds for these two storms may be beyond the accuracy of measurement of either rainfall or runoff.

To summarize, it is apparent that retention of rainfall by agricultural watersheds in different land use will vary greatly for different storms. Furthermore, any specific watershed will have a wide range of retention capacities for similar storms occurring during a particular season of the year. For a specific storm period it is conceivable that any land use practice on similar areas may have the minimum retention capacity which is possibly associated with the amount of previous rainfall absorption.

Values of Q were secured by direct measurements for the nine storms, and values of I were calculated, using the time of rise of the hydrograph as the time of concentration. The time of rise of the hydrograph from a specific rainfall intensity block may fail to be as great as the theoretical time for water to flow from the most remote portions of the watersheds. This is due to the fact that high rainfall intensity is in some instances not of sufficient duration to result in an approach to the condition of uniform flow from all parts of a watershed.

A linear correlation with Q as the dependent variable and I as the independent variable was performed to determine the degree of relationship between the two variables. This introduced two constants, namely a, the intercept of Q where I is equal to zero, and b the slope of the regression equation $Q=a+bI$. Values of a and b were determined from the data by the method of least squares. The resulting correlation coefficients were found to be below the level of 0.67, required for significance at the 5-percent level, with the exception of the terraced pasture (Pa-A) which was 0.86. If the relationship $Q=CI$ approximated the trend of the data, a would have approached zero, and the term b would have become the value of C. Obviously, for the storms studied, the equation $Q=CI$ does not adequately express the storm runoff phenomena with I as here determined. A summary of all values and the correlations are given in table 49.

TABLE 49.—*Regression equation and correlation coefficients determined for the 9 storms given in table 48*

Watershed	$Q=a+bI$			$Q=a+b\,(I-R)$		
	a	b	r [1]	a	b	r [1]
Pa-A	−0.41	0.48	0.86	0.03	0.56	0.86
Pa-B	2.38	−.47	.58	.03	.71	.96
D-1	1.35	.28	.15	.37	.75	.85
D-2	.09	.40	.50	−.31	.81	.92
D-3	.40	.64	.54	.52	.76	.75
I-58	1.86	.09	.22	−.29	1.04	.84
U-1	2.42	−.10	.10	.21	.79	.84

[1] Coefficient of correlation 1-percent level of significance .80, 5-percent level of significance .67.

A further study of the relationship of Q and I-R where R equals the retention rate index was made. The correlation used was of the linear type represented by the equation $Q=a+b(I-R)$. On each watershed values of Q increased with increases in the quantity of I-R. The resulting correlation coefficients were above the 1-percent level of 0.80 required for high significance. These values are also shown in table 49.

Further study leads to the conclusion that b in this latter equation approaches unity when the time of concentration is properly evaluated. Thus different watershed characteristics and different conservation practices would be reflected in a varying time of concentration as well as a varying retention rate. The formula $Q=I-R$ is, therefore, presented as an estimating equation of significance. It recognizes the fact that the runoff rate is dependent upon the rate of absorption of rainfall. Values of R may be derived from myriad data which have been obtained without benefit of devices to determine the rates of runoff.

Effect of soil loss on peak runoff rates.—Areas in intertilled crops, particularly those farmed without adequate supporting practices, lose large volumes of soil which in themselves may appreciably affect the rate of runoff. As an example, a 1-inch storm of May 16, 1941, falling on watershed D–3 when corn was 3 to 4 inches high, caused a total runoff of 0.65 inch. A soil loss of 24 tons per acre was included in this runoff amount. Assuming the specific gravity to be 2.65, the soil loss on a volume basis was equivalent to 16 percent of the runoff, or 0.10 inch. Obviously these relatively large volumes of soil affect the peak rate of runoff.

A limited study of the volume of soil carried by storm runoff, in relation to the rate of runoff, was made in June 1941, on watershed D–3 while a corn crop occupied the ground. Samples of the storm runoff were secured manually by dipping from the throat of the 2-foot Parshall flume, with which the watershed runoff is measured. Such samples were obtained at 15-second intervals throughout the rise and fall of the hydrograph. They were analyzed for dry-matter content in the usual manner.

The results of the study for two runoff periods occurring on June 2 and June 9, 1941 are shown graphically in figure 52. The rates of runoff from the 4.485-acre watershed are expressed in cubic feet per second. The pounds of soil per cubic foot of runoff secured from the flume sampling are plotted in the lower portion of the figure.

The runoff of June 2 contained soil which, on a volume basis, was equivalent to 5.4 percent of the total runoff. The first runoff sampled contained approximately 13 pounds of soil per cubic foot. The peak runoff, which occurred some 4 minutes later, contained approximately 14 pounds per cubic foot. The density of soil loss in runoff then dropped to 7 pounds per cubic foot during a 3-minute recession of the hydrograph. A second rise of the hydrograph resulted in a slight increase in runoff density and the following recession resulted in a rapid decrease. It is apparent that a decrease in runoff density is occurring with time and the removal of the more easily transported particles. However, the density of runoff continued to rise for approximately 2 minutes during the recession of the second flash of runoff. This is believed to be indicative of relatively heavy soil loss coming from the upper slope reaches. The rate of soil loss in cubic feet per second, and the percent soil loss in runoff was calculated at 1-minute intervals throughout the storm. The rate of water loss was obtained by subtracting the rate of soil loss in cubic feet per second from the rate of runoff in cubic feet per second. Accumulative values of total runoff, water loss, and soil loss are also shown in cubic feet. Accumulative soil loss in tons per acre is plotted in the lower part of the figure.

The watershed had lost 20 tons of soil per acre and 1.91 inches of runoff in the week prior to the storm of June 9, which is also plotted in figure 52. Much of the loose soil had been removed from the field and numerous rills were formed in conveying the runoff to the measuring equipment. While the soil loss from the storm is not large the several peaks of runoff afford an opportunity for study of increases and decreases of runoff density. The first flash of runoff here appears to

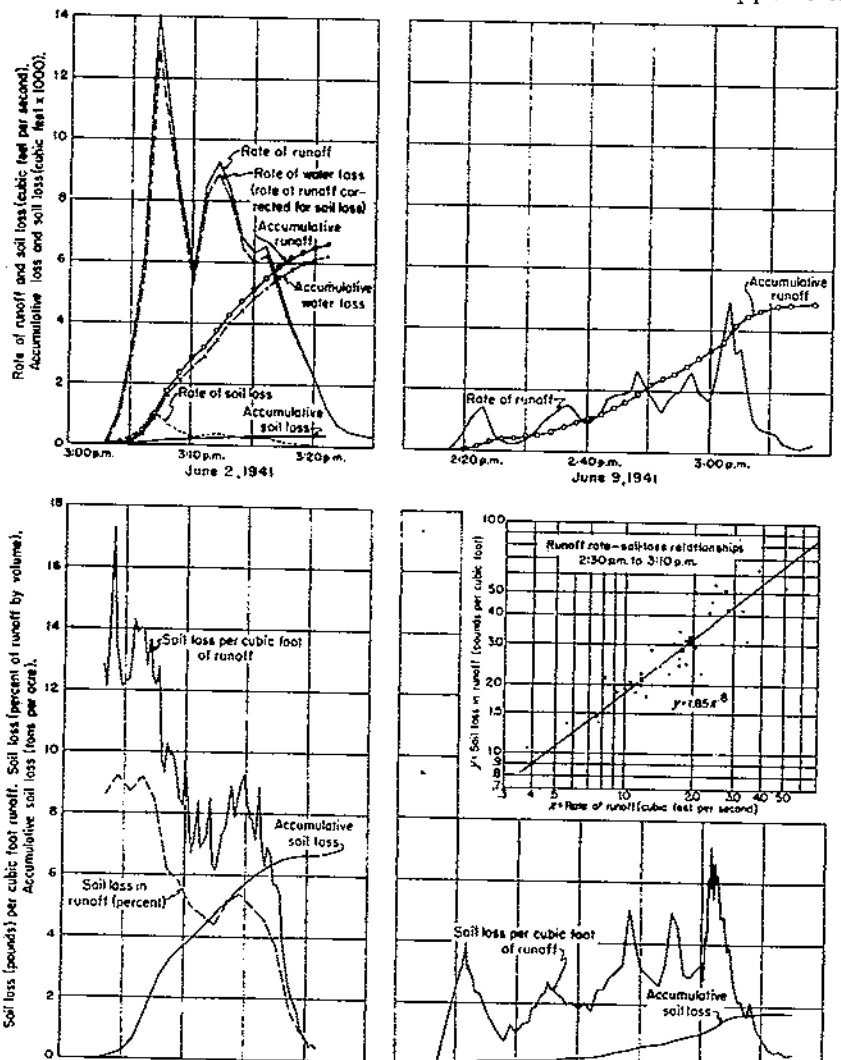

FIGURE 52.—Runoff hydrographs from watershed D-3 on June 2, 1941, and June, 9, 1941, and accompanying water and soil loss relationships throughout the storms.

carry a relatively large amount of soil. Throughout the remainder of the runoff the density of runoff appears to bear a relationship to the runoff rate. In this particular instance the relationship is approximated by the equation:

$$y=1.85X^{.8}$$

where y=soil loss in runoff in pounds per cubic feet, and X=the rate of runoff in cubic feet per second.

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APPENDIX

In order to avoid an excess of tabular material throughout the text, the data of the individual tables necessary for deriving the summary tables and figures used in the text have been placed in this appendix as tables 50 to 77.

The data presented in this appendix probably will be of only minor interest to the casual reader, but as they give specific records of the results of experimentation from year to year, they will be of practical value and interest to technical workers in the field of soil conservation.

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TABLE 50.—*Description of the experimental plots from which soil and water losses were measured*

Plot No.	Plot series No.	Width	Length	Area	Soil	Average slope	Cropping practice	Soil treatment	Period of records: Began	Period of records: Ended
		Feet	*Feet*	*Acres*		*Percent*				
1	1 (1)	6	145.2	0.02	Shelby silt loam	8	Corn continuously	None	Aug. 1930	Dec. 31, 1942
2		6	72.6	.01	do		do	do	do	Do.
3		6	72.6	.01	do		3-year rotation of corn, wheat, and clover-timothy.	do	do	Do.
4		6	72.6	.01	do		do	do	do	Do.
5		6	72.6	.01	do		do	do	do	Do.
6		6	72.6	.01	do		do	3 tons of lime per acre in 1930; 250 pounds of 20-percent superphosphate on wheat.	do	Do.
7		6	72.6	.01	do		Alfalfa continuously	3 tons of lime per acre in 1930; 250 pounds of 20-percent superphosphate every three years.	do	Do.
8		6	72.6	.01	do		Bluegrass continuously	None	do	Do.
9		6	72.6	.01	do		Fallow	do	do	Do.
10		6	72.6	.01	do		do	Desurfaced	do	Do.
A		6.83	80	.01255	Shelby clay loam		Corn continuously; after 1939 same as No. 7.	Desurfaced and spaded 3 inches deep; 250 pounds of 4-12-4 broadcast annually; meadow established 1940 same as No. 7.	Spring 1932	In operation.
11		6.83	80	.01255	do		Corn continuously; after 1939 same as No. 7 except hay removed.	Desurfaced and spaded 7 inches deep; 250 pounds of 4-12-4 fertilizer broadcast annually; meadow established 1940 same as No. 7.	do	Do.
1	2 (2)	10.50	80	.0193	Shelby silt loam	8.5	4-year rotation of corn, oats, clover-timothy, and clover-timothy.	None	do	Do.
2		10.50	80	.0193	Shelby clay loam		4-year rotation of corn, oats, clover-timothy, and clover-timothy.	Desurfaced	do	Do.
3		10.50	80	.0193	do		4-year rotation of corn, oats, clover-timothy, and clover-timothy.	Desurfaced; 3 tons of lime in 1930; 250 pounds of 4-12-4 fertilizer preceding oats.	do	Do.
4		10.50	80	.0193	do		3-year rotation of corn, oats, and clover-timothy.	Desurfaced; 3 tons of lime in 1930; 188 pounds of 4-12-4 fertilizer preceding oats.	do	Do.
5		10.50	80	.0193	do		3-year rotation of corn, oats, and sweetclover.	Desurfaced; 3 tons of lime in 1930; 188 pounds of 4-12-4 fertilizer preceding oats.	do	Do.
6		10.50	80	.0193	do		do	Desurfaced; 3 tons of lime in 1930; 188 pounds of 20-percent superphosphate preceding oats; 8 tons of manure preceding corn, except fall of 1941.	do	Do.
7		10.50	80	.0193	do		Clover and grass mixture of timothy, sweetclover, alsike, red clover, and lespedeza.	Desurfaced; 3 tons of lime in 1930; 188 pounds of 4-12-4 fertilizer in 1931. Fall spaded 1941 for corn in 1942.	do	Do.
8		10.50	80	.0193	do		Corn continuously	Desurfaced; 8 tons of manure annually; changed to oats-lespedeza 1936; 125 pounds of 20-percent superphosphate per acre with oats.	Spring 1935	Do.

A-1		10.50	125	.03013	Shelby silt loam			do	16 tons of manure annually	Jan. 1933	Dec 31, 1939
A		10.50	125	.03013	do			4-year rotation of corn, soybeans cultivated in rows, oats, and clover-timothy.[1]	200 pounds of 20-percent superphosphate on oats.	Nov. 1931	Do.[5]
B		10.50	125	.03013	do			4-year rotation of corn, drilled soybeans, wheat and clover-timothy.[1]	200 pounds of 20-percent superphosphate on wheat.	do	Do.[5]
1		10.50	125	.03013	do			Corn continuously	3 tons of lime in 1930; 250 pounds of 4-12-4 fertilizer broadcast annually.	do	Do.
2	3	10.50	125	.03013	do		8.1	3-year rotation of corn, oats, and clover-timothy.	3 tons of lime in 1930; 180 pounds of 20-percent superphosphate on oats; 8 tons of manure on corn; stalks left on plot.	do	Dec. 31, 1941
3	(3)	10.50	125	.03013	do			do	3 tons of lime in 1930; 180 pounds of 20-percent superphosphate on oats; all crops removed.	do	Do.
4		10.50	125	.03013	do			Fallow	4 tons of oats straw each fall at spading	do	Dec. 31, 1935
5		10.50	125	.03013	do			do	4 tons of legume hay each fall at spading	do	Do.
6		10.50	125	.03013	do			do	16 tons of manure each fall at spading	do	Do.
7		10.50	125	.03013	do			do	None	do	Do.
1		[2]43.67	270	[2].267	Grundy-Shelby silt loam.			3-year rotation of corn, wheat, and clover-timothy with each crop on a separate strip.	150 pounds of 4-12-4 fertilizer with wheat; 2 tons of manure preceding corn.	July 1934	In operation[6]
2		[2]43.67	270	[2].267	do			3-year rotation of corn, wheat, and clover-timothy with each crop on a separate strip.	do	do	Do.[7]
3	5	[2]43.67	270	[2].267	do		6.6	3-year rotation of corn, wheat, and clover-timothy with each crop on a separate strip.	do	do	Do.[6]
4	(2)	[2]43.67	270	[2].267	do			3-year rottaion of corn, wheat, and clover-timothy.	do	do	Do.[7]
5		[2]43.67	270	[2].267	do			3-year rotation of corn, wheat, and clover-timothy with each crop on a separate strip.	do	do	Do.[6]
6		[2]43.67	270	[2].267	do			3 year rotation of corn, wheat, and clover-timothy.	do	do	Do.[7]
1	9	60	229	.3415	Shelby silt loam		11.6	Pasture, grazed moderately	None.	Spring, 1932	Dec. 31, 1941
2		60	229	.3424	do			Pasture, grazed intensively	do	do	Do.
1		28	90	.0564	do			Continuous corn; after 1939 wheat, meadow, corn.	do	Fall, 1933	In operation
2	15	[2]28	180	.1142	do			do	do	do	Do.
3		[2]28	270	.1721	do			do	do	do	Do.
4		[2]28	180	.1142	do			do	do	do	Do.
5	(3)	28	90	.0564	do			do	do	do	Do.

[1] The plot was fallow in 1931.
[2] Exclusive of 3-foot dikes.
[3] Geib multislot divisor units were on these plots after June 1935.
[4] Concrete tank.
[5] Soil and water losses were secured in spring and summer of 1940 with Plot A disked and 2 tons per acre oat straw mulch and Plot B disked only.
[6] Change to corn planted up and down hill in 1942, followed by wheat and meadow 1 year.
[7] Continued planting on contour with corn in 1942, followed by wheat and meadow 1 year.

TABLE 51.—*Description of the terraces for which soil and water losses were measured* [1]

Terrace No.	Length	Grade per 100 feet	Vertical spacing	Terrace slope	Land slope	Soil	Cropping practice	Soil treatment	Period of records	
									Began	Ended
	Feet	*Inches*	*Feet*	*Percent*	*Percent*					
1-H	876	Variable 1-2-3-4	5	10.0	6.4	Shelby loam	Corn, oats with sweetclover; the sweetclover was turned under.	4 tons of lime per acre in 1930; 200 pounds of 20-percent superphosphate per acre on oats.	March 1936	Dec. 31, 1941
2-H	1,050	Variable 0-1-2-3-4	5	11.7	8.3	do	do	do	Spring 1932	Do.
3-H	1,050	do	5	11.9	8.5	do	Corn, soybeans, wheat, clover with timothy.	200 pounds of 20-percent superphosphate per acre with wheat in the fall of 1932.	do	Do.
4-H	1,050	do	5	12.9	9.6	do	do	3 tons of lime per acre in 1935; 200 pounds of 4-12-4 fertilizer per acre with wheat in the fall of 1935.	do	Do.
5-H	1,050	do	5	13.6	9.7	do	do	2.5 tons of lime per acre in 1934-35; 200 pounds of 4-12-4 fertilizer per acre with wheat in the fall of 1934.	do	Do.
6-H	1,050	do	5	13.9	9.8	do	do	200 pounds of 20-percent superphosphate per acre with wheat in the fall of 1933.	do	Do.
2-G	650	Uniform, 4	6	16.0	12.0	do	Alfalfa, oats-lespedeza 1938-39.	3 tons of lime per acre in 1933; 300 pounds of 4-12-4 fertilizer per acre in 1933.	Nov. 1932	Dec. 31, 1939
3-G	700	do	5	18.7	12.4	do	Corn, oats, clover with timothy.	200 pounds of superphosephate per acre on oats.	Spring 1931	Dec. 31, 1940
4-G	700	do	7	17.6	13.9	do	do	do	do	Do.
5-G	700	do	9	16.1	13.2	do	do	do	do	Do.
2-I	1,375	Variable, 0-1-2-3-4-5	5	11.6	7.9	do	Corn, corn, oats, clover with timothy.	do	Spring 1933	Dec. 31, 1938
4-I	2,450	do	5	12.1	8.4	do	do	do	do	Do.
5-C	1,200	Uniform, 8	5	16.3	10.9	do	Corn, oats, clover with timothy.	do	Jan. 1932	Dec. 31, 1940
6-C	1,200	Uniform, 6	5	16.0	11.0	do	do	do	Spring 1931	Do.
7-C	1,200	Uniform, 4	5	17.5	11.7	do	do	do	Spring 1931	Do.
8-C	1,200	Uniform, 2	5	15.9	10.8	do	do	do	Jan. 1932	Do.
9-C	1,200	Level	5	16.8	11.1	do	do	do	Spring 1931	Do.
10-C	1,200	Variable, 1-2-3-4	5	17.7	11.8	do	do	do	do	Do.
2-N	836	Level	4	11.2	6.5	Grundy loam	do	do	do	Do.
4-N	1,040	Uniform, 4	3	11.0	6.3	Shelby loam	do	do	Mar. 1936	Dec. 31, 1938
5-N	1,040	do	5	9.8	7.4	do	do	do	Spring 1931	Dec. 31, 1940
6-N	1,040	do	7	8.4	6.8	do	do	do	do	Do.
8-N	725	Level	4	13.1	8.2	do	do	do	do	Do.
Area 7-CN (3 terraces).	1,315	do	5.5	17.0	9.1	do	do do	do do	Oct. 1, 1932 Apr. 1933	Dec. 31, 1938 Do.

[1] Measuring equipment consists of either 1- or 2-foot Parshall flume, float water stage recorder, silt box, and Ramser silt sampler.

TABLE 52.—*Description of the watersheds for which soil and water losses were measured*

Watershed designation	Land slope	Area	Soil	Terraces			Cropping practice	Soil treatment	Period of records	
				Length	Grade per 100 feet	Vertical spacing			Began	Ended
	Percent	*Acres*		*Feet*	*Inches*	*Feet*				
Pasture A [1]	13.0	[6] 2.03	Shelby loam	[2] 1,710	Variable, 0-1-2	6	Bluegrass pasture, excellent vegetation.	None: 4-12-4 fertilizer on terrace channels and ridges.	Jan. 1, 1934	In operation.
Pasture B	9.5	[3] 5.56	do				Bluegrass pasture, excellent vegetation.	None: 4-12-4 fertilizer in waterway	Jan. 1, 1932	Do.
Pasture C [7]	11.0	1.97	do	2,950	Level [7]	1	Bluegrass pasture, excellent vegetation.	None	Apr. 1, 1937	Do.
I-58	9.1	2.11	do				Alfalfa; oats-lespedesa began 1938.	3 tons of lime per acre in 1932; 200 pounds of 20-percent superphosphate per acre in 1932; 250 pounds of 4-12-4 fertilizer per acre in 1933; 125 pounds 0-20-0 per acre with oats-lespedeza.	Jan. 1, 1933	Do.
IJ-1	9.2	2.13	do				Corn, oats, clover with timothy.[10]	2.5 tons of lime per acre on strip C in 1934; 1.64 tons per acre on strip B in 1935; 200 pounds of 4-12-4 fertilizer per acre on strip C in 1934 and on strip B in 1935; 200 pounds 0-20-0 per acre with oats.	July 1, 1933	Do.
D-1	6.5	7.51	do				Corn, oats, wheat, clover with timothy.	5 tons of lime per acre in 1930; 125 pounds of 4-12-4 fertilizer per acre on wheat; 125 pounds of 20-percent superphosphate on oats.	July 1, 1934	Do.
D-2 [4]	7.0	8.03	do	[5] 5,050	3	5	do	do	July 1, 1934	Do.
D-3	6.7	[9] 4.49	do				do.[8]	150 pounds of 20-percent superphosphate per acre on oats before 1939.	July 1, 1932	Do.

[1] Pasture A contains six terraces that discharge into a common outlet.
[2] Total length of the six terraces on pasture A.
[3] The area of pasture B was 6.52 acres until the fall of 1935.
[4] Field D-2 contains eight terraces that discharge into a common outlet.
[5] Total length of the eight terraces on field D-2.
[6] 2.12 acres prior to fall of 1938.
[7] Contour furrows constructed by Wooley furrowing machine in Nov. 1939
[8] Corn, corn, oats, clover prior to 1937.
[9] 4.85 acres prior to May 1934.
[10] Corn, soybeans, wheat, clover with timothy prior to 1936.

TABLE 53.—*Seasonal and annual runoff and soil loss*[1] *and crop yields from control plots 1 to 10 of plot series 1, 1931–40*[2]

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Tons or bushels*
PLOT 1												
1931	0.17	0	0.78	47,315	5.27	103,565	7.07	60,454	13.20	211,334	Corn	20.0
1932	.47	1,866	1.34	38,786	2.94	62,505	.20	2,192	5.04	105,349	Corn	44.1
1933	0	0	.70	14,945	8.42	115,405	.29	0	9.41	130,350	Corn	43.7
1934	.02	0	2.85	110,845	3.46	53,675	4.04	30,805	10.37	195,515	Corn	0
1935	.91	15,050	11.31	190,045	.44	4,365	.46	2,735	13.12	212,195	Corn	17.8
1936	3.56	1,570	.46	5,345	2.42	11,660	1.11	24,070	7.55	42,645	Corn	0
1937	3.78	8,200	.58	21,065	.18	2,250	.13	20	4.67	31,535	Corn	41.6
1938	0	0	1.13	33,440	3.11	49,730	.40	830	4.64	84,000	Corn	4.5
1939	.75	9,270	5.10	183,410	1.61	43,330	.88	8,075	8.34	244,085	Corn	16.8
1940	1.16	6,570	1.70	46,430	.82	2,020	.17	275	3.85	55,295	Corn	22.2
Total	10.82	42,526	25.95	691,726	28.67	448,505	14.84	129,546	80.28	1,312,303		
Average	1.08	4,253	2.60	69,173	2.87	44,851	1.48	12,954	8.03	131,230		
PLOT 2												
1931	0.17	0	0.80	37,414	4.78	76,499	7.44	54,426	13.19	168,339	Corn	20.7
1932	.23	534	1.65	31,311	3.63	63,760	.35	2,256	5.86	97,861	Corn	36.7
1933	0	0	.82	12,650	8.89	86,850	.34	0	10.05	99,500	Corn	49.3
1934	.05	0	2.92	95,160	3.91	50,810	4.55	25,760	11.43	171,730	Corn	0
1935	1.25	7,530	8.53	138,030	.54	2,670	.64	2,010	10.96	150,240	Corn	16.7
1936	2.49	230	.77	7,890	3.23	13,270	1.37	16,480	7.86	37,870	Corn	0
1937	3.53	1,120	.67	13,850	.31	1,710	.18	20	4.69	16,700	Corn	35.0
1938	0	0	1.28	27,830	2.89	26,880	.54	670	4.71	55,380	Corn	5.0
1939	.98	4,670	5.45	142,450	1.52	26,770	.80	3,100	8.75	176,990	Corn	11.8
1940	1.09	1,610	2.10	38,780	1.11	3,060	.18	320	4.48	43,770	Corn	26.4
Total	9.79	15,694	24.99	35,365	30.81	352,279	16.39	105,042	81.98	1,018,380		
Average	.98	1,569	2.50	3,337	3.08	35,228	1.64	10,504	8.20	101,838		
PLOT 3												
1931	0.20	0	0.93	29,679	4.44	56,399	5.12	21,882	10.69	107,960	Corn	30.6
1932	.14	8	.20	12	.96	3,159	0	0	1.30	3,179	Wheat	30.9
1933	0	0	.04	10	2.07	370	0	0	2.11	380	Meadow	1.61
1934	.02	0	1.54	2,870	4.02	43,610	3.48	15,260	9.06	61,740	Corn	0
1935	.75	3,360	10.71	17,900	.02	0	0	0	11.48	21,260	Wheat	12.6

1936	1.68	70	.03	10	.12	40	.03	0	1.86	120	Meadow	1.72
1937	2.51	190	.43	2,530	.31	1,090	.16	10	3.41	3,820	Corn	37.0
1938	0	0	3.06	24,850	3.36	4,310	.04	10	6.46	29,170	Wheat	4.0
1939	.67	230	3.55	2,240	.51	70	.01	0	4.74	2,540	Meadow	1.10
1940	.54	40	1.37	7,580	1.16	1,660	0	0	3.07	9,280	Corn	26.1
Total	6.51	3,898	21.86	87,681	16.97	110,708	8.84	37,162	54.18	239,449		
Average	.65	390	2.19	8,768	1.70	11,070	.88	3,716	5.42	23,945		
PLOT 4												
1931	0.03	0	0.01	0	1.18	3,869	3.19	2,621	4.41	6,490	Wheat	41.4
1932	.13	397	.17	10	.05	3	0	0	.35	410	Meadow	1.63
1933	0	0	.20	410	6.89	55,180	.11	0	7.20	55,590	Corn	43.3
1934	.03	0	2.48	24,140	2.75	2,870	1.92	200	7.18	27,210	Wheat	8.7
1935	.41	250	5.33	400	.01	0	0	0	5.75	650	Meadow	1.38
1936	2.07	60	.31	610	1.86	6,110	.76	1,410	5.00	8,190	Corn	0
1937	2.52	180	.11	160	.05	50	.01	0	2.69	390	Wheat	20.7
1938	0	0	.05	20	.11	50	0	0	.16	70	Meadow	1.48
1939	.31	10	4.15	38,330	1.33	8,960	.26	710	6.05	48,010	Corn	21.4
1940	1.05	510	2.76	6,330	.37	200	0	0	4.18	7,040	Wheat	10.0
Total	6.55	1,407	15.57	70,410	14.60	77,292	6.25	4,941	42.97	154,050		
Average	.66	141	1.56	7,041	1.46	7,729	.63	494	4.30	15,405		
PLOT 5												
1931	0.03	0	0.03	0	0.61	1,212	4.92	2,217	5.59	3,429	Meadow	2.68
1932	.14	13	1.66	9,321	2.81	30,326	0	0	4.61	39,660	Corn	49.7
1933	0	0	.23	140	2.60	660	0	0	2.83	800	Wheat	10.6
1934	.06	0	1.60	510	.12	190	1.15	120	2.93	820	Meadow	.34
1935	.12	0	5.68	8,060	.07	190	.02	70	5.89	8,320	Corn	15.0
1936	3.03	70	.22	240	3.02	2,310	1.20	4,790	7.47	7,410	Wheat	22.5
1937	3.29	1,220	1.55	10,250	.62	650	.02	0	5.48	12,120	Meadow	.57
1938	0	0	.99	8,920	3.54	24,480	.01	10	4.54	34,400	Corn	4
1939	.68	1,620	5.83	38,380	1.14	2,200	.26	140	7.91	42,340	Wheat	1.7
1940	.99	100	1.48	880	.07	0	0	0	2.54	880	Meadow	.99
Total	8.34	3,033	19.27	76,701	14.60	63,218	7.58	7,347	49.79	150,179		
Average	.83	303	1.93	7,670	1.46	6,322	.76	735	4.98	15,018		

See footnotes at end of table.

TABLE 53.—*Seasonal and annual runoff and soil loss*[1] *and crop yields from control plots 1 to 10 of plot series 1, 1932–40*[2]—Continued

PLOT 6

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Tons or bushels*
1931	0.01	0	0.01	0	0.47	795	2.79	1,175	3.28	1,970	Meadow	3.14
1932	.07	6	1.30	10,017	1.52	9,856	0	0	2.89	19,879	Corn	51.6
1933	0	0	.05	10	2.80	1,050	0	0	2.85	1,060	Wheat	24.1
1934	.03	0	1.51	930	.06	220	1.46	150	3.06	1,300	Meadow	.52
1935	.28	10	5.24	12,950	.05	180	0	0	5.57	13,140	Corn	12.9
1936	2.25	150	.05	60	1.77	3,180	.93	5,540	5.00	8,930	Wheat	31.7
1937	3.71	2,010	.59	2,470	.68	920	.08	0	5.06	5,400	Meadow	1.55
1938	0	0	.75	8,890	2.47	22,660	.01	10	3.23	31,560	Corn	1.0
1939	.61	1,680	4.64	50,110	1.32	5,630	.32	250	6.89	57,670	Wheat	1.6
1940	.95	140	1.71	1,940	.32	0	0	0	2.98	2,080	Meadow	.87
Total	7.71	3,996	15.85	87,377	11.46	44,491	5.59	7,125	40.81	142,989		
Average	.77	4,000	1.58	8,738	1.15	4,450	.60	712	4.08	14,299		

PLOT 7

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1931	0	0	0.03	0	0.54	548	0.57	253	1.14	801	Alfalfa	2.21
1932	.02	1	.31	18	.04	2	0	0	.37	21	do	5.68
1933	0	0	.02	0	2.33	510	0	0	2.35	510	do	5.41
1934	.04	0	1.57	60	.05	130	1.18	200	2.84	390	do	2.50
1935	.74	10	6.15	240	.01	0	0	0	6.90	250	do	3.05
1936	1.45	30	.02	10	.04	50	0	0	1.51	90	do	1.85
1937	2.26	160	.06	40	.03	30	.01	0	2.36	230	do	2.91
1938	0	0	.03	10	.04	10	0	0	.07	20	do	3.01
1939	.63	10	1.29	140	.02	0	0	0	1.94	150	do	4.33
1940	.83	40	.07	0	0	0	0	0	.90	40	do	4.30
Total	5.97	251	9.49	518	3.10	1,280	1.76	453	20.38	2,502		
Average	.60	25	.95	52	.31	128	18	45	2.04	250		

PLOT 8

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1931	0.21	0	0.06	0	0.52	984	4.11	816	4.90	1,800	Bluegrass[2]	
1932	.10	13	.31	40	6	8	0	0	.47	61	do	
1933	0	0	.02	0	2.70	360	0	0	2.72	360	do	

1934	.06	0	1.50	170	.05	170	1.54	90	3.15	430	do	
1935	.10	0	5.26	220	.01	0	0	0	5.37	220	do	0.85
1936	2.10	30	.02	10	.05	40	.01	0	2.18	80	do	.47
1937	2.43	60	.04	10	0	0	.06	0	2.53	70	do	.95
1938	0	0	.04	10	.0	0	0	0	.07	10	do	.59
1939	.71	10	1.27	40	.02	0	0	0	2.00	50	do	.42
1940	.93	0	.08	0	0	0	0	0	1.01	0	do	.67
Total	6.64	113	8.60	500	3.44	1,562	5.72	906	24.40	3,081		
Average	.66	11	.86	50	.34	156	.57	91	2.44	308		
PLOT 9												
1931	0.14	0	0.93	27,499	6.44	135.820	2.96	47,551	10.47	210,870	Fallow	
1932	.01	3	1.75	33,399	4.76	132,743	.33	3,955	6.85	170,100	do	
1933	0	0	.88	17,620	9.88	271,060	0	0	10.76	288,680	do	
1934	0	0	2.26	61,560	3.86	84,740	3.90	23,940	10.02	170,240	do	
1935	.40	11,200	14.15	260,430	.94	15,130	.04	250	15.53	287,010	do	
1936	1.97	3,140	.95	8,460	2.94	22,180	.83	5,450	6.69	39,230	do	
1937	2.68	4,770	.98	22,190	.93	12,010	0	0	4.59	38,970	do	
1938	0	0	2.03	59,180	3.89	92,990	.33	770	6.25	152,940	do	
1939	1.02	4,810	5.94	158,840	1.84	37,300	.68	4,720	9.48	205,670	do	
1940	1.74	6,650	3.07	46,230	1.89	6,780	.04	0	6.74	59,660	do	
Total	7.96	30,573	32.94	695,408	37.37	810.753	9.11	86,636	87.38	1,623,370		
Average	.80	306	3.29	69,541	3.74	81,075	.91	8,664	8.74	162,337		
PLOT 10												
1931	0.38	0	0.03	0	5.54	111,476	2.87	36,415	8.82	147,891	Fallow	
1932	.03	10	1.98	14,258	3.47	70,576	.20	2,025	5.68	86,869	do	
1933	0	0	.69	10,050	10.25	203,320	0	0	10.94	213,370	do	
1934	.03	0	2.94	60,860	2.83	42,970	4.93	17,080	10.73	120,910	do	
1935	.35	2,130	12.94	212,480	.67	5,070	.09	230	14.05	219,910	do	
1936	4.95	3,500	.83	3,650	2.27	13,010	.64	2,960	8.69	23,120	do	
1937	4.77	10,750	.71	15,070	.79	5,590	0	0	6.27	31,410	do	
1938	0	0	1.32	22,030	3.06	46,720	.14	610	4.52	69,360	do	
1939	1.66	9,030	6.13	131,230	1.53	25,720	.15	1,540	9.37	167,520	do	
1940	3.06	11,870	3.27	31,280	1.39	6,690	0	0	7.72	49,840	do	
Total	15.23	37,290	30.84	500,908	31.80	531,142	9.02	60,860	86.79	1,130,200		
Average	1.52	3,729	3.08	50,091	3.18	53,114	.90	6,086	8.68	113,020		

[1] Soil loss in pounds per acre, water loss in inches per acre.
[2] Bluegrass established by seeding with timothy and not harvested until 1935.

TABLE 54.—*Average seasonal and annual runoff and soil loss*[1] *from plot series I for 10-year period 1931–40*

Plot	First quarter		Second quarter		Third quarter		Fourth quarter		Total	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss
	Inches	*Tons*	*Inches*	*Tons*	*Inches*	*Tons*	*Inches*	*Tons*	*Inches*	*Tons*
1	1.08	2.126	2.50	34.586	2.87	22.425	1.49	6.478	8.03	65.615
2	.98	.785	2.50	27.268	3.08	17.614	1.64	5.252	8.20	50.919
3, 4, 5, (corn),	.60	.016	1.73	5.415	2.65	11.449	1.00	1.968	5.98	18.848
3, 4, 5 (wheat),	.83	.288	2.57	5.608	1.55	.982	.66	.389	5.61	7.267
3, 4, 5, (meadow),	.73	.115	1.39	711	.43	.130	.62	.117	3.17	1.073
5	.84	.153	1.93	3.830	1.46	3.161	.75	.367	4.98	7.511
6	.79	.200	1.60	4.369	1.14	2.225	.56	.356	4.08	7.150
7	.60	.013	.95	.027	.32	.064	.18	.023	2.05	.127
8	.67	.008	.86	.025	.35	.078	.58	.045	2.46	.156
9	.79	1.520	3.30	34.818	3.74	40.537	.91	4.332	8.74	81.216
10	1.52	1.606	3.08	25.046	3.18	26.558	.91	3.043	8.69	56.513

[1] Soil loss in tons per acre, runoff in surface inches.

TABLE 55.—*Seasonal and annual runoff ar*[1] *soil loss*[1] *and crop yield for plots 3, 4, and 5 of series 1 for the 10-year period, 1931–40*

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Yield per acre
	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Tons or bushels*
CORN YEARS											
1931	0.20	0	[illegible]	29,679	4.41	56,399	5.12	21,882	10.69	107,960	30.6
1932	.14	13	.8	9,321	2.81	30,326	0	0	4.61	39,660	49.7
1933	0	0	.20	410	6.89	55,180	.11	0	7.20	55,590	43.3
1934	.02	0	1.54	2,870	4.02	43,610	3.48	15,260	9.06	61,740	0
1935	.12	0	5.68	8,060	.07	190	.02	70	5.89	8,320	15.0
1936	2.07	60	.31	610	1.86	6,110	.76	1,410	5.00	8,190	0
1937	2.51	190	.43	2,530	.31	1,090	.16	10	3.41	3,820	37.0
1938	0	0	.99	8,920	3.54	25,470	.01	10	4.54	34,400	4.0
1939	.31	10	4.15	38,330	1.33	8,960	.26	710	6.05	48,010	21.4
1940	.54	40	1.37	7,580	1.16	1,660	0	0	3.07	9,280	26.1
Total	5.91	313	16.23	108,310	26.43	228,995	9.92	39,352	59.52	376,970	......
Average	.59	31	1.62	10,831	2.64	22,900	.99	3,935	5.95	37,697	......
WHEAT YEARS											
1931	0.03	0	0.01	0	1.18	3,869	3.19	2,621	4.41	6,490	41.4
1932	.14	8	.20	12	.96	3,159	0	0	1.30	3,179	30.9
1933	0	0	.23	140	2.60	660	0	0	2.83	800	10.6
1934	.03	0	2.48	24,140	2.75	2,870	1.92	200	7.18	27,210	8.7
1935	.75	3,300	10.71	17,900	.02	0	0	0	11.48	21,200	12.6
1936	3.03	70	.22	240	3.02	2,310	1.20	4,790	7.47	7,410	22.5
1937	2.52	180	.11	160	.05	50	.01	0	2.69	390	20.7
1938	0	0	3.06	24,850	3.36	4,310	.04	10	6.46	29,170	4.0
1939	.68	1,620	5.83	38,380	1.14	2,200	.26	140	7.91	42,340	1.7
1940	1.05	510	2.76	6,330	.37	200	0	0	4.18	7,040	10.0
Total	8.23	5,748	25.61	112,152	15.45	19,628	6.62	7,761	55.91	145,289	......
Average	.82	575	2.56	11,215	1.55	1,963	.66	776	5.59	14,529	......
MEADOW YEARS											
1931	0.03	0	0.03	0	0.61	1,212	4.92	2,217	5.59	3,429	2.68
1932	.13	397	.17	10	.05	3	0	0	.35	410	1.63
1933	0	0	.04	10	2.07	370	0	0	2.11	380	1.61
1934	.06	0	1.60	510	.12	190	1.15	120	2.93	820	.34
1935	.41	250	5.33	400	.01	0	0	0	5.75	650	1.38
1936	1.68	70	.03	10	.12	40	.03	0	1.86	120	1.72
1937	3.29	1,200	1.55	10,250	.62	650	.02	0	5.48	12,120	.67
1938	0	0	.05	20	.11	50	0	0	.16	70	1.48
1939	.67	230	3.55	2,240	.51	70	.01	0	4.74	2,540	1.10
1940	.99	110	1.48	770	.07	0	0	0	2.54	880	.09
Total	7.26	2,277	13.83	14,220	4.29	2,585	6.13	2,337	31.51	21,419	......
Average	.73	228	1.38	1,422	.43	259	.61	234	3.15	2,142	......

[1] Soil loss in pounds per acre, water loss in inches.

TABLE 56.—*Seasonal and annual runoff and soil loss, and crop yields from plots A, B, and plot 1 through 8 of series 2* [1]

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Tons or bushels*
PLOT A												
1932	0	0	2.45	67,028	6.17	127,097	0.87	2,853	9.49	196,978	Fallow	.....
1933	0	0	1.28	25,273	9.91	145,963	.03	0	11.22	171,236	Corn	9.6
1934	0	0	2.96	87,527	3.97	44,353	4.13	6,909	11.06	138,789	do	0
1935	1.56	9,875	13.51	160,867	.72	3,571	.27	88	16.06	174,401	do	21.1
1936	0	0	1.36	11,299	3.23	17,371	.79	4,749	5.38	33,419	do	0
1937	4.31	6,175	1.18	16,192	.65	2,414	0	0	6.14	24,781	do	28.1
1938	0	0	2.02	28,804	2.56	22,015	.46	765	5.04	51,584	do	4.8
1939	.68	3,092	6.15	122,905	1.27	14,848	.75	1,546	8.85	142,391	do	1.4
Total	6.55	19,142	30.91	519,895	28.48	377,632	7.30	16,910	73.24	933,579		
Average	.82	2,393	3.86	64,987	3.56	46,829	.91	2,114	9.16	116,697		
PLOT B												
1932	0	0	1.99	29,672	3.60	96,485	0.13	1,371	5.72	127,528	Fallow	.....
1933	0	0	.94	21,407	9.39	78,736	.02	0	10.35	100,143	Corn	28.7
1934	0	0	3.36	46,673	3.15	41,659	2.53	2,192	9.04	90,524	do	0
1935	.43	8,026	11.08	154,667	.43	1,777	.05	16	11.99	164,486	do	16.5
1936	0	0	.63	4,765	2.58	9,298	.81	4,072	4.02	18,135	do	0
1937	3.54	5,538	.89	16,773	.34	821	0	0	4.77	23,132	do	30.2
1938	0	0	1.55	22,884	2.61	21,904	.48	686	4.64	45,474	do	3.2
1939	.12	279	4.83	110,983	1.31	17,901	.74	1,976	7.00	131,139	do	3.7
Total	4.09	13,843	25.27	407,824	23.41	268,581	4.76	10,313	57.53	700,561		
Average	.51	1,730	3.16	50,978	2.93	33,573	.59	1,287	7.19	87,750		
PLOT 1												
1932	0	0	0	41	0	0	0	0	0	41	Meadow	0.68
1933	0	0	.03	0	1.68	1,036	0	0	1.71	1,036	do	1.76
1934	0	0	.84	2,378	5.36	31,148	5.51	7,568	11.71	41,094	Corn	0
1935	.60	984	14.05	47,003	.57	47	.23	0	15.45	48,034	Oats	30.0
1936	0	0	0	10	.25	99	.14	99	.39	208	Meadow	1.21

See footnotes at end of table.

TABLE 56.—*Seasonal and annual runoff and soil loss, and crop yields from plots A, B, and plot 1 through 8 of series 2*[1]—Continued

PLOT 1—Continued

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Tons or bushels*
1937	1.04	5	.07	52	.06	21	0	0	1.17	78	Meadow	1.13
1938	0	0	.80	11,295	3.58	31,004	.54	544	5.01	42,843	Corn	.5
1939	.50	3,191	5.17	48,562	1.30	4,077	.25	88	7.22	55,918	Oats	2.5
1940	.14	36	.92	342	.01	5	0	0	1.07	383	Meadow	.38
Total	2.28	4,216	21.97	109,683	12.81	67,437	6.67	8,299	43.73	189,635		
PLOT 2												
1932	0	0	1.23	1,637	1.37	740	0	0	2.60	2,377	Meadow	0.67
1933	0	0	.08	0	10.01	1,528	0	0	10.09	1,528	do	.74
1934	0	0	3.33	29,350	2.45	32,971	2.17	18,591	7.95	80,912	Corn	0
1935	.59	6,760	9.69	80,492	.11	88	0	0	10.39	87,340	Oats	6.5
1936	0	0	.01	36	.70	280	.38	451	1.09	767	Meadow	.66
1937	2.99	871	.47	1,669	.30	57	0	0	3.76	2,597	do	.06
1938	0	0	.77	7,300	2.87	25,459	.44	461	4.08	33,220	Corn	2.1
1939	.39	1,865	5.04	61,751	1.38	6,263	.02	31	6.83	69,910	Oats	1.3
1940	.36	93	1.68	880	.02	31	0	0	2.06	1,004	Meadow	.16
Total	4.33	9,589	22.30	183,115	19.21	67,417	3.01	19,534	48.85	279,655		
PLOT 3												
1932	0	0	0.04	88	0	0	0	0	0.04	88	Meadow	1.47
1933	0	0	.03	124	2.34	3,539	0	0	2.37	3,663	do	1.16
1934	0	0	1.68	3,947	2.00	18,026	2.43	11,479	6.11	33,452	Corn	0
1935	.22	4,771	7.86	31,318	0	0	0	0	8.08	36,089	Oats	26.7
1936	0	0	0	5	.03	67	.01	42	.04	114	Meadow	1.08
1937	3.44	1,819	.08	109	0	0	0	0	3.52	1,928	do	.36
1938	0	0	.96	3,617	2.47	21,491	.20	176	3.63	25,284	Corn	1.6
1939	.36	1,616	3.76	15,235	.62	1,409	0	0	4.74	18,260	Oats	6.4
1940	.50	62	.52	217	0	0	0	0	1.02	279	Meadow	.69
Total	4.52	8,268	14.93	54,660	7.46	44,532	2.64	11,697	29.55	119,157		

PLOT 4

1932	0	0	0.05	93	0	0	0	0	0.05	93	Meadow	1.43
1933	0	0	.82	969	7.78	81,493	.21	0	8.81	19,462	Corn	23.5
1934	0	0	1.89	29,417	2.16	5,424	3.37	2,507	7.42	37,348	Oats	3.6
1935	.28	2,207	8.96	10,443	0	0	0	0	9.24	12,650	Meadow	.36
1936	0	0	.21	549	1.23	1,622	.70	6,632	2.14	8,803	Corn	0
1937	2.93	2,741	.79	5,156	.26	145	.01	5	3.99	8,047	Oats	47.8
1938	0	0	.82	716	1.15	866	0	0	1.97	1,582	Meadow	.57
1939	.01	57	4.58	67,438	.77	5,905	.50	1,109	5.86	74,509	Corn	13.9
1940	.87	2,461	1.88	7,408	.14	124	0	0	2.89	9,993	Oats	10.4
Total	4.09	7,466	20.00	122,189	13.49	32,579	4.79	10,253	42.37	172,487		

PLOT 5

1932	0	0	0	41	0	0	0	0	0	41	Meadow	
1933	0	0	.37	1,476	4.79	24,088	.09	0	5.25	25,564	Corn	32.1
1934	0	0	2.15	21,404	1.28	2,952	1.22	1,503	5.65	25,859	Oats	3.2
1935	.23	870	6.60	2,891	0	0	.01	0	6.81	3,761	Meadow	
1936	0	0	.32	974	1.40	1,974	.58	4,964	2.39	7,912	Corn	0
1937	2.58	1,985	.77	4,850	.41	311	.04	57	3.80	7,203	Oats	52.6
1938	0	0	.62	684	.02	10	0	0	.64	694	Meadow	
1939	0	0	4.66	75,664	.68	6,895	.49	1,130	5.83	83,689	Corn	15.4
1940	.79	2,916	1.44	7,263	.37	306	0	0	2.60	10,485	Oats	14.7
Total	3.60	5,771	16.93	115,247	9.04	36,536	2.43	7,654	32.97	165,208		

PLOT 6

1932	0	0	0.08	41	0	0	0	0	0.08	41	Meadow	
1933	0	0	.55	1,694	6.76	20,809	.11	0	7.42	22,503	Corn	30.4
1934	0	0	3.67	23,437	1.30	2,331	2.62	736	7.59	35,504	Oats	4.3
1935	.32	798	6.85	1,465	0	0	0	0	7.17	2,263	Meadow	
1936	0	0	.50	1,176	.92	1,637	.39	4,444	1.81	7,357	Corn	0
1937	2.47	2,637	.68	3,399	.29	166	.01	5	3.45	6,207	Oats	55.0
1938	0	0	.09	99	0	0	0	0	.09	99	Meadow	
1939	.18	52	4.41	60,601	.54	4,667	.22	373	5.35	65,693	Corn	12.6
1940	.93	1,948	.52	1,135	.02	57	0	0	1.47	3,140	Oats	24.8
Total	3.90	5,435	17.35	102,047	9.83	29,667	3.35	5,558	34.43	142,707		

See footnote at end of table.

TABLE 56.—*Seasonal and annual runoff and soil loss, and crop yields from plots A, B, and plot 1 through 8 of series 2* [1]—Continued

PLOT 7[2]

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Tons or bushels*
1932	0	0	0.09	119	0	0	0	0	0.09	119	Meadow	
1933	0	0	.07	0	1.57	446	0	0	1.64	446	do	
1934	0	0	2.29	435	.01	0	2.13	135	4.43	570	do	
1935	0	0	3.49	217	0	0	0	0	3.49	217	do	
1936	0	0	0	0	0	0	0	5	0	5	do	
1937	.81	176	.04	10	0	0	0	0	.85	186	do	
1938	0	0	.02	0	0	0	0	0	.02	0	do	
1939	.14	21	1.51	0	0	0	0	0	1.65	21	do	
1940	.39	36	0	0	0	0	0	0	.39	36	do	
Total	1.34	233	7.51	781	1.58	446	2.13	140	12.56	1,600		
Average	.15	26	.83	87	.18	50	.24	16	1.40	178		

PLOT 8

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1936	0	0	0.25	544	0.25	244	0.32	2,741	0.82	3,529	Oats; lespedeza	0.8
1937	2.84	8,005	1.31	6,482	.01	93	0	0	4.16	14,580	do	1.04
1938	0	0	.80	1,549	.05	52	0	0	.85	1,601	do	2.32
1939	.86	383	2.73	2,093	.46	192	0	0	4.05	2,668	do	.91
1940	.59	36	.01	0	0	0	0	0	.60	36	do	1.64
Total	4.29	8,424	5.10	10,668	.77	581	.32	2,741	10.48	22,412		
Average	.86	1,685	1.02	2,134	.15	116	.06	548	2.10	4,483		

[1] Soil loss in pounds per acre; water loss in inches.

This plot was not harvested.

TABLE 57.—*Runoff and soil loss*[1] *by seasons and years, and crop yields from plots A-1, 1, A, B, 2, and 3 of series 3*

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Tons or bushels*
PLOT A-1												
1933	0	0	0.29	4,100	6.47	51,481	0.06	0	6.82	55,581	Corn	50.1
1934	0	0	1.48	39,286	3.70	53,355	2.42	1,850	7.60	94,491	Corn	0
1935	.44	6,802	8.59	80,870	.16	889	0	0	9.19	88,561	Corn	10.0
1936	0	0	.64	6,026	1.36	6,782	.31	2,204	2.31	15,032	Corn	0
1937	1.65	933	.58	11,822	.17	784	0	0	2.40	13,539	Corn	36
1938	0	0	1.58	33,741	3.09	49,187	.27	339	3.49	83,277	Corn	.7
1939	.07	176	5.05	136,316	.52	5,769	.17	282	5.81	142,543	Corn	37.9
Total	2.16	7,911	18.21	313,061	15.47	168,247	3.23	4,675	39.07	493,894		
Average	.31	1,130	2.60	44,723	2.21	21,035	.46	668	5.58	70,556		
PLOT 1												
1933	0	0	0.87	11,503	11.07	84,228	0.16	0	12.10	95,731	Corn	56.0
1934	0	0	3.30	48,000	4.58	70,583	2.35	3,062	10.23	121,645	Corn	0
1935	.76	16,750	16.52	171,950	.58	2,297	.03	0	17.89	190,997	Corn	8.5
1936	0	0	.75	9,184	1.84	7,702	.55	3,024	3.14	19,910	Corn	0
1937	3.17	7,985	.82	23,203	.24	701	0	0	4.23	31,889	Corn	31.8
1938	.00	0	1.37	38,465	3.51	55,716	.56	748	5.44	94,929	Corn	2.3
1939	.07	196	5.51	179,550	.88	12,121	.77	3,327	7.23	195,194	Corn	8.2
Total	4.00	24,931	29.14	481,855	22.70	233,348	4.42	10,161	60.26	750,295		
Average	.57	3,562	4.16	68,835	3.24	33,335	.63	1,451	8.61	107,185		
PLOT A												
1932	0	0	1.54	34,748	0.99	31,816	0	0	2.53	66,564	Soybeans	2.15
1933	0	0	.92	8,991	4.89	5,405	.00	0	5.81	14,396	Oats	34.8
1934	0	0	1.52	1,069	.47	233	1.64	472	3.63	1,774	Meadow	.86
1935	.12	139	3.13	16,805	.10	604	.12	847	3.47	18,395	Corn	15.6
1936	0	0	.90	11,765	4.25	23,050	1.46	27,083	6.61	61,898	Soybeans	0
1937	2.40	3,694	1.55	26,005	.88	604	.08	113	4.91	30,416	Oats	71.6

See footnote at end of table.

TABLE 57.—*Runoff and soil loss*[1] *by seasons and years, and crop yields from plots A–1, 1, A, B, 2, and 3 of series 3*—Continued

PLOT A—Continued

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Tons or bushels*
1938	0	0	1.47	1,745	1.25	512	0.03	7	2.75	2,264	Meadow	0.87
1939	.11	30	5.62	47,038	.87	5,253	.71	1,119	7.31	53,440	Corn	26.1
Total	2.63	3,863	16.65	148,166	13.70	67,477	4.04	29,641	37.02	249,147		
Average	.33	483	2.08	18,521	1.71	8,435	.50	3,705	4.63	31,143		
PLOT B												
1932	0	0	1.43	33,907	0.27	1,009	0	0	1.70	34,916	Soybeans	2.54
1933	0	0	.13	292	3.90	2,065	0	0	4.03	2,357	Wheat	20.5
1934	0	0	1.96	3,005	.08	17	1.89	163	3.93	3,185	Meadow	1.08
1935	.08	126	4.03	32,055	.37	1,842	.33	2,025	4.81	36,048	Corn	14.5
1936	0	0	.85	17,617	2.28	10,936	.83	5,762	3.96	34,315	Soybeans	0
1937	1.93	1,142	.28	654	.16	93	.04	66	2.41	1,955	Wheat	2.15
1938	0	0	.26	219	.54	485	0	0	.80	704	Meadow	1.43
1939	.05	20	5.19	38,885	.54	2,467	.33	342	6.11	41,714	Corn	13.4
Total	2.06	1,288	14.13	126,634	8.14	18,914	3.42	8,358	27.75	155,194		
Average	.26	161	1.77	15,830	1.02	2,364	.43	1,045	3.47	19,399		
PLOT 2												
1932	0	0	0.31	196	0	0	0	0	0.31	196	Meadow	1.69
1933	0	0	.19	1,597	4.59	10,997	0	0	4.78	12,594	Corn	75.2
1934	0	0	1.39	7,205	.79	4,296	1.03	133	3.21	11,634	Oats	10.3
1935	.09	60	2.85	347	0	0	.02	13	2.96	420	Meadow	1.34
1936	0	0	.10	371	.49	1,569	.14	1,789	.73	3,729	Corn	0
1937	1.45	432	.74	7,351	.20	59	0	0	2.39	7,842	Oats	89.2
1938	0	0	.04	30	0	0	0	0	.04	30	Meadow	1.08
1939	.01	0	4.25	10,629	.02	53	.02	27	4.30	10,709	Corn	36.6
1940	.05	50	.05	229	0	13	0	0	.10	292	Oats	46.6
1941	.04	0	.06	50	0	0	.11	0	.21	50	Meadow	1.73
Total	1.64	542	9.98	28,005	6.09	16,987	1.32	1,962	19.03	47,496		

PLOT 3

1932	0	0	0.23	196	0	0	0	0	0.23	196	Meadow	1.66
1933	0	0	.33	2,115	5.98	20,209	0	0	6.31	22,324	Corn	56.9
1934	0	0	2.31	19,077	2.77	4,752	3.38	341	8.46	24,170	Oats	10.9
1935	.50	574	7.34	765	0	0	0	0	7.84	1,339	Meadow	1.56
1936	0	0	.23	504	1.63	4,321	.73	8,652	2.59	13,567	Corn	0
1937	1.95	1,374	1.30	16,946	.62	358	.02	33	3.89	18,711	Oats	57.1
1938	0	0	.24	140	.31	50	0	0	.55	190	Meadow	1.03
1939	.01	0	4.82	23,144	.58	1,564	.53	707	5.94	25,415	Corn	11.1
1940	.56	717	1.85	4,266	.28	132	0	0	2.69	5,115	Oats	20.6
1941	.04	0	.84	103	0	0	.84	10	1.72	113	Meadow	.121
Total	3.06	2,665	10.40	67,346	12.17	31,386	5.50	9,743	40.22	111,140		
Average	.31	266	1.05	6,735	1.22	3,139	.55	974	4.02	11,114		

[1] Soil loss in pounds per acre; runoff in surface inches.

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TABLE 58.—*Runoff and soil loss*[1] *by seasons and years and crop yields for contour-cropped plots 2, 4, and 6 of series 5, by individual crops by a 3-year rotation, 1936–41*

PLOT 2, CORN OCCUPYING ENTIRE PLOT

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Yield per acre
	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Tons or bushels*
1936	0	0	0	0	0.10	88	0.03	16	0.13	104	0
1937	3.08	874	.31	1,089	[2] 0	3	0	0	3.39	1,966	30.1
1938	0	0	.30	1,221	.23	147	0	0	.53	1,368	16.9
1939	.30	9	3.27	34,373	.62	4,377	0	0	4.10	38,759	16.4
1940	.41	19	1.96	10,755	.07	32	0	0	2.44	10,806	31.6
1941	0	0	1.64	6,614	0	0	1.45	2,207	3.09	8,821	16.8
Total	3.79	902	7.48	54,052	1.02	4,467	1.48	2,223	13.77	61,824	-------
Average	.63	150	1.25	9,009	.17	774	.25	371	2.30	10,304	-------

PLOT 4, WHEAT OCCUPYING ENTIRE PLOT

Year	First quarter Run-off	First quarter Soil loss	Second quarter Run-off	Second quarter Soil loss	Third quarter Run-off	Third quarter Soil loss	Fourth quarter Run-off	Fourth quarter Soil loss	Total Run-off	Total Soil loss	Yield per acre
1936	0	0	0	0	0.55	136	0.40	309	1.04	445	22.0
1937	2.76	182	.04	26	0	0	0	0	2.80	208	22.3
1938	0	0	.47	818	.87	345	0	0	1.34	1,163	[3] 38.5
1939	.05	36	2.49	1,757	.33	198	0	0	2.87	1,991	5.6
1940	.43	713	.22	137	.02	2	0	0	.67	852	18.0
1941	.74	74	1.47	189	1.74	25	0	0	3.95	288	[3] 22.5
Total	3.98	1,005	4.69	2,927	3.51	706	.40	309	12.67	4,947	-------
Average	.66	168	.78	471	.58	118	.08	52	2.11	825	-------

PLOT 6, RED CLOVER AND TIMOTHY OCCUPYING ENTIRE PLOT

Year	First quarter Run-off	First quarter Soil loss	Second quarter Run-off	Second quarter Soil loss	Third quarter Run-off	Third quarter Soil loss	Fourth quarter Run-off	Fourth quarter Soil loss	Total Run-off	Total Soil loss	Yield per acre
1936	0	0	0	0	0.22	19	0.24	100	0.46	119	1.40
1937	3.28	979	[2] .28	406	[2] .16	40	0	0	3.72	1,425	1.38
1938	0	0	0	8	0	0	0	0	0	8	1.50
1939	.52	36	3.09	293	.23	8	0	0	3.84	337	.57
1940	.02	1	.90	160	0	0	0	0	.92	161	.74
1941	.15	9	.54	26	0	0	1.17	36	1.86	71	2.01
Total	3.97	1,025	4.81	893	.61	67	1.41	136	10.80	2,121	-------
Average	.63	171	.80	149	.10	11	.24	23	1.80	351	-------

[1] Soil loss in pounds per acre, water loss in surface inches.
[2] Box leaked.
[3] Wheat, winter-killed; oats, seeded in spring. Yield is for oats.

TABLE 59.—*Runoff and soil loss* [1] *by seasons and years, and crop yields from strip cropped plots 1, 3, and 5 of series 5, by crop location on the slope in a 3-year rotation of corn, wheat and meadow 1936–41*

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Yields per acre		
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Corn	Wheat	Meadow
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Bushels*	*Bushels*	*Tons*
PLOT 1, CORN OCCUPYING LOWER STRIP													
1936	0	0	0	0	0.36	148	0.17	119	0.53	267	0	18.9	1.84
1937	3.16	636	.12	41	0	0	0	0	3.28	677	41.8	17.0	1.36
1938	0	0	.26	1,121	.23	176	0	0	.49	1,297	14.3	[2] 38.3	2.23
1939	.16	30	2.64	9,714	.31	636	0	0	3.11	10,380	6.3	5.3	.81
1940	.19	30	.02	4,418	0	0	0	0	.21	4,448	33.7	17.7	.90
1941	.10	3	1.39	1,419	0	0	1.69	944	3.18	2,366	10.5	[2] 22.5	2.10
Total	3.61	699	4.43	16,713	.90	960	1.86	1,063	10.80	19,435			
Average	.60	116	.74	2,785	.15	160	.31	177	1.80	3,239			
PLOT 3, WHEAT OCCUPYING LOWER STRIP													
1936	0	0	0	0	0.21	33	0.23	95	0.44	128	0	28.8	1.36
1937	2.99	264	.32	289	.06	17	0	0	3.37	570	53.1	18.8	1.60
1938	0	0	.16	241	.27	67	0	0	.43	308	17.8	[2] 35.8	1.97
1939	.16	73	2.69	1,205	.36	80	0	0	3.21	1,358	8.1	3.6	.47
1940	.40	234	1.00	229	.01	1	0	0	1.41	464	55.4	16.6	.69
1941	.14	23	1.64	539	0	0	1.44	67	3.22	629	19.9	[2] 22.5	1.73
Total	3.69	594	5.81	2,503	.91	198	1.67	162	12.08	3,457			
Average	.62	99	.97	417	.15	33	.28	27	2.01	576			
PLOT 5, RED CLOVER AND TIMOTHY OCCUPYING LOWER STRIP													
1936	0	0	0	0	0.01	4	0.07	10	0.08	14	0	18.9	1.53
1937	2.90	814	.15	174	.06	12	0	0	3.11	1,000	36.0	23.1	1.38
1938	0	0	.16	77	.20	52	0	0	.36	129	14.7	[2] 41.6	1.74
1939	.38	26	2.98	4,391	.29	246	0	0	3.65	4,663	19.3	8.2	.57
1940	.18	11	1.29	386	0	0	0	0	1.47	397	15.1	20.7	.77
1941	.52	27	1.57	633	0	0	2.17	711	4.26	1,371	13.8	[2] 22.5	2.57
Total	3.98	878	6.15	5,661	.56	314	2.24	721	12.93	7,574			
Average	.66	146	1.02	944	.09	52	.32	104	2.16	1,262			

[1] Soil loss in pounds per acre, runoff in surface inches.

[2] Wheat, winter-killed; oats, planted in spring. Yield is for oats.

TABLE 60.—*Seasonal and annual soil and water losses*[1] *and grazing data, from bluegrass pasture plots 1936–41*

SERIES 9, PLOT 1

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Unit[2] pasture per acre	Change in animal weight per acre
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss		
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Days*	*Pounds*
1936	0.88	9.0	0	0	0	2	0	1	0.88	12	121	145
1937	3.15	0	0	2	0	0	0	0	3.15	2	154	384
1938	0	0	0	1	0	0	0	0	0	1	141	141
1939	.21	0	.05	0	0	0	0	0	.26	0	98	57
1940	0	0	0	0	0	0	0	0	0	0	129	190
1941	0	0	0	0	.87	123	.07	0	.94	123	36	255
Total	4.24	9.0	.05	3	.87	125	.07	1	5.23	138		
Average	.71	1.50	0.1	.50	.15	20.83	.01	.17	.87	23		

SERIES 9, PLOT 2

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Unit[2] pasture per acre	Change in animal weight per acre
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss		
1936	1.40	33.0	0	0	0	3	0	1	1.40	37	95	134
1937	2.36	0	.01	8	0	0	.01	0	2.38	8	275	51
1938	0	0	.03	3	0	0	0	0	.03	3	203	213
1939	.15	0	2.29	14	.04	6	0	0	2.48	20	157	−67
1940	0	0	.24	11	.03	2	0	0	.27	13	218	−680
1941	.29	0	2.02	214	0	0	.22	10	2.53	224	89	−586
Total	4.20	33.0	4.59	250	.07	11	.23	11	9.09	305		
Average	.70	5.50	.77	41.67	.01	1.83	.04	1.83	1.52	50.83		

[1] Soil loss in pounds per acre; runoff in inches.
[2] A unit pasture day is equivalent to the grazing of 5 sheep for 1 day.

TABLE 61.—*Seasonal and annual runoff and soil loss*[1] *and crop yields, from length of slope plots 1 to 5 of plot series 15, 1934–40*[2]

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Bushels*
PLOT 1, 90 FEET LONG												
1934	0	0	1.37	2,553	1.15	3,961	2.79	5,285	5.31	11,799	Corn	0
1935	.78	3,370	8.03	62,643	0	292	.01	18	8.82	66,323	do	24.2
1936	0	0	.07	429	1.54	6,223	.60	7,392	2.21	14,044	do	0
1937	3.20	7,312	.02	126	.27	619	.06	340	3.55	8,397	do	37.1
1938	0	0	.93	18,525	2.18	19,917	.02	11	3.13	38,453	do	7.1
1939	.30	2,570	4.04	73,530	.80	10,137	.08	517	5.31	86,754	do	37.5
1940	1.51	2,110	.37	371	.28	92	0	0	2.16	2,573	Wheat	17.3
Total	4.37	132,520	14.82	157,806	6.22	41,149	3.56	13,563	28.33	225,770		
Average	.73	2,209	2.41	26,301	.99	6,858	.59	2,277	4.72	37,628		
PLOT 5, 90 FEET LONG												
1934	0	0	2.07	16,764	0.96	6,215	2.26	4,549	5.29	27,528	Corn	0
1935	.32	2,693	6.72	81,420	.03	239	0	21	7.07	84,373	do	41.2
1936	0	0	.5	626	.75	2,347	.39	3,443	1.19	6,416	do	0
1937	3.48	6,883	.02	76	.09	195	.03	122	3.62	7,276	do	50.9
1938	0	0	.70	16,504	1.46	14,167	.02	7	2.18	30,678	do	16.1
1939	.23	2,163	3.59	69,883	.63	10,482	.08	285	4.53	82,813	do	43.6
1940	.36	848	.55	754	.17	51	0	0	1.08	1,656	Wheat	19.0
Total	4.03	11,739	13.15	185,273	3.92	33,645	2.78	8,427	23.88	230,084		
Average	.67	1,956	2.19	30,879	.65	5,608	.46	1,571	3.98	39,847		
PLOT 2, 180 FEET LONG												
1934	0	0	0.93	3,485	1.04	12,734	1.96	10,820	3.93	27,039	Corn	
1935	.44	4,732	8.57	166,481	0	279	0	0	9.01	171,492	do	32.3
1936	0	0	.04	678	.85	4,545	.41	10,669	1.30	15,892	do	0
1937	3.10	16,539	0	49	.17	526	.02	145	3.29	17,259	do	44.6
1938	0	0	.82	38,456	1.57	28,246	.03	10	2.42	66,714	do	12.6
1939	.32	6,948	3.73	174,251	.57	15,197	.06	337	4.68	196,733	do	38.9
1940	.76	6,803	.22	345	.33	93	0	0	1.31	7,241	Wheat	23.6
Total	3.86	28,219	14.09	383,402	4.20	61,527	2.48	21,981	24.63	495,129		
Average	.64	4,703	2.35	63,900	.70	10,255	.41	3,664	4.11	82,522		

See footnotes at end of table.

TABLE 61.—*Seasonal and annual runoff and soil loss* [1] *and crop yields, from length of slope plots 1 to 5 of plot series 15, 1934–40* [2]—Continued

PLOT 4, 180 FEET LONG

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
	Inches	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*		*Bushels*
1934	0	0	1.69	6,995	1.58	11,942	3.41	19,550	6.68	38,487	Corn	0
1935	.43	8,093	8.20	187,492	.20	774	.20	136	9.03	196,495	do	25.0
1936	0	0	.02	835	1.01	7,303	.53	8,924	1.56	17,062	do	0
1937	3.14	14,926	0	46	.14	269	.01	71	3.29	15,312	do	42.0
1938	0	0	.78	31,052	1.55	19,822	.05	46	2.38	50,920	do	17.9
1939	.28	8,038	3.80	149,034	.73	16,812	.10	482	4.91	174,366	do	32.6
1940	.53	5,035	.70	1,006	.36	156	0	0	1.59	6,197	Wheat	15.8
Total	3.85	31,057	14.49	375,454	5.21	56,922	4.30	29,209	27.85	492,642		
Average	.64	5,176	2.42	62,576	.87	9,487	.72	4,868	4.64	82,107		

PLOT 3, 270 FEET LONG

Year	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1934	0	0	1.34	13,129	1.52	16,175	4.58	21,810	7.44	51,114	Corn	0
1935	.61	10,730	7.95	203,002	.05	790	.09	109	8.70	214,631	do	25.1
1936	0	0	.08	1,836	1.18	6,732	.50	15,944	1.76	24,512	do	0
1937	3.45	22,030	0	44	.12	328	.03	278	3.60	22,680	do	41.3
1938	0	0	.80	38,851	1.56	30,653	.03	36	2.39	69,540	do	18.4
1939	.35	10,390	4.71	257,797	.60	18,114	.06	179	5.72	286,580	do	32.1
1940	1.66	22,217	.70	2,233	.49	270	0	0	2.85	24,720	Wheat	20.9
Total	4.41	43,150	14.88	514,659	5.03	72,892	5.29	38,356	29.61	669,057		
Average	.74	7,192	2.48	85,776	.84	12,149	.88	6,393	4.94	111,510		

[1] Soil loss in pounds per acre, water loss in surface inches.
[2] Corn years, 1934 through 1939. All plots were in wheat in 1940 and are not totaled or averaged with the corn years.

TABLE 62.—*Annual soil and water losses and crop yields from terrace 2–G, cropped to alfalfa 1933–37 and to oats-lespedeza 1938–39*

Year	Runoff		Soil loss per acre	Crop	Crop yield per acre	
	Amount	Maximum rate per hour				
	Inches	*Inches*	*Tons*		*Tons*	*Bushels*
1933	7.52	1.97	1.49	Oats [1]		
1934	7.07	3.30	1.24	Alfalfa	0.00	
				Alfalfa	.90	
1935	10.75	1.84	.91	Alfalfa	.89	
1936	.97	.16	.00	Alfalfa	1.48	
1937	3.11	.24	.21	Alfalfa	1.20	
1938	1.15	.98	.22	Oats		42.2
				Lespedeza [2]	.00	
1939	4.31	4.10	.36	Oats		17.5
				Lespedeza	.81	

[1] Alfalfa was established with oats as a nurse crop in the spring of 1933 and was not harvested.
[2] A stand of lespedeza did not result from the first seeding.

TABLE 63.—*Annual soil and water losses and crop yields from designated terraced areas in a 2-year rotation of corn and oats with sweetclover, turned under*

Year	Corn					Oats				
	Terraced area	Runoff		Soil loss per acre	Crop yield per acre	Terraced area	Runoff		Soil loss per acre	Crop yield per acre
		Amount	Maximum rate per hour				Amount	Maximum rate per hour		
		Inches	*Inches*	*Tons*	*Bushels*		*Inches*	*Inches*	*Tons*	*Bushels*
1932	1–H	(1)	(1)			2–H	2.05	0.44	0.530	45.9
1933	2–H	6.00	1.41	0.319	24.6	1–H	(1)	(1)		
1934	1–H	(1)	(1)			2–H	7.27	3.50	6.560	8.9
1935	2–H	7.82	.94	.104	8.2	1–H	(1)	(1)		
1936	1–H	3.41	.80	.129	0.0	2–H	2.87	.48	.315	60.6
1937	2–H	3.32	.37	.285	40.1	1–H	3.06	1.78	.193	65.2
1938	1–H	.93	.21	.144	12.2	2–H	.91	.22	.131	51.1
1939	2–H	4.39	2.85	.361	14.7	1–H	5.22	2.20	.574	10.3
1940	1–H	2.57	1.22	.751	34.8	2–H	1.52	.03	.116	35.9
1941	2–H	3.68	1.19	.500	10.4	1–H	2.86	.42	.116	42.7

[1] Not measured.

TABLE 64.—*Annual soil and water losses and crop yields from designated terraced areas in a 4-year rotation corn, soybeans, wheat, and meadow*

Year	Corn					Soybeans				
	Terraced area	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop yield per acre	Terraced area	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop yield per acre
		Inches	*Inches*	*Tons*	*Bushels*		*Inches*	*Inches*	*Tons*	*Tons*
1932	6-H	4.42	1.95	8.260	22.4	3-H	3.09	2.60	4.157	2.10
1933	5-H	10.68	1.95	4.373	35.5	6-H	7.50	1.05	9.842	2.14
1934	4-H	12.82	2.47	3.282	0	5-H	11.01	3.21	5.853	.41
1935	3-H	8.97	2.08	8.750	7.2	4-H	10.42	1.89	3.924	.08
1936	6-H	3.95	.93	1.048	0	3-H	3.88	.52	1.305	0
1937	5-H	2.92	.98	1.378	42.8	6-H	2.47	.26	.760	.97
1938	4-H	1.24	.70	.640	12.9	5-H	2.96	.37	1.055	.88
1939	3-H	4.41	3.28	3.748	31.8	4-H	6.66	3.09	4.457	.90
1940	6-H	2.54	1.35	1.020	35.4	3-H	2.29	1.29	.748	1.04
1941	5-H	5.99	1.78	1.205	17.1	6-H	4.50	1.45	1.292	.75
	Wheat					Meadow				
1932	5-H	5.21	1.60	2.609	14.7	4-H	3.26	1.50	0.416	0.76
1933	3-H	8.10	1.78	2.159	23.6	4-H	5.64	.94	.377	.77
1934	6-H	10.68	2.93	2.117	13.0	3-H	6.02	2.91	3.524	.47
1935	5-H	11.69	1.19	2.161	18.7	6-H	8.84	.93	1.227	1.33
1936	4-H	3.79	.54	.230	30.0	5-H	2.05	.35	.032	1.25
1937	3-H	3.07	.62	.406	21.4	4-H	4.06	1.07	.488	.41
1938	6-H	2.23	.30	.271	16.7	3-H	.57	.13	.034	1.97
1939	5-H	4.81	2.49	.898	8.4	6-H	4.63	2.20	.200	0
1940	4-H	1.15	.56	.131	22.4	5-H	1.60	.35	.023	.78
1941	3-H	3.41	.59	.176	[1] 41.7	4-H	2.22	.23	.033	1.08

[1] Seeded to oats after wheat winter-killed.

TABLE 65.—*Annual soil and water losses and crop yields from terraces of various vertical spacing*

Year	Terrace 3-G, 5-foot vertical interval on a 12.4 percent slope					Year	Terrace 4-G, 7-foot vertical interval on a 13.9 percent slope				
	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre		Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	In.	*In.*	*Tons*		*Bu. or tons*		*In.*	*In.*	*Tons*		*Bu. or tons*
1932	2.89	1.13	0.303	Oats	43.9	1932	2.14	0.62	0.467	Oats	43.9
1933	5.47	.94	.229	Meadow	1.68	1933	4.40	.89	.431	Meadow	1.68
1934	9.35	3.63	3.148	Corn	0	1934	9.52	3.21	2.517	Corn	0
1935	10.02	2.40	3.652	Oats	30.3	1935	10.65	2.36	4.025	Oats	34.5
1936	1.25	.05	.008	Meadow	1.26	1936	1.35	.10	.009	Meadow	1.67
1937	3.76	1.64	1.256	Corn	30.8	1937	3.74	1.40	1.526	Corn	42.3
1938	1.74	.54	.269	Oats	44.6	1938	1.25	.39	.196	Oats	43.1
1939	5.15	3.09	.280	Meadow	0	1939	4.31	3.03	.231	Meadow	0
1940	2.41	1.76	.936	Corn	41.2	1940	2.70	1.70	1.102	Corn	49.7

TABLE 65.—*Annual soil and water losses and crop yields from terraces of various vertical spacing*—Continued

Terrace 5-G, 9-foot vertical interval on a 13.2 percent slope

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	In.	*In.*	*Tons*		*Bu. or tons*
1932	1.56	0.46	0.329	Oats	43.9
1933	3.32	.76	.215	Meadow	1.68
1934	7.74	3.02	3.371	Corn	0
1935	8.35	2.01	3.368	Oats	41.7
1936	1.02	.05	0	Meadow	2.20
1937	3.20	1.37	1.602	Corn	56.3
1938	.55	.24	.084	Oats	41.4
1939	3.10	2.62	.114	Meadow	0
1940	1.71	1.58	.899	Corn	57.6

Terrace 5-N, 5-foot vertical spacing on a 7.4 percent slope

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	In.	*In.*	*Tons*		*Bu. or tons*
1932	1.77	0.21	0.131	Oats	59.6
1933	3.22	.50	.205	Meadow	1.73
1934	7.73	2.18	2.505	Corn	0
1935	9.73	1.52	3.002	Oats	39.5
1936	1.11	.34	.009	Meadow	1.87
1937	2.20	.18	.220	Corn	40
1938	.52	.08	.030	Oats	40.7
1939	4.23	2.58	.174	Meadow	0
1940	1.55	1.01	.500	Corn	51.1

Terrace 4-N, 3-foot vertical interval on a 6.3 percent slope

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1932	2.56	0.41	0.245	Oats	62.4
1933	1.13	.26	.068	Meadow	1.73
1934	3.78	1.50	1.160	Corn	0
1935	5.90	1.08	2.051	Oats	31.1
1936	1.04	.67	.024	Meadow	1.28
1937	2.12	.23	.193	Corn	44.1
1938	.53	.11	.035	Oats	39.1
1939	3.37	2.23	.329	Meadow	0
1940	1.54	.86	.281	Corn	54.3

Terrace 6-N, 7-foot vertical spacing on a 6.8 percent slope

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1932	1.44	0.40	0.201	Oats	59.6
1933	2.24	.61	.156	Meadow	1.73
1934	6.47	.176	4.570	Corn	0
1935	8.24	.178	3.730	Oats	40.6
1936	.85	.23	.006	Meadow	1.49
1937	1.77	.27	.302	Corn	36.7
1938	.28	.08	.026	Oats	36.5
1939	3.33	2.51	.213	Meadow	0
1940	1.54	1.10	.631	Corn	45.4

TABLE 66.—*Annual soil and water losses and crop yields from terraces of various channel grades*

Terrace 5-C; channel grade, 8 inches per 100 feet

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	In.	*In.*	*Tons*		*Bu. or tons*
1932	4.19	3.30	7.167	Corn	27.5
1933	4.84	1.44	.657	Oats	64.1
1934	5.72	2.40	.901	Meadow	.86
1935	12.33	2.40	14.598	Corn	8.0
1936	4.07	.48	.523	Oats	58.5
1937	3.67	.29	.340	Meadow	.61
1938	2.72	2.06	5.319	Corn	8.6
1939	5.14	2.23	.080	Oats	24.1
1940	1.14	.36	.013	Meadow	1.31

Terrace 7-C; channel grade, 4 inches per 100 feet

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	In.	*In.*	*Tons*		*Bu. or tons*
1932	3.21	2.55	2.913	Corn	27.5
1933	3.94	.71	.424	Oats	64.1
1934	4.03	2.13	.692	Meadow	.96
1935	9.41	1.96	5.586	Corn	8.0
1936	2.56	.49	.159	Oats	67.8
1937	3.41	.17	.099	Meadow	.67
1938	2.02	1.03	1.650	Corn	13.7
1939	4.87	1.92	.556	Oats	24.1
1940	.08	.17	.004	Meadow	1.31

Terrace 6-C; channel grade, 6 inches per 100 feet

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1932	3.50	3.00	3.335	Corn	27.5
1933	4.02	.87	.419	Oats	64.1
1934	5.71	2.10	.525	Meadow	.83
1935	10.32	2.04	4.929	Corn	8.0
1936	3.08	.54	.177	Oats	48.6
1937	3.51	.16	.163	Meadow	.55
1938	2.25	1.60	3.004	Corn	10.4
1939	4.40	2.01	.486	Oats	24.1
1940	1.01	.26	.005	Meadow	1.31

Terrace 7-C North; channel grade, level (overtopping)

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1933	2.11	0.75	0.540	Oats	64.1
1934	3.08	2.10	.760	Meadow	.79
1935	4.34	1.14	2.040	Corn	8.0
1936	1.35	1.06	.090	Oats	57.9
1937	3.56	.07	.270	Meadow	3.30
1938	.17	.25	.170	Corn	14.3

TABLE 66.—*Annual soil and water losses and crop yields from terraces of various channel grades*—Continued

Terrace 8-C; channel grade, 2 inches per 100 feet

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	In.	*In.*	*Tons*		*Bu. or tons*
1932	3.03	2.05	0.956	Corn	27.5
1933	3.71	.40	.308	Oats	64.1
1934	4.51	1.40	.202	Meadow	.83
1935	0.74	1.54	3.143	Corn	8.0
1936	2.21	.25	.049	Oats	65.2
1937	3.28	.21	.102	Meadow	.71
1938	1.51	.38	.801	Corn	21.1
1939	3.90	1.25	.330	Oats	24.1
1940	.73	.12	.003	Meadow	1.31

Terrace 9-C; channel grade, level

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1932	1.59	0.51	0.626	Corn	27.5
1933	2.56	.30	.213	Oats	64.1
1934	2.90	.75	.285	Meadow	.99
1935	9.09	1.02	2.646	Corn	8.0
1936	1.70	.37	.043	Oats	54.6
1937	3.18	.13	.143	Meadow	.73
1938	.32	.14	.202	Corn	23.6
1939	2.23	.76	.088	Oats	24.1
1940	.31	.02	.000	Meadow	1.31

Terrace 10-C; channel grade, variable 1 to 4 inches per 100 feet

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	In.	*In.*	*Tons*		*Bu. or tons*
1932	2.84	2.42	2.218	Corn	27.5
1933	2.51	.38	.201	Oats	64.1
1934	2.45	1.68	.388	Meadow	1.09
1935	10.44	2.23	5.272	Corn	8.0
1936	1.01	.23	.056	Oats	51.1
1937	3.60	.15	.120	Meadow	.77
1938	1.18	.78	1.028	Corn	28.5
1939	3.20	1.25	.209	Oats	24.1
1940	.60	.10	.001	Meadow	1.31

Terrace 2-N; channel grade, level

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1936	0.64	0.01	0	Meadow	1.57
1937	1.52	.23	.150	Corn	54.8
1938	.20	.07	.010	Oats	42.0

Terrace 8-N; channel grade, level

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1933	1.25	0.32	0.060	Meadow	1.19
1934	2.03	.70	1.140	Corn	0
1935	4.20	.54	.660	Oats	31.2
1936	.76	.03	.010	Meadow	1.43
1937	2.25	.06	.110	Corn	40.5
1938	.26	.12	.030	Oats	39.2

TABLE 67.—*Annual soil and water losses and crop yields from terraces of various lengths*

Terrace 2-I, terrace length, 1,375 feet

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	Inches	*Inches*	*Tons*		*Bu. or tons*
1934	1.76	0.62	0.98	Meadow	1.18
1935	5.84	1.36	4.29	Corn	22.4
1936	1.26	.25	.34	Corn	0
1937	3.43	.41	1.54	Oats	61.8
1938	.64	.21	.14	Meadow	1.64

Terrace 4-I; terrace length, 2,450 feet

Year	Runoff: Amount	Runoff: Maximum rate per hour	Soil loss per acre	Crop	Crop yield per acre
	Inches	*Inches*	*Tons*		*Bu. or tons*
1934	4.96	1.80	1.34	Meadow	0.77
1935	10.69	1.91	10.86	Corn	13.7
1936	3.50	.62	1.29	Corn	0
1937	3.29	1.02	2.08	Oats	68.6
1938	1.47	.37	.17	Meadow	1.53

TABLE 68.—*Annual precipitation, runoff, soil loss, and crop yields from terraced bluegrass pasture watershed (Pa–A)*[1]

[Area, 2.026 acres,[2] average slope, 13.0 percent; 6 terraces (1,710 feet), grade, less than 2 inches per 100 feet]

Year	Rainfall	Runoff			Soil loss per acre	Grazing[3] animal-unit-days per acre
		Amount	Percent of rainfall	Maximum rate per hour		
	Inches	*Inches*	*Percent*	*Inches*	*Tons*	*Days*
1934	31.18	4.48	14.4	1.59	7.134	
1935	37.33	7.92	21.2	1.22	1.183	
1936	24.11	.64	2.7	.02	.000	82.3
1937	21.84	2.99	13.7	.17	.014	117.0
1938	27.23	.06	.2	.14	.003	50.3
1939	27.27	.98	3.6	1.59	.021	28.2
1940	27.79	.41	1.5	.31	0	79.1
1941	35.41	1.91	5.4	.76	.037	82.0
1942	32.90	1.86	5.7	.17	.052	101.1

[1] Terraces were constructed in the fall of 1933.
[2] Area consisted of 2.117 acres prior to August 12, 1938, on which date the outlet was relocated.
[3] Pastures were grazed with horses, cattle and sheep in 1936 and cattle thereafter. The fenced grazing area is 4.04 acres. Fence was installed May 19, 1936.

TABLE 69.—*Annual precipitation, runoff, soil loss, and crop yields from normal bluegrass pasture watershed (Pa–B)*

[Area 5.563 acres;[1] average slope 9.5 percent]

Year	Rainfall	Runoff			Soil loss per acre	Grazing[2] animal-unit-days per acre
		Amount	Percent of rainfall	Maximum rate per hour		
	Inches	*Inches*	*Percent*	*Inches*	*Tons*	*Days*
1932	27.36	0.70	2.6	0.21	0.920	
1933	31.37	2.75	8.8	1.23	1.342	
1934	31.18	2.83	9.1	2.55	1.875	
1935	37.33	9.96	26.7	1.76	3.259	
1936	24.11	.90	3.7	.12	.073	75.8
1937	21.84	3.37	15.4	.03	.125	65.7
1938	26.51	.01	0	0	0	62.3
1939	26.89	.59	2.2	.73	.043	45.3
1940	27.84	.38	1.4	.18	.003	102.4
1941	35.03	2.06	8.4	1.56	.109	104.0
1942	32.63	2.17	6.7	.56	.069	108.4

[1] Area was reduced from 6.520 acres by relocation of measuring equipment and dikes on November 11, 1935. Before, the larger portion of soil loss came from gully banks above the flume. Such loss was eliminated by moving the measuring equipment.
[2] Pastures were grazed with horses, cattle, and sheep in 1936. Cattle have been used subsequently. The fenced grazing area is 7.53 acres. Fence was installed May 19, 1936.

TABLE 70.—*Annual precipitation, runoff, soil loss, and crop yields from contour-furrowed bluegrass pasture (Pa–C)*[1]

[Area, 1.974 acres; average slope, 11.0 percent; 7950 feet of contour furrows placed at 1-foot vertical intervals]

Year	Rainfall	Runoff			Soil loss per acre	Grazing[2] animal-unit-days per acre
		Amount	Percent of rainfall	Maximum rate per hour		
	Inches	*Inches*	*Percent*	*Inches*	*Tons*	*Days*
1937 [3]	16.93	0.34	2.0	0.11	0.049	59.5
1938	27.23	.33	1.2	.10	.006	59.0
1939	27.27	1.13	4.2	1.36	.055	34.6
1940	27.79	.47	1.7	.16	.020	56.9
1941	35.41	3.22	9.1	.40	.136	71.0
1942	32.90	2.93	8.9	.29	.060	103.5

[1] Contour furrows were constructed on Nov. 27, 1939 with a contour-furrowing machine developed by the University of Missouri. Previous measurement of the watershed was for calibration purposes with other pastures.
[2] The pasture was grazed with cattle. The fenced grazing area is 3.44 acres.
[3] The watershed was placed under measurement Apr. 1, 1937. Data for 1937 cover the remainder of the calendar year only. Total rainfall for the year was 21.84 inches.

TABLE 71.—*Annual precipitation, runoff, soil loss, and crop yields from cultivated watershed (D-3)*

[Area, 4.485 acres;[1] average slope 6.7 percent; control practices, none (farmed with field boundaries]

Year	Rainfall	Runoff			Soil loss per acre	Cropping[2]	
		Amount	Percent of rainfall	Maximum rate per hour		Crop kind	Yield per acre
	Inches	*Inches*	*Percent*	*Inches*	*Tons*		*Tons or bushels*
1932[3]	17.65	0.38	2.2	0.10	0.910	Meadow	0.47
1933	31.37	6.02	19.2	2.07	27.731	Corn	28.0
1934	31.18	6.18	19.8	2.48	40.016	Corn	(4)
1935	36.07	11.54	32.0	4.62	47.380	Oats	38.0
1936	24.28	2.00	8.2	.18	.880	Meadow	1.66
1937	21.68	3.50	16.1	.91	19.712	Corn	33.9
1938	26.22	1.22	4.7	2.66	2.628	Oats	50.0
1939	27.09	5.41	20.0	3.36	25.845	Wheat	9.0
1940	28.17	2.17	7.7	1.53	3.275	Meadow	1.50
1941	34.89	5.69	16.3	3.52	63.938	Corn	8.3
1942	33.20	5.89	17.7	2.72	38.443	Oats	27.8

[1] Area reduced from 4.847 to 4.485 acres on May 11, 1934.
[2] Rotation was corn, corn, oats, clover and timothy previous to 1937 at which time it was changed to corn, oats, wheat, clover and Timothy and placed in phase with watersheds D-1 and D-2.
[3] Data cover last 6 months of year only; total for the year was 27.36 inches.
[4] No harvest.

TABLE 72.—*Annual precipitation, runoff, soil loss, and crop yields from contour cultivated watershed (D-1)*[1]

[Area, 7.510 acres; average slope, 6.5 percent; contour farming operation, grassed waterways, wire checks and sod dams;[2] Soil treatment, limed 5 tons per acre in 1930 and 125 pounds per acre fertilizer applied with each small grain crop]

Year	Rainfall	Runoff			Soil loss per acre	Cropping[3]	
		Amount	Percent of rainfall	Maximum rate per hour		Crop kind	Yield per acre
	Inches	*Inches*	*Percent*	*Inches*	*Tons*		*Tons or bushels*
1934[4]	21.26	5.93	27.9	2.38	24.040	Oats	49.0
1935	36.07	10.31	28.6	3.18	16.969	Wheat	20.1
1936	24.77	1.94	7.8	.13	.113	Meadow	1.83
1937	21.63	4.06	18.8	.48	1.825	Corn	35.2
1938	26.13	.71	2.7	1.24	.164	Oats	40.9
1939	26.68	3.65	13.7	3.18	.776	Wheat	7.9
1940	27.62	1.93	7.0	1.43	.079	Meadow	1.78
1941	35.04	5.03	14.4	2.77	1.378	Corn	7.9
1942	32.89	3.65	11.1	.77	.785	Oats	25.7

[1] Cultivation lines deviated from the contour by as much as 5% at a few points prior to 1939. The lines were relaid on an approximate terrace spacing and grade in the fall of 1938. Back furrowing on these lines at that time and again in November 1940 has formed small ridges which have increased depression storage and resulted in a reduced soil and water loss.
[2] Practices were initiated in 1930 before installation of measuring equipment.
[3] Rotation of corn, oats, wheat, and clover and timothy meadow.
[4] Measurement was for last 6 months of year only. Total for the year 31.18 inches.

TABLE 73.—*Annual precipitation, runoff, soil loss, and crop yields from terraced cultivated watershed (D–2)*

[Area, 8.03 acres; average slope, 7.0 percent; terracing (8 terraces, total length 5,050 feet, vertical interval 5 feet, grade 3 inches per 100 feet), bluegrass outlet, contour farming, furrow slice thrown up slope in plowing;[1] soil treatment, limed 5 tons per acre in 1930, and 125 pounds per acre fertilizer applied with each small grain crop]

Year	Rainfall	Runoff: Amount	Runoff: Percent of rainfall	Runoff: Maximum rate per hour	Soil loss per acre	Cropping[2]: Crop kind	Cropping[2]: Yield per acre
	Inches	*Inches*	*Percent*	*Inches*	*Tons*		*Tons or bushels*
1934[3]	21.26	5.37	25.3	2.19	4.545	Oats	40.5
1935	36.07	7.97	22.1	1.48	1.625	Wheat	20.5
1936	24.28	1.37	5.6	.05	.006	Meadow	1.66
1937	21.62	2.99	13.8	.14	.293	Corn	40.7
1938	26.21	.72	2.7	.16	.055	Oats	41.0
1939	26.71	3.52	13.2	2.36	.632	Wheat	9.5
1940	27.59	1.66	6.0	.53	.045	Meadow	1.68
1941	34.88	4.68	13.4	2.07	1.123	Corn	12.0
1942	32.83	3.29	10.0	.29	.581	Oats	30.0

[1] Practices were initiated in 1930 before installation of measuring equipment.
[2] Rotation of corn, oats, wheat, clover and timothy meadow.
[3] Measurement for last 6 months of year only. Total for the year was 31.18 inches.

TABLE 74.—*Annual precipitation, runoff, soil loss, and crop yields from continuous alfalfa watershed (1–58)* [1]

[Area, 2.112 acres; average slope 9.1 percent; soil treatment, limed 3 tons per acre in 1932, 250 pounds per acre of 4–12–4 fertilizer with original alfalfa seeding, 125 pounds per acre of 0–20–0 fertilizer annually with oats]

Year	Rainfall	Runoff: Amount	Runoff: Percent of rainfall	Runoff: Maximum rate per hour	Soil loss per acre	Cropping: Crop kind	Cropping: Yield per acre
	Inches	*Inches*	*Percent*	*Inches*	*Tons*		*Tons or bushels*
1933	31.37	5.84	18.6	2.96	9.885	Alfalfa	0.24
1934	31.18	4.75	15.2	3.80	6.309	do	1.47
1935	36.07	12.57	34.9	3.52	7.634	do	1.75
1936	24.73	.87	3.5	.00	.002	do	1.00
1937	22.01	2.40	10.9	.22	.292	do	1.03
1938	20.82	2.37	8.8	2.34	6.416	Oats	44.7
1938						Lespedeza	(2)
1939	27.69	3.36	12.1	3.99	8.10	Oats	15.8
1939						Lespedeza	.88
1940	28.17	.73	2.6	.44	.056	Oats	37.1
1940						Lespedeza	.66
1941	35.12	2.93	8.3	.70	.026	Oats	25.1
1941						Lespedeza	.99
1942	33.92	2.39	7.0	2.20	.324	Oats	27.2
1942						Lespedeza	.71

[1] Continuous alfalfa was plowed out in the fall of 1937 and a small grain-lespedeza annual rotation is now being studied.
[2] No harvest.

TABLE 75.—*Annual precipitation, runoff, soil loss, and crop yields from rotation strip-cropped watershed (IJ-1)* [1]

[Area, 2.128 acres; average slope 9.2 percent; strip cropping, contour cultivation, grassed waterway; soil treatment, 200 pounds per acre of 0-20-0 fertilizer with each small grain seeding]

Year	Rainfall	Runoff				Cropping—kind and yield per acre [2]
		Amount	Percent of rainfall	Maximum rate per hour		
	Inches	*Inches*	*Percent*	*Inches*	*Tons*	
1933 [3]	21.39	5.08	23.4	1.44	22.594	Upper two strip seeded to meadow, no yield; corn 14.5 bu; soybeans, 3.17 tons.
1934	31.18	2.58	8.3	2.06	7.395	Cl and t [4] 1.4 tons; corn, no harvest; soybeans .57 ton; wheat 10.5 bu.
1935	36.07	10.91	30.3	3.00	10.186	Corn 8.5 bu; soybeans 1.02 tons; wheat 21.4 bu; cl and t [4] .79 ton.
1936	24.73	1.42	5.7	.09	.018	Oats 60.2 bu; corn, no harvest; cl and t [4] 1.65 tons.
1937	22.01	3.17	14.4	1.35	1.639	Cl and t [4] .95 ton; oats 57.4 bu; corn 59.6 bu.
1938	26.82	.49	1.8	.52	.088	Corn 9.1 bu; cl and t [4] 1.49 tons; oats 41.1 bu.
1939	27.69	3.42	12.4	3.12	.874	Oats 19.6 bu; corn 40.3 bu; cl and t [4] no harvest.
1940	28.17	2.19	7.8	1.12	.353	Cl and t [4] 2.6 tons; oats 40.2 bu; corn 45.2 bu.
1941	36.12	1.77	5.6	1.31	.192	Corn 11.8 bu; cl and t [4] 2.26 tons; oats 32.5 bu.
1942	33.92	1.98	5.8	.58	.118	Oats 39.4 bu; corn 73.6 bu; cl and t [4] 2.37 tons.

[1] The watershed was cropped in four strips of corn, soybeans, wheat, and clover and timothy from 1933 to 1936. The strips were of equal width in 1933. They were relocated to an exact contour in 1934. The rotation was changed to corn, oats, clover and timothy in 1936 and a small strip at the bottom of the slope retired to permanent hay.

[2] Crops and yields given in the sequence of their position from the top to the bottom of the slope.

[3] Data cover last 6 months of the year only. Total for the year was 31.37 inches.

[4] Clover and timothy.

TABLE 76.—*Annual amount and duration of precipitation falling at rates equal to or greater than the indicated rates in inches per hour, 1931–41*

Year	Total amount	Total duration	0.25 Min.		0.50 Min.		0.75 Min.		1.00 Min.		1.50 Min.	
			Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time
	In.	*Min.*										
1931	42.10	26,162	18.62	1,267	15.64	801	12.61	517	10.38	342	7.12	174
1932	27.36	11,372	13.15	800	10.57	371	9.68	283	8.75	232	7.40	166
1933	31.37	9,967	18.74	1,457	14.83	679	13.58	532	12.09	416	9.12	251
1934	31.18	12,737	15.34	943	12.18	427	11.18	325	10.19	251	8.79	181
1935	36.07	17,109	15.79	1,128	12.88	643	10.54	376	9.41	261	8.20	220
1936	24.29	10,759	9.96	891	7.21	450	4.88	215	3.91	141	2.27	60
1937	21.72	11,031	7.26	580	5.30	273	4.40	176	3.21	112	1.81	46
1938	26.16	12,972	12.21	733	10.91	521	9.33	365	7.52	235	5.31	123
1939	26.84	12,503	13.39	862	11.08	487	9.43	319	8.51	251	6.31	164
1940	27.76	16,823	10.48	713	8.71	412	7.39	277	6.01	172	4.73	106
1941	31.62	19,045	14.14	1,164	10.80	531	8.94	317	7.08	220	5.23	126

TABLE 76.—*Annual amount and duration of precipitation falling at rates equal to or greater than the indicated rates in inches per hour, 1931–41*—Continued

2.00 Min.		3.00 Min.		4.00 Min.		5.00 Min.		6.00 Min.		7.00 Min.		8.00 Min.		9.00 Min.	
Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time	Amount	Time
5.21	100	3.51	54	1.06	19	0.85	8	0.67	6	0.27	2	0.14	1	-----	-----
5.76	115	4.00	64	1.14	13	.92	10	.40	4	-----	-----	-----	-----	-----	-----
7.58	186	3.71	59	1.70	22	.61	5	.39	3	.29	2	.29	2	0.15	1
7.48	138	5.16	76	3.15	40	.83	8	.46	4	.16	1	.16	1	.16	1
6.07	126	4.55	78	.92	13	.20	2	.20	2	-----	-----	-----	-----	-----	-----
1.58	35	.79	13	.31	4	.09	1	-----	-----	-----	-----	-----	-----	-----	-----
1.55	34	.46	7	.27	4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
3.95	75	2.26	32	1.55	20	.59	7	-----	-----	-----	-----	-----	-----	-----	-----
4.86	104	2.37	38	.68	7	.68	7	.15	1	.15	1	.15	1	.15	1
4.01	78	2.25	30	.73	10	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
4.02	82	2.38	39	1.06	13	.56	6	.10	1	-----	-----	-----	-----	-----	-----

TABLE 77.—*Amount and duration of precipitation falling at rates equal to or greater than the indicated, in inches per hour, by calendar months, for the 10-year period 1931–40*

Month	Amount	Duration	0.25 Min.		0.50 Min.		0.75 Min.		1.00 Min.		1.50 Min.	
			Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time
	In.	*Min.*										
January	11.76	11,102	0.48	71	0.10	7	0.07	4	0.07	4	-----	-----
February	6.27	6,413	.21	33	.06	5	.02	1	.02	1	-----	-----
March	12.67	11,152	3.72	414	2.15	141	1.32	59	.90	27	0.80	21
April	25.51	16,609	9.35	673	7.05	309	5.97	190	5.18	137	4.44	102
May	38.59	17,674	19.66	1,568	15.67	793	12.74	484	10.63	320	8.71	228
June	30.66	9,731	25.51	1,484	22.52	977	19.57	671	17.82	524	13.05	332
July	25.35	6,390	15.28	765	13.97	520	12.82	406	11.45	318	8.98	202
August	41.58	13,955	26.20	1,558	23.05	1,052	20.09	748	16.64	516	13.04	314
September	35.26	11,753	18.88	1,371	14.48	666	12.86	489	11.07	375	7.85	205
October	17.82	8,369	7.90	641	5.75	318	4.25	172	3.69	127	2.20	55
November	26.35	17,296	6.91	748	3.79	237	2.79	145	2.09	75	1.08	24
December	11.03	11,081	.81	48	.75	30	.52	16	.42	9	.40	8
Total	294.85	141,525	134.94	9,374	109.34	5,064	93.02	3,385	79.98	2,442	61.15	1,491

Month	2.00 Min.		3.00 Min.		4.00 Min.		5.00 Min.		6.00 Min.		7.00 Min.		8.00 Min.		9.00 Min.	
	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time
January	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
February	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
March	0.51	10	0.41	7	0.07	1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
April	3.66	75	1.67	22	1.04	11	0.83	8	0.46	4	0.16	1	0.16	1	0.16	1
May	7.08	158	4.26	71	1.13	14	.35	4	.20	2	-----	-----	-----	-----	-----	-----
June	11.27	237	6.60	107	2.69	34	1.03	10	.59	5	.29	2	.29	2	.15	1
July	7.24	140	4.64	74	1.52	19	.72	7	.63	6	.13	1	-----	-----	-----	-----
August	9.79	200	5.42	80	2.95	37	1.57	17	.24	2	.14	1	.14	1	-----	-----
September	5.77	118	4.17	66	2.02	26	.24	2	.15	1	.15	1	.15	1	.15	2
October	1.61	34	.97	19	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
November	.78	13	.70	11	.47	7	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
December	.34	6	.22	3	.22	3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total	48.05	991	20.06	400	12.11	152	4.77	48	2.27	20	.87	6	.74	5	.46	3

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