

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search http://ageconsearch.umn.edu aesearch@umn.edu

Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.



START



MICROCOPY RESOLUTION TEST CHART NATIONAL BUREAU OF STANDARDS-1963-4



MICROCOPY RESOLUTION TEST CHART NATIONAL BUREAU OF STANDARDS-1963-A

Technical Bulletin No. 883 · April 1945



Investigations in Erosion Control and Reclamation of Eroded Shelby and Related Soils at the Conservation Experiment Station, Bethany, Mo., 1930-42.1

By D. D. SMITH, project supervisor, D. M. WHITT, soil conservationist, AUSTIN W. ZINGG, agricultural engineer, A. G. MCCALL, senior soil conservationist, and F. G. BELL, chief, Erosion Control Practices Division, Research, Soil Conservation Service²

THE UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, IN COOPERATION WITH THE MISSOURI AGRICULTURAL EXPERIMENT STATION

CONTENTS

3	nge	1	Page
Summory of results and their application to land use planning	1911225222222234	Itesuits and discussion, etc.—Continued. Vegetative studies Topography Terracing Strip cropping. Contour fillage Contour fillage Contour fillage Pickt trial of soil conservation practices Reclamation of soverely croded land Vegetation in drainageways. Strinetures for water disposal. Hydraulic studies Watershed studies Literature cited Appendix	51 69 75 91 92 95 99 108 115 118 128 128 130 143

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. Hoisnan, and C. M. Weedruff.



Ì

0

1 3

Zi.

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 I (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. Pages 50, 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 S, 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 118, 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, tab'es 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."

662226---45

-

e 1.

۰.

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 elimate, 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 crosion survey of 1934 indicated that on the Shelby and related soils, crosion, 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 cornwheat-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 wire 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 crosion 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 crosion when in a fallow condition. Runoff and crosion 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 Oc-

tober 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 $3\frac{1}{2}$ 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 crosion 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 pariod 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 200foot 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 tonsper 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-oatsmeadow. 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 crossion. 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 concentrationpoints; 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 croded 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 outs fourfold and first-year meadow Any plowing should preferably be done in the fall to improve twofold. 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 pro-This will often require a transition to a livestock sysduction costs. tem 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, sodhump 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 The measured runoff from the contoured watershed was practices. 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 15minute 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 Ż

10 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 crossion 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

^{*} 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 crosion 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 Podzelie group. The Shelby loam is the most extensive on the experiment station plots.

WOODRUFF, C. M., and Smith, D. D. PROGRESS REPORT OF THE PROBLEM ABEA OF SHELBY LOAM AND RELATED SOILS. SOIL AND WATER CONSERVATION EXPERIMENT STATION, BETHANY, MO. 1938. [Processed.]

And RELATED SOLS. Sold AND WATER CONSERVATION EXPERIMENT STATION, DETRAN, MO. 1900. [Processed] ³ 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 antiterance 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.

A

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

The Lindley toam.—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 darkdrab 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 「「「「「「「「「「「「「「」」」」」

14 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE



FIGURE 2.—Profile of uncroded and croded 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 saucershaped 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 gallies. 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 caten 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.

16 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

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.

							Cases	; in which	precipita	tion amou	inted to-	-					
51-year period	20.0 22 inc	0 to 22 .49 hes	2.50 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 t 39.99 Inches	o 40.00 42.4 inch	to 42.5 9 44. es incl	0 to 45. 90 47 hes in	00 to 47 7.49 ches in	7.50 to 49.99 nches	50.00 to 52.49 inches	52.50 to 54.99 inches	Mean precipi- tation
	Nu	mber N	umber 3	Number 8	Number 3	Number 7	Number 6	Number 8	Numbe 2	er Numl 6	ber Num 2	nber Nu	mber N 0	umber 1	Number 1	Number 2	Inches 34. 18
					DIS	STRIBUT	YION OF	MONTI	LY PRE	CIPITA	TION						
							Ca	ses in wh	ch precip	itation arr	nounted t	0—					
Month		0.00 to 0.99 inches	1.00 t 1.99 inche	o 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 precipi- tation
January February		Number 26 22	Numb	er Number 4 7	Number	Number	Number	Number 1	Numher	Number	Number	Number	Number	Numbe	r Number	Number	Inches 1,21
March April May June July July August September October		7 3 3 7 2 7 10	1	$egin{array}{cccc} 1&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&$	9 10 8 7 6 12 9 5	4 4 5 4 8 11 4 3	1 4 3 8 4 2 10 2		2 3 1 2 2 1	4 3 1 1	3 3 2	2 1 1 1		1			1, 28 2, 08 3, 04 4, 24 4, 75 3, 87 4, 05 4, 03 2, 41
December		16 27			5 3		1	2	1							-	1, 93 1, 29 34, 18

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

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 Yamell'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	f stor ms
January		0	July	40
February	· -	0-1	August	40
March	· · · · ·	3~10	September	40
April	· • - ·	610	October	9 - 10
MIAV	-	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.

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 0.01(+0.20.

						Freque	iey distr	ibution c	of month	y mean	temperat	ure (°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	\$0.0- 84.9	85.0- 89.9	Mean monthly tempera ture (°F.
Month: January February	Number 1	Number 3 1	Number 3 2	Number 9	Number 10 13	Number 9 5	Number 1 5	Number	Numbér	Number	Number	Numbe	Number	Numbér	Number	Number	Numher	24.5
April	*******	•			2	3	10	14 - 1	4 9	1 21 6	3	1	8	1				40.2 51.4
June July August	• • • • • • • • • • • • • • • • • • •											ï	9 1	-17 	8 17	s	2	72.1 77.8
September. October November	• • • • • • • • • • • •	· · · · · · · · · · · · · · · · · · ·				3	19	14	1	17	1 11	6 3	21 1		10 10	4	ן א. בי גיבייק אין	66. S 55. 5
December			2	5	12	12	3				• • · · • • • • • • • • • • • • • • • •	1		• • • • • • • •	· • • • • • • • •	•		40.6 28.7

TABLE 2.—Frequency of occurrence of different mean monthly temperatures for the 51-year period 1890-1940, Bethany, Mo.

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

20 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

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 a	of first	and last	killing	frosts,	by week
	periods and l	ength of g	rowing	scason			

Last killing frost in spri	ing	First killing frost in fr	Length of growing senson		
Period	Cuses	Period	Cases	Range	Cases
Mar. 24-31. Apr. 1-7. Apr. 8-14. Apr. 15-21. Apr. 29-May 5. May 0-13. May 10-23. May 21-20.	Number 2 10 7 13 7 5 1 2	Sept. 7-13. Sept. 14-20. Sept. 24-26. Sept. 27-Oct. 3. Oct. 4-10. Oct. 11-15. Oct. 18-24. Oct. 28-24. Oct. 28-24. Nov. 1-7.	Number 1 3 5 11 9 6 6 1	Days 115-124 125-134 135-144 145-154 165-174 165-174 185-104 185-104	Number 1 0 4 13 6 5 8 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 Calculations based on this survey showed 5 inches of surin 1934. face 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 Thus, in 70 years of farming, approximately one-half of Missouri. 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

INVESTIGATIONS IN EROSION CONTROL

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 crosion does not precede but closely follows extended sheet crosion.

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, ' expressed as percentages of farm acreages

			Erosion class								
County	Approx- imate total form			Serious sh	ret ernston						
	ncreage	slight 2	Modecate ³	Moderate Serious gullying ' gullying *		Severe erosion 6					
Worth Gentry	Acres 169,000 310,000	Percent 20, 6 39, 3	Percent	Percent 20.0	Percent 43.8 38.7	Percent 20.6					
De Kalb Harrison Daviess	205, 000 460, 000 365, 000	20. \$ 29, \$ 19, 7	17. 0 19. 0 15. 1	22.6 13.7	39. 6 40. 9 51. 5	16. 3					
Total	1, 569, 000	26, 4	10.2	12.7	43. 0	7.7					
	SUE	LBY-LIND	LEY SOIL								
Mercer Linn Putnam Sullives	291, 000 398, 000 330, 000 415, 000	\$.6 18.5 12.1 18.1	2.1 19.8	10.3	44.6 41.0 37.9 32.5	34. 4 20. 4 50. 0 49. 4					
Adair	375, 000 522, 000	5. 1 18. 9 22. 4	5, 1 5, 3 19, 1	12.7 11.5	36.5 20,0 34.5	40.6 41.3 24.0					
Total	2, 528, 000	16, 3	8.9	3.9	34.8	36.1					
		OTHER S	orts	· · · · · · · · · · · · · · · · · · ·		·					
Remaining counties of the State	39, 450, 000	23.8	-29, 1	25.5	16.4	1.9					

SHELBY-GRUNDY SOIL

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 castern part of the State. ² 80 or more percent of the surface soil remaining.

 40 to 60 percent of the surface soil remaining, with occasional gullying.
 40 to 60 percent of the surface soil remaining, with underate gullying.
 40 to 60 percent of the surface soil remaining, with serious gullying.
 40 to 60 percent of the surface soil remaining, with serious gullying.
 Less than 40 percent of the surface soil remaining, with serious gullying; 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.

a di sharara

and the second and the second and the second sec

The rate of soil loss increases at an accelerated rate with increase indegree 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

County and State	Shelby- Grundy- Lindley soil	Lindley soil	County and State	Shelby- Grundy- Lindley soil	Lindley soil
Worth County, Mo Gentry County, Mo Do Kalb County, Mo Daviess County, Mo Daviess County, Mo	Parcent 73.6 81.8 70.7 70.1 76.3	Percent 4.7 (12) (2) (2) (2) (2) (2)	Ringgold County, Iowa Decatur County, Iowa Wayne County, Iowa Chrk County, Iowa Lucas County, Iowa	Percent 83, 7 (?) 92, 8 85, 7 (?)	Percent 1, 2 (?) , 0 1, 9 (?)
OROUP 2. EASTERN	SECTION	OF PRO	BLEM AREA, SHELBY-LIN	DLEY S	DIP DIP
Mercer County, Mo Linn County, Mo Putnam County, Mo Sullivan County, Mo Schuyler County, Mo	90.5 84.1 90.7 91.6 95.0	(⁷) S. 4 21, 7 25, 0 16, 7	Adair County, Mo Macon County, Mo Appanoose County, Iowa Davis County, Iowa	90.6 71.0 76.6 (*)	39, 5 16, 7 10, 8 (5)

OROUP I. WESTERN SECTION OF PROBLEM AREA, SHELBY-GRUNDY SOIL

¹ Data from U. S. Dept. Agr. soil survey reports, ¹ Trace.

^a Survey incomplete.

N (Sheil (1	by-Grundy 0 counties)	soils	Shel	Shelby-Lindley soils (9 counties)			
. Factor	1880 (20,182 farms)	1910 (21, 556 forms)	1920 (20,320 farms)	1880 (20, 588 farms)	1910 (22,530 farms)	1920 (21,191 forms)		
Average size at form	152, 2	139.5	142.3	125.7	132.0	139.9		
Land in crops 1 Corn and sorghums. Small grains. Wheat. Mendow. Grasses. Legumes. Timothy and clover. Miscellancous crops. Permaceat pasture 1 Timber. Unimproved.	Percent 70.6 34.2 5.0 23.4 23.4 21.9 22.0 10.7	Percent 60. 2 34. 3 9. 9 1. 9 21. 3 6. 6 .2 14. 6 .7 51.3 13. 7 8. 3	Percent 74. 8 35. 1 25. 3 13. 5 13. 8 7. 2 0 45. 8 45. 8 45. 8 45. 8 45. 8 45. 8	Percent 60, 0 9, 1 2, 4 24, 9 	Percent 54.8 20.1 0.1 22.0 6.1 .2 15.7 .6 55.5 18.2 4,1	Percent 62.0 15.9 5.7 10.1 10.0 .3 8.8 .3 54.1 17.9 5.0		
Liveslock per farm: Cattle Horses and mules Sheep Hogs	Number 13.5 4.3 5.9 25,6	Number 15.3 7.0 9.5 21,9	Nu wher 14.4 6.4 10,1 22.6	Number 11.4 3.8 7.6 20.5	Number 13.6 5.5 14.0 12.5	Number 14.5 5.0 13.0 15.4		

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

Not comparable with 1930-10.

² 1880 not comparable with 1910-20 figures.

	Shelby-Gr	undy soils	Shelby-Li	ndley soils
	30 cou	intles	9 equ	ntics
Pactor	1930	1940	1830	1940
	(19,725	(18,709	(19,710	(19,306
	farms)	farms)	farms)	farins)
A verago size per farmeeres	150.0	159, 4	146. 8	152. (
Cropland 1 Coru Sorgiumis Soybenny aud cowpeas Smail grains. Grass or legume meadow. Miscellancous crops. Crop fuilures. Idid land. Plowable pasture. Timberland. Nouplowable pasture (not timber), lots, etc. Livestock per farm: Cattle 1. Horses or mules 1. Sheep 2. Hogs 1.	Percent 81.5 31.9 .5 10.6 10.7 2.0 2.0 3.0 40.3 14.8 13.4 Number 4.5 8.5 20.3	J ² oroent 71.2 24.9 1.5 24.9 1.9.4 19.4 19.4 19.4 10.7 2.9 4.0 10.2 20.1 20.1 Number 14.6 3.5 12.1 13.3	Percent 67.6 23.1 1.2 10.1 26.1 1.6 1.8 3.6 48.7 91.4 12.6 Number 12.3 3.0 12.5 8.7	Percent 52 (16,5 1,1 1,7 8,3 1,4 3,6 7,3 1,7 2 1,7 9 Number 13,1 3,1 18,0 8,2

TABLE 7.--Farm brends for the veried 1930-40

¹ Not comparable with 1880-1920 figures. [†] 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.

24 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE



FIGURE 4.— Contour map of the Soil and Water Conservation Experiment Station near Bothany, 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

INVESTIGATIONS IN EROSION CONTROL

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 ling 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 S0-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



Frome 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 rockmasonry 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 5%-percent (D-2 outlet), and 12-percent (G outlet) slopes by measuring runoff from natural storms. A similar study was made of terrace channel 4–1.

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-



PIGURE 7.—Plot series 3, growth of outs 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 S.—Organic matter and nitrogen content in the Shelby soil profile

Depth	Nitrogen	Organie matter
inches	Percent	Percent
0-7	0, 16	3, 23
7-12	, 11	2, 17
12-20	, 09	1, 59
20-24	, 07	, 82
24-38	, 07	, 27
-(\$-16)	, 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.

						Yield I	er nere	
Plot designation	Cropping system	Soil treatment	Years	Crop	Gr	ain	Fo	rage
					Normal soll	Desur- faced soil	Normal soil	Desur- faced soil
 Plot series 2: Plot 1, normal; plot 2, desurfaced. Plot series 3: Plot 3, normal. Plot series 2: Plot 4, desurfaced. Plot series 3: Plot 2, normal Plot series 2: Plot 6 desurfaced. 	 4-year rotation of corn. oats. clover with timothy, and clover with timothy. 3-year rotation of corn, oats, and clover with timothy. 3-year rotation of corn, oats, and clover with timothy. 3-year rotation of corn, oats with sweetclover plowed under. 	None Lime; 180 pounds 20-percent phosphate per acre, drilled with oats. 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 sweet- clover plowed under before corn; corn- stalks removed.	Number 3 3 3 3 3 4 4 4 4	Corn 1 Outs First-year meadow Second-year mea- dow. Corn Outs Meadow Corn Corn Outs Meadow	Bushels 14, 3 23, 2 26, 0 33, 5 37, 3 46, 9	Bushels 6,8 5,9 12,5 19,9 17,3 25,7	<i>Tons</i> 1. 30 .97 .75 1. 28 1. 42 .94 1. 33 2. 09 1. 14 1. 46	<i>Tons</i> 1, 17 30 50 33 1, 56 60 72 2, 15 .89 (1)

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

¹ No corn yields in 2 of the 3 years, 1934 and 1938, because of droughts and insect damage. ² Plowed under.
32 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

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 fail 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





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 surfacesoil 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.

INVESTIGATIONS IN EROSION CONTROL

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.

615654-45-2

34 T

TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE



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 1% 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.

TYBLE 10.-- Crop yields on control plot, series 1 for the 12-year period 1931-42

Flot No.	Crop	Y 	ield of 1832	eorn ar 1933	241 wh: 1931	at thus 1935	hets pe 	r aere) 	and m 1938	estdow 1939	(10118 1940	per aer 	e) 1942
12333444555566478	Corn Corn Corn Wheat Clover-timothy Corn Wheat Clover-timothy Corn Wheat Clover-timothy Corn Wheat Clover-timothy Corn Wheat Bluegrnss	20, 6 20, 7 30, 6 41, 4 2, 65 3, 14 12, 89	14, 1 36, 7 30, 9 1, 63 49, 7 51, 6 5, 68 12, 29	13.7 19.3 1.61 43.3 10.6 21.1 5.41 (2)	6, 0 0, 0 0, 0 8, 7 , 34 , 52 2, 50 (²)	17. S 16. 7 12. 6 1. 38 15. 0 12. 9 3. 05 . S5	0, 0 0, 0 1, 72 0, 0 22, 5 31, 7 1, 85 .47	11.6 35.0 37.0 20.7 1.55 2.01 .95	4.5 5.0 4.0 1.48 4.0 1.0 3.01 .59	16. S 11. 8 21, 4 1. 7 1. 6 4. 33 . 42	22, 2 26, 4 20, 1 10, 0 . 90 . 90 . 87 4, 30 . 67	7.9 9.6 32.5 13.3 15.9 2.65 .90	21. 2 25. 8 1. 47 40. 7 13. 1 17. 6 2. 28 . 25

¹ Timothy

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 \$26 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 plauning.

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 Zingg⁷ 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 '

	Acres 11.	- · ·		- · · · ·								. —	
Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totał
	In.	In.	1н.	In.	in.	 In.	In.	In.	In.	In,	In.	In.	In.
1931.	60.40	0.76	1.13	2.40	3, 46	3,62	3.73	7.27	5.74	i 4.42	6.61	3.16	42,10
1932	5 1.01	. 33	. 30	1.71	2.72	3.50	4.94	5.23	2.76	1.73	1.66	1.17	27.36
1933	54		1.44	- 53	5.05	2.12	3, 05	10.78	5.32	. 73	-40	1.11	31.37
1934	67	1.02	1 . 13	4, 20	1.65	9.95		4, 90	6.48	2.60	2.32	. 14	31.48
1935	1.06	· 1.0i	1.47	1 2 72	9.51	5.74	14	1.47	5.34	1.54	2.58	49	36.07
1936	4.96	97	1.1	1.93	4.57	1.33	50	1 1.24	7.66	2.57	i ii	1.46	24,20
1937	19.55	្រស	1 39	\$ 34	22.51	1.11	5.06	1 08	49	1 30	1 00	55	21.72
1935	1 30	- 44	1.68	2.92	5 31	- 96	-2.50	6.40	74	31	9.97	70	26 18
1939		10	9.70	2 96	5 74	9 55	2 67	2 78	3.5	1.12	1.00	72	26.84
19.0	en r i	1 10		0.10		6 48	1 05	1 1 1 2	1.1	1131		1 11	27 78
A cur	1 18	1.13	1 47	40	1.1	1 47	9.51	4 46	3.53	1.78	П.	5 16	+ 0 55
A 16	1. 1.7							1.10	1 100		-,	1.10	
									•	•			

⁴ Amounts from min 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 والالبار البوائي والاراح بالمراكبين المتهادين فالمتحقق فيلأ

c)

⁷ ZINGG, A. W. COMPILATION OF RAINFALL AND RUNOFF FROMTHE WATERSHEDS OF THE SHELBY LOAM AND RELATED SOILS, CONVERSATION EXPERIMENT STATION, METHANY, MO. U. S. Dept. Agr. Soil Conserv. Serv. (TP-39, 194).





38

ومحمولاته والمرادية والمراجع الماسم والمراجع والمراجع والمراجع

والمعارج بالاستعار ويعاودوا والمعاد والمعاد

2 I I

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. 4

and the second of the second

		<u></u>	<u></u>		<u></u>							····					<u> </u>	
		January			February	t -	e line of the Second Second	March			April			May			June	
Year	Maxi- mum	Mini- mum	Mean	Maxi- mum	Mini- mum	Mean	Maxi- mum	Mini- mum	Mean	Maxi- mum	Mini- mum	Mean	Maxi- mum	Mini- mum	Mean	Maxi- mum	Mini- mum	Mean
1931	$\begin{array}{r} 43.9\\ 36.2,\\ 47.9\\ 40.0\\ 36.0\\ 22.8\\ 27.8\\ 32.2\\ 44.5\\ 18.9\\ \hline 35.0\\ \end{array}$	$\begin{array}{r} 22.4\\ 22.3\\ 24.6\\ 23.3\\ 18.0\\ 3.8\\ 9.6\\ 18.7\\ 23.1\\ -1.6\\ \hline 16.4\end{array}$	33. 2 29. 3 36. 3 31. 7 27. 0 13. 3 18. 7 25. 5 33. 8 8. 7 25. 7	49.5 47.1 41.0 40.6 41.0 21.5 32.3 45.8 40.9 35.6 39.5	$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	38. 5 36. 3 28. 3 29. 6 33. 0 11. 9 24. 8 35. 2 27. 4 27. 8 29. 3	45.5 42,9 51.0 51.7 56.3 57.6 45.0 64.7 52.7 49.2 51.7	27. 2 23. 4 32. 0 28. 5 34. 8 31, 7 28. 8 23. 5 29. 1 29. 1 28. 8	36. 3 33. 2 41. 5 40. 1 45. 6 44. 7 36. 9 44. 1 40. 9 39. 2 40. 3	63.8 61.1 62.9 68.5 58.1 62.2 60.5 65.5 63.5 62.8 62.8	39.9 42.5 40.0 38.7 39.5 37.7 41.6 40.0 39.6 40.0	51.9 51,8 51,5 53,6 48.8 50,1 50,6 53.6 53.6 53.6 53.6 51.8 51.2 51.5	70. 8 75. 4 75. 9 85. 4 64. 3 77. 6 76. 0 72. 4 83. 0 73. 4 75. 0	47. 4 52. 4 51. 0 54. 7 49. 9 55. 6 53. 9 52. 8 55. 9 48. 4 52. 2	59.1 63.9 61.5 70.1 57.1 66.6 65.0 62.6 62.6 69.0 60.9 63.6	86.8 82.9 95.0 94.6 76.5 86.9 83.9 84.5 82.1 85.6 85.9	65.3 63.2 64.5 64.5 58.2 61.0 63.9 63.7 61.4 62.7	76. 1 73. 0 79. 8 79. 6 67. 4 74. 0 72. 6 74. 2 72. 9 73. 5 74. 3
Year		July			August		s	eptembe	r		October		N	Tovembe	r	1	Decembe	
1931	90. 8 92. 4 92. 0 101. 5 92. 7 102. 2 90. 7 92. 3 91. 9 92. 2	67.1 68.6 63.0 74.7 70.3 70.6 65.8 67.6 65.7	80.0 80.5 77.5 88.1 81.5 86.4 78.3 79.9 79.8 79.8	85. 2 91. 4 86. 0 91. 6 89. 9 99. 4 93. 6 92. 2 85. 1 84. 1	$\begin{array}{c} 61.1\\ 61.2\\ 61.0\\ 68.0\\ 64.8\\ 69.6\\ 68.5\\ 67.1\\ 62.5\\ 63.8\\ \end{array}$	73. 2 76. 3 73. 5 80. 0 77. 4 84. 5 81. 1 79. 7 73. 8 74. 0	85. 0 82. 7 85. 0 72. 9 77. 0 81. 8 83. 5 83. 7 83. 7 83. 3	62, 3 53, 4 58, 9 51, 7 55, 2 60, 8 54, 8 54, 8 56, 5 59, 1 55, 9	$\begin{array}{c} 73.\ 7\\ 68.\ 1\\ 72.\ 3\\ 62.\ 3\\ 66.\ 4\\ 71.\ 8\\ 69.\ 2\\ 70.\ 1\\ 73.\ 9\\ 69.\ 6\end{array}$	69. 6 65. 6 68. 1 71. 9 64. 3 64. 5 66. 3 79. 9 73. 9 79. 1	$\begin{array}{r} 49.\ 4\\ 38.\ 3\\ 44.\ 3\\ 46.\ 6\\ 41.\ 8\\ 44.\ 8\\ 42.\ 4\\ 52.\ 9\\ 45.\ 6\\ 48.\ 5\end{array}$	59.5 52.0 56.2 59.3 53.1 54.7 54.4 60.4 60.0 63.8	57. 6 45. 1 56. 0 56. 0 44. 7 51. 5 31. 7 54. 0 53. 6 48. 3	38. 9 24. 3 33. 0 35. 0 29. 1 27. 5 26. 3 29. 4 34. 2 28. 2	$\begin{array}{r} 48.3\\ 34.7\\ 44.5\\ 45.5\\ 36.9\\ 40.0\\ 39.0\\ 41.7\\ 43.9\\ 38.3\\ \end{array}$	45. 4 33. 0 39. 6 34. 0 35. 8 41. 7 37. 3 41. 7 47. 3 41. 6	31. 3 18. 0 23. 3 18. 0 18. 6 25. 0 19. 6 21. 2 26. 2 24. 7	38. 4 25. 5 31. 5 26. 0 27. 2 33. 4 28. 5 31. 5 36. 8 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

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

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 Plot 6 was limed with 3 tons per acre in 1930 and received treatment. 250 pounds per acre of 20 percent superphosphate fertilizer with the The treated plot was adjacent to the plot devoted to conwheat. tinuous 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.

42 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

				Surface	runofI			Soll 1	oss în	0	
		Am	mnt	Terco ra	ent of În	Densi ocre-	ty per linch	TU110	ff per re	per per	yields uere
Crop	lkninfult	t7ntreated	Troated	Untreated	'l'reatori	Untreated	Treated.	Untreated	Trented	Untrented	Trented
Coru	<i>In.</i> 31, 14 28, 12 31, 21	In. 5.02 6.07 4.14	1n. 3.90 4.91 3.59	Pci. 16, 1 21, 6 13, 3	Pct, 12.5 17.5 11.5	Tons 2.71 1.39 52	Tous 2.70 2.30 .37	Tons 13, 73 8, 43 2, 16	Tons 10, 76 11, 28 1, 34	Bu. or lons 22, 9 11, 6 1, 14	Bu. or tons 21. S 19. 1 1, 52
Rotation average	30.16	5.05	4.13	16.8	13.7	1.60	1.89	8.11	7.79		

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

1 Plots of series 1, 0.01 mere in size, 72.6 feet long on an 8-percent slope. Plot 5 is untreated; plot 6 was limed and received 250 pounds per mere 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 1982-41

				Surface	runofí		Soil loss in		Cran violds		
		Am	mut	Perce ra	nt of în	Densi aere-	ty per inch	runol ne	î per re	per	ucre ucre
Стор	Ruthfall	Unfreated	Treated	[⁺ 11treated	Treated	Untreamed	Treated	Unireated	Treated	Unirented	Treated
Corn Onts Meadow Rotation average.	$\begin{array}{c} In,\\ 28,15\\ 27,67\\ 32,12\\ \hline 29,31 \end{array}$	<i>In.</i> 4, 94 5, 02 2, 58 4, 18	<i>In.</i> 3, 27 1, 91 , 058 2, 02	Pd. 17.5 18.1 8.0 14.3	Pet. 11.6 6.9 2.7	Толя 2,07 1,59 ,09	Tons 1,38 1,72 ,10 1,30	Tons 10, 22 5, 00 , 23 6, 15	Tons 4.51 3.29 .09 2.63	13u. or 10us 26.0 32.5 1.37	Bu. or tons 37.3 48.8 1.46

¹ Plots of series 3, 0.03013 acre in size, 125 feet long, on un S.1 percent slope. The untreated plot is plot 3, and the trented 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 senson 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.—Purticle-size	distribution of samples of	normal and desurfaced Shelby
loam after shaking for	various periods, expressed	as percentages of the total soil
sample ¹		
ISamples of	collected March 1, 1933, plots 9 and	10 of series 1]

	Aggregate sizes after mixing for periods of-												
Particle size	0 mi	nutes	5 minutes		15 mi	nutes	30 mi	notes	Until dispersed ?				
SIZÇ	Nor- mal soil	Desur- faced soil	Nor- uml Soil	Desur- faced soil	Normal soil	Desur- faced soil	Normal soil	Desur- faced soil	Normal soil	Desur- faced soil			
Millimeter 0.5 .525 .251 .1	Percent 10, 60 14, 17 48, 25 26, 98	Percept 31, 17 21, 06 31, 07 15, 88	Percent 5.05 12.02 41.30 41.63	Percent 8,48 26,70 20,18 38,50	Percent 3, 61 8, 06 37, 58 49, 85	Percent 4, 39 12, 38 34, 38 48, 83	Percent 3, 78 6, 79 32, 68 56, 75	Percent 3, 93 6, 55 31, 99 57, 53	Percent 3, 27 6, 82 21, 90 67, 95	Percent 3, 14 5, 28 12, 08 79, 47			

Plot 9 represents normal soil and plot 10 desurfaced soil.
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 produced 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.

Depth in profile to center of core	Volume weight	Specific gravity	Porosity	Field moisturo content	Calculated moisture content at saturation, by weight	Calculated weight of an acre- inch of soil	Moisture cquiva- lent
			Percent	Percent	Percent	Tons	Percent
Surface	1,41	2.62	46.2	26.1	32.7	139.8	
312 inches	[1.43	2.62	45.4	26.0	31,7	162.0	24.9
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. L	17.5	20.4	194.9	27.1
inches	1 77	2.72	34.9	15.1	19.7	200.6	23.0
54 inches	$1 \hat{1} \hat{8} \hat{8}$	2 71	31.7	13.4	17.1	209.6	22.9
72 inches	1.85	2,71	31.7	13.3	1.7. 1	209.0	31.7

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

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 and the second second

and the second

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 scaled.

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.

Date of rain	Matshura		Rainfall		Surface i Indient		
	content of surface soil	Amount during preceding 15 days	Amount o0 indi- cated date	Maximum 5-minute inteusity on indicated date	Amount	Percent of rainfall	Soil loss in runoff per acre
Aug. 14-15, 1934	Perce it <10	Inches 0.09	Inch [0.97	Inches 3.60	Inch	Percent	Tons 0.75
May 15, 1935	>25	3, 84	1.50	.45 ; .34 ;	. 65	90, 3	2, 21

TABLE 17.—Surface runoff and soil loss from the bare fallow plot 9, series 1, as affected by antecedent rains and the consequent moisture content of the soil

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 I (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

	1				- Suil loss in				
Стор	Rain- fall	Am	ount	Percent	t of rain	Densi acre	ty per -inch	Soil 1 runofi	oss in per acte
	 	Surface soil	Subsail	Surface soil	Subsoil	Surface soil	Subseil	Sarface soil	Subsoff
Corn Oats First-year meadow Second-year meadow	:Inches 30.91 32.79 27.27 29.89	Inches 7,00 11,34 .49 .77	Inches 5. 88 8. 61 1. 92 5. 08	Percent 22. 6 34. 6 1. 8 2. 6	Percent 19.0 26.3 7.0 20.0	Tons 2. 16 2. 29 . 20 . 25	Tons 3. 65 4. 57 . 36 . 12	Tons 15, 12 25, 99 , 10 , 19	Tons 21, 45 39, 32 .69 .74
wordenon average	30.22	4,90	5.60	16, 2	1S. 5	2, 11	2.78	10.35	15:55

 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

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	19Kainjall,	runojj, and A and I	soil losses 3 of scries S	from straw 1, 1940 ¹	mulch an	d check	plots
							·

	_				Soil				
Date	Rnin- fall	Am	ount	Percen	t of rain	Dens acre	ty per inch	ru per	ioff acre
		Check	Straw	Check	Straw	Check	Straw	Check	Straw
May 7 May 20-21. June 9-10. June 11-12. June 21. June 22. July 26. July 30. August 9. August 10-12.	<i>Fuches</i> 0.87 .60 1.86 1.87 1.67 .71 .71 .72 .62 1.78	Inchess 0, 14 .03 .70 .33 .09 .28 .07 .02 .14	Tuches 0 0.05 .30 .13 .01 0 0 0	Percent 16. I 5. 0 37. 0 17. 0 50. 3 30. 4 31. 1 0. 7 2. 2 7. 9	Pcrcent 0 2.7 16.0 0.6 1.4 0 0 0 0	Tons 3, 64 , 67 2, 36 . 73 1, 11 . 86 . 14 0 . 14	Tons 0 0, 60 . 03 1, 00 0 0 0	Tons 0.51 .02 1.65 .24 1.10 .24 1.10 .24 0.24 0.01 0 .02	Tons 0 0.03 .01 .03 .01 0 0 0 0 0
Total		2.05	. 40					3.79	.08

Plot A received 2 tons per acro 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 crosion 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.

615654-45-4

and the second state of th

50 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 fallspaded 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 springspaded plots for the 10-year period, 1931-10.

F.

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 waterholding 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):

series 1 by 1-inch profile increments

TABLE 20.-Changes in chemical composition of bluegrass control plot 8 of plot

Profile depth	Exchangeable calcium per 100 grams of soil	Exchangeable magneskim per 100grams of soil	Total nitro- gen	Total organic matter
Inches 0-1 1-2 2-3 3-4 -t-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12 12-13	Millicquiru- lent 14, 60 10, 93 11, 92 12, 98 10, 63 10, 55 11, 50 12, 94 13, 79 15, 64 16, 32 17, 57 17, 48	Milliegnica- lent 3, 68 3, 37 4, 75 3, 50 3, 50 3, 69 7, 00 7, 12 8, 31 9, 13 9, 10	Percent 9, 270 1, 181 179 178 177 121 111 110 105 .007	Pcrcent 5,71 3,75 3,75 3,71 3,61 3,09 2,44 2,29 2,10 2,10 2,10 2,10 2,10 2,10 2,10 2,10

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:

Meadow crop
Red clover 8 pounds, timothy 7 pounds,
Do.
Do.
Do. ·
Do.
Lespedeza 15 pounds.
Do.
Alfalfa 15 pounds, timothy 6 pounds.
Do.
Do.
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





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 See.

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.

	Rain- fall								
Crup		Amount		Percent of min		Density per acre-inch		off per nero	
		Plot A	Piot B	Plot A	Plot B	Plot A	Plot B	Plot A	Plot B
Corn	<i>Inches</i> 31, 46 25, 83 26, 55 26, 55 28, 67	Inches 5, 39 4, 57 5, 36 3, 19	<i>Inches</i> 5, 46 2, 83 3, 22 2, 37	Percent 17, 13 17, 09 20, 19 11, 13	Percent 17, 36 10, 95 12, 13 8, 27	<i>Tons</i> 3.3 7.0 2.1	Tous 3, 6 6, 1 .3 .4	<i>Tons</i> 17, 96 32, 12 J1, 20 1, 01	Tons 19.44 17.31 1.0S .97
Rotation average	28.13	·t. 63	3, 47	16.4G	12, 34	3.4	2.8	15. 57	0.70

 TABLE 21.—Average annual rainfall, runoff, and soil losses from rotations on plots

 A and B of series 3 for the S-year period 1932-39

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 closegrowing 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



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.

58 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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-eropped 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 1-58 alfalfa died out in the waterways and poorly drained depressions in 1935.

		Rainfall	Surface	runofi	Soil loss	A línlia yield per acre	
Area	Year		Amona	Percent of rainfall	in runoff per dere		
Plot 7 of series 1: Area, 0.01 acro, land slope, Spercem	1933 1934 1935 1936 1936	Inches 31, 37 31, 18 36, 07 21, 29 21, 72	Inches 2, 35 2, 84 6, 60 1, 51 2, 36	Percent 7, 5 9, 1 19, 1 6, 2 10, 9	<i>Tons</i> 0,40 .01 .26 .20 .13	Tons 5, 41 2, 50 3, 05 1, 85 2, 94	
Average		28.03	3, 19	11.0	20	3.11	
Terence 2-G : Area, 0.75 acre, land slope, 12 percent	(1933 1934 1935 1936 1936 1937	31, 37 31, 18 36, 07 24, 29 21, 72	7, 52 7, 67 10, 75 . 97 3, 11	$\begin{array}{c} 21.0\\ 24.6\\ 29.8\\ -4.0\\ -4.3\\ -4.3\end{array}$	1, 49 1, 24 , 91 , 00 , 21	0, 90 	
Аустаде		28.03	6. (10)	21).7	.77	1.09	
Watershed I-58; Atea, 2.112 acres, land slope, 9.1 percent	{ 1933 1934 1935 1935 1936 1937	31.37 31.18 36.07 24.29 21.72	5.84 4.75 12.57 .87 2.37	18.6 15.2 34.8 3.0 10.9	9, 89 6, 40 7, 63 , 00 , 20	0.24 1.47 1.65 1.00 1.63	
Average		28, 93	5. 25	15.3	4. 5-1	1.05	

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

_. _. . _

A survey showed that this area amounted to 16 percent of the wateracreage. 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 1-58. 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 seedbend 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 1-58 during the spring of 1935. The plants had heaved during the winter months and the area was colled 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 Korcan 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 croded to the point where production of other meadow crops is uneconomical. The crop is usually a part of a double-cropping system of oatslespedeza. 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 crossional 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 rescedings 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 crosion 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	234	nnual	runoff,	soil l	ossce,	and	crop	yields,	from	oals-F	orean	lespedeza
cropping												
						_						

			Surface	runoli	Soil loss	Oats	Lospedeza	
Area	Year	Rainfall	Amount	Percent of rainfall	in runoff per acre	per acro	bny yleid per aere	
Subsoil plot 5 of series 2, 0,0193 neres; had stope 3.3 porcent; 125 pounds per acre of 20-per- cent superphosphate anguled annually with outs seeding	(1936 1937 1938 1939 1940 1940 1941 1942	fuction 24, 24 21, 72 26, 16 26, 84 27, 76 34, 62 33, 82	fuches 0, 82 4, 10 , 85 4, 05 , 61 , 77 , 53	Percent 3.4 19,2 3.2 15,1 2.2 2.2 1,6	Toas 1, 76 7, 29 .80 1, 13 .02 .03 .13	Hushels 39, 7 47, 8 31, 6 2, 5 18, 9 15, 4 3, 5	Tons 0 1, 75 1, 19 1, 19 2, 12	
Watersheil 3-55, 2,112 aeres; land slope 9.1 percent; 125 pounds per acre of 20-percent super- phosphate applied annually with oats seeding	$\begin{cases} 1938\\ 1939\\ 1940\\ 1041\\ 1942 \end{cases}$	26, 16 26, 84 27, 76 34, 62 33, 93	2.37 3.36 .73 2.03 3.39	9.1 12.5 2.6 8.5 10.0	6, 42 , 81 , 06 , 03 , 32	44, 7 15, 8 37, 1 25, 1 27, 2	0 .85 .66 .90 .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 bogan 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.

TURFE	24.—Rainfall,	runoff,	und	soil lo	ss from	pasture	arazina	plots	of Serie	r 9
				1936	-41	•				· •,
					· -					

Year			Surface					
	Rainfall	Am	ani	Percent o	of reinfall	Soil loss per nere		
		Controlled grazing	Intensive grazing	Controlled grazing	Intensive grazing	Controlled grazing	Intensive grazing	
1936 1937 1	Inches 24, 17 22, 08	Inches 0.88	Inches 1.40	Percent 3.64	Percent 5.70	Pounds 12	Pounds 37	
1938 1039 1940 1941	26, 24 26, 80 27, 52 35, 03	. 00 . 26 . 00 . 94	. 03 2. 48 . 27 2. 53	0,00 .97 0,00 2.6\$.11 0.25 .98 7.29	1 0 0 123	20 20 13 224	
A verage	27.95	. 42	1, 34	1.50	4.07	27		

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.

New	Unit pastu	re-days per re	Change in animal weight per acre			
) eur	Controlled grazing	Intensive grazing	Controlled grazing	Intensive grazing		
			Ponnds	Panuda		
1036.	. 121	95	145	131		
1937.	154	275	351	ភា		
1035	10	203	- 141 -	213		
1930	98.0	157	3 7	-67		
1040.	129	216	110	- 650		
1941	. 36	89	255	556		
A vernee .	113	173	195 j	—).5G		

TABLE 25. - Unit pasture days and change in animal weight an moderately and intensively grazed virgin bluegrass postures

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, onts, 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.

INVESTIGATIONS IN EROSION CONTROL

It is obvious that vegetative cauopy 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

the set of					
Crop	Inclusive dates	Number of storms	Precipitation	Intercept precipits	ion of ation
Alfaifa. Cora Soybenns Dats	Apr. 27-Sept. 15. May 27-Sept. 15 June 2-Aug. 17 Apr. 15 June 20	46 47 24 35	Inches 10, 81 7, 12 6, 25 6, 77	Inches 3, 57 1, 10 , 91 , 47	Percent 35.8 15.5 14.6 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 canopics. 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 regetation density on runoff velocity.—From the standpoint of flood bazard 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 closegrowing vegetation reduced the maximum rate of runoff. This was true even when the total runoff was the same from the two crops.

⁶ NORTON, R. A., and SMITH, D. D. EFFECT OF DENSITY OF VERETATION 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.

	Num-	Maximum rate of runoff per hour per rain Total runoff per rain		Barnety						
Period	Der of rains	Corn	Clover- Limothy	Ratio 1	Соги	foru Clover- timothy		;		
		Inches	Inches		Inches	Inches				
1932-34	24	0, 91	0.37	2.5	0, 71	0, 43	1.6	Rains severe but well dis- tributed.		
1935	61	. 52	- 23	2.3	. 44	. 43	1.0	Moderate rains abnost continu- ous during spring.		
1935	7	.22	. 03	7.3	.25	.04	7.0	Rains light and well distribut-		
1029_36	50	67	97	25	. 57	35) ā	Average for 5-year period.		
1033-34	36	1,79	1.20	4.31	ə. 34	1.13	2.6	Rains severe but well distribut-		
1935,	19	4 1. 23	1.53	2.3	\$.52	50 ، ا	1.0	Moderate rains almost con- tinuous during spring.		
1933-36 J	77	4.70	1,23	3.0	4,33	+,20	1.6	Average for 4-year period.		

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

¹ Ratio=corn+clover and timothy=corn+bluegmss, etc.

¹ Data for first four periods are from standard design terraces on eroded Shelby soil of 9.4 percent slope, ² Corn.

4 Bluegrass. 4 Oats.

4 4-year rotation corn, corn, oats, clover and timothy, Jan. I 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 fallplowed 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 clovertimothy 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. INVESTIGATIONS IN EROSION CONTROL



FIGURE 20.— Monthly ratios, corn to meadow, of maximum rates of runoff and total runoff from the H-ferraces during the period, 1932-36, and semimonthly ratios of maximum rates of runoff, and total runoff, oats to bluegrass, from water sheds 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.

66 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

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





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 The yield of first-year meadow on surface soil without and subsoil. 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.

		Shelby s	arface se	il (8 incl	res deep)			Shelby sabsoit				
Year	Mixed	clover an Jær	el timoti acre	ıy yield	Alfalfa yield per acre	Oats- lespe- deza yield per acre	Mixed clover and tim- othy yield per acre			Oats- lespe- deza yield per acre		
	Check 4 Series ()	Plot 17 Series 2	Plot 32 Series 3	Plot 24 Series 3	Piekd 3	Water- shed * 1-58	Plot 27 Series 2	Plot 4 ⁴ Series 2	Plot 39 Series 2	Plot 8 ¹⁰ Series 2		
1931	Tons 2.68	Tons	Tous	Tons	Tons	Tons	Tons	Тона	Tons	Tons		
1982 1933 1934	1, 63 1, 61 34	-0.95 +.15	+0.03	+0.05	+1.37		-0.96 87	-0.20	-0.16 45			
1935 1936 1937 1938	1.38 1.72 .57 1.48	51 +, 50	+. 18 45	-, 04	十.57 十.57 十.59 十.59	+. 29	1, ()); , 51	-1.02	, (니 , 일(-0,28 +1.23 +1.35		
1930 1940. 1941.	1, 10 . 99 . 56	61 +.38	4.65	+1.17	+, 53 +1, 17 +1, 39	+, 63 +1, 21 +1, 53	-, 83 -, 36	03	-, 30 -, 18	15 +. 95 +1.03		
A verage — yield difference 1st- year mendow,	0,00	-, 69	+, 10	4.20	+.62	+. 92	- , 95	, 54	-, 37	+. 69		
A verage yield difference 2d- year meadow_		+ , 34					58	· · · · • • · · · · ·	28			

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

 Plots 3, 4, or 5, relation of corn-wheat-meadow, no soil treatment.
 Rotation of corn-oats-mendow-meadow, no soil treatment.
 Rotation of corn-oats-mendow, 3 tons per acre line and 180 lb, per acre 6-20-6 on oats.
 Rotation of corn-oats-meadow, 3 tons per acre line and 180 lb, per acre 6-20-6 on oats.
 Rotation of corn-oats-meadow, 3 tons per acre line and 180 lb, per acre 6-20-6 on oats. on corn.

a configuration of the second s

10 Onts-lespedera annually, 125 H, per here 0-20-0 on oats, 8 lons 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 ± 88 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

INVESTIGATIONS IN EROSION CONTROL

хię.

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:

$$A = CS^{\frac{1}{2}} L^{\frac{1}{2}}$$

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.

÷ð:

ý

A. 3. 1. 1. 1. 2.

۰.

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

 $L = \begin{pmatrix} A \\ \overline{C} \end{pmatrix}^{\dagger} S^{-\varsigma}$

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.

		Surface	ranoff	Soil	Ratio of to sho	iong plot rt plot	Ratio of soil loss in run-
Plot and year	Rain- fail	Amount	Percent of rain- fall	loss in runofi per acre	Surface runoff	Soil loss per acre	of slope to loss from bottom of slope
Series 1, plot 2, 72.6 feet long: 1931 1932 1933 1934 1935 1936 1936 1938 1938 1939 1940 1940 1940	Inches 42,222 28,79 32,43 32,51 37,99 24,43 21,80 26,65 27,50 28,32	Inches 13.20 5.85 10.09 11.43 10.96 7,86 4.09 4.71 8.75 4.49	Percent 31, 3 20, 3 31, 1 35, 2 28, 6 32, 2 21, 5 17, 7 31, 8 15, 9	Tons 84, 22 48, 93 49, 75 85, 87 75, 12 18, 94 8, 35 27, 69 88, 50 21, 89			
A vernge	42, 22 28, 79 32, 43 32, 51 37, 90 24, 43 21, 80 26, 65 27, 50 28, 32	8, 20 13, 30 5, 04 9, 42 10, 40 13, 12 7, 35 4, 67 4, 64 8, 34 3, 85	31. 5 17. 5 29. 0 32. 0 34. 5 30. 9 21. 4 17. 4 30. 3 13. 6	$\begin{array}{c} 105, 67\\ 52, 68\\ 65, 18\\ 97, 76\\ 106, 10\\ 21, 32\\ 15, 77\\ 42, 00\\ 122, 04\\ 27, 65\\ \end{array}$	L. 01 . 86 . 03 . 91 1. 20 . 96 1. 00 . 99 . 95 . 86	L 25 L 08 L 31 L 14 L 14 L 13 L 89 L 52 L 38 L 38 L 38	1, 50 1, 16 1, 62 1, 28 1, 28 1, 28 1, 26 2, 78 2, 04 1, 76 1, 52
1 rerail0	30, 26	8.03	26, 5	65, 62	0.97	1,34	1.67

TABLE 29 .--- Surface runoff and soil losses from plots of 72.6- and 145.2-foot length i

Each plot: 6 feet wide, 8-percent slope, continuous corn, Sheiby 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.

	Surface run		runoff		Ratio of long plot to short		Calculated ratio loss in runoff	of soil	
Plot designation	Усаг	Rain-		Per-	Soil loss in runoff	pi	01 	different section the slope	ions of
		1411	Amount	eent- age of rain- fall	per acre	Sur- face run- off	Soil loss per acre	Section	Soil loss ratio
Series 15, plots 1 and 5, 90 feet long, 28 feet wide, 10- percent slope, continuous corn, Shelby loam	1934 1935 1936 1937 1938 1939	Iuches 31.65 37,32 24.11 21.84 27.23 27.27	Inches 5,30 7,94 1,70 3,59 2,66 4,93	Per- cent 16.7 21.3 7.1 10.4 9.8 18.1	<i>Tons</i> 9, 85 37, 74 5, 12 3, 92 17, 29 42, 40	1.00 1.00 1.00 1.09 1.09 1.00	1.00 1.00 1.00 1.00 1.00 1.00	("pper 90 leet do do do do	1.00 1.00 1.00 1.00 1.00 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, Sheiby loam	1934 1935 1936 1937 1938 1039	$\begin{array}{r} 31.05\\ 37.32\\ 24.11\\ 21.84\\ 27.23\\ 27.23\\ 27.27\end{array}$	$5, 30 \\ 9, 03 \\ 1, 43 \\ 3, 20 \\ 2, 40 \\ 4, 80$	10, 7 24, 2 5, 9 15, 1 8, 8 17, 6	16.38 01.96 8.24 8.15 20.40 02.78	1.00 3.14 .92 .90 .97	1, 66 2, 44 1, 61 2, 08 1, 70 2, 10	Center 90 feet	2, 32 3, 88 2, 22 3, 16 2, 40 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 1935 1936 1037 1938 1938	31.65 37.32 24.11 21.84 27.23 27.25	7,42 8,69 1,76 3,60 2,39 5,72	23, 4 23, 3 7, 3 16, 5 8, 8 21, 0	25, 58 107, 33 12, 26 11, 34 34, 77 143, 29	1, 40 1, 09 1, 04 1, 00 , 90 1, 16	2.59 2.84 2.40 2.89 2.01 3.38	Lower 90 feet do do do do do do	4, 45 3, 63 4, 01 4, 51 2, 63 5, 76
A verage		28.24	4.93	17.5	55.76	l. 10	2.69		4.17

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

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.

72 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

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 f	or 90-,	180-,	and	270-fool	plots for	the	ycars
	1934	and 19	30					•

			.											
Dis- tance from			Plot r	2 eleva corling	stion s	Piot F	3 eleva rading	tion s	Plot r	4 elevi cading	ation S	Piot r	5 eleva cading	ition S
top of plot (feet) 193	4 1939	Dif- fer- ence	1034	1939	Dif- fer- ence	1034	1939	Dif- fer- ence	1934	1939	Dif- fer- ence	1934	1939	Dif- fer- ence
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	t Freet 42 100, 42 100, 44 55, 98, 38 43, 96, 25 36, 94, 14 37, 93, 33 56, 92, 45 56, 92, 45 56, 92, 45 56, 92, 45 56, 92, 45 57 57 57 57 57 57 57 57 57 57 57 57 57	Fcet +0.02 - 16-17 - 13-19 - 17-19 - 19 - 20+02 + 26	Feet 100, 14 90, 30 98, 44 90, 30 97, 44 90, 48 93, 44 94, 48 95, 42 94, 34 92, 21 94, 34 92, 21 94, 34 92, 21 94, 34 92, 21 94, 34 93, 34 92, 21 94, 34 92, 21 94, 34 92, 21 94, 34 92, 34 94, 34 92, 34 94, 34 95, 42 94, 34 94, 34 96, 36, 36 96, 36, 36, 36, 36, 36, 36, 36, 36, 36, 3	Feed 100, 20 99, 23 98, 30 97, 32 96, 29 94, 13 99, 27 99, 28 94, 13 99, 97 99, 29 94, 13 99, 97 99, 29 94, 13 99, 91 89, 90 89, 90 88, 79 83, 71 82, 92	Freet +0.06 	Fee 588 14 44 44 49 44 94 44 49 45 55 55 55 55 55 55 55 55 55 55 55 55	Fed 99, 519, 51 99, 51, 976, 52, 99, 53, 99, 53, 99, 53, 99, 53, 99, 53, 99, 53, 99, 53, 99, 53, 99, 53, 99, 53, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54	Fcc0 311 15 33 45 9 5 6 7 9 7 9 7 5 6 7 9 7 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Fred 91, 21 99, 41 89, 53 85, 65 87, 80 85, 13 84, 13 82, 10 81, 09 78, 88 82, 15 82, 10 81, 09 77, 80 77, 80 77, 80 77, 80 77, 80 71, 63	Feel 91, 22 90, 29, 29, 28 85, 45 85, 76 85, 76 85, 85 84, 85 85, 85 84, 85 85, 85 84, 85 85 84, 85 84, 85 84, 85 84, 85 85 85 86 86 86 86 86 86 86 86 86 86 86 86 86	/ ced +0.01 -12 -11 -12 -14 -12 -14 -16 -14 -12 -17 -17 -17 -17 -17 -17 -17 -17	Feat \$2,56 \$1,40 \$0,28 70,21 75,12 77,08 74,76 73,90 	<i>Fod</i> <i>S2</i> , 41 <i>S2</i> , 41 <i>S1</i> , 27 <i>S0</i> , 17 <i>7</i> , 94 <i>7</i> , 94 <i></i>	Feel -0.15 22 11 16 15 18 +.24 +.24 +.24

Additional investigations with a rainfall simulator on prepared fallow plots were made in 1939. These previously reported investigations (3S) 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 occurrencefrequency. 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 4percent 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. INVESTIGATIONS IN EROSION CONTROL





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 wegetal 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

 75°

and a second second with a second second

76 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 ceaches 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

⁴ Smith, D. O. FOUR-YEAR SUMMARY OF ENGINEERING EXPERIMENTS AT THE RETHANY SOIL CONSERVA-TION EXPERIMENT STATION. Presented at the Amer. Soc. Agron. Corn Bell meeting, Urbana, IN. June 1936.

INVESTIGATIONS IN EROSION CONTROL

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 backfurrow-





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.

ings with a plow. The terrace ridges and channels are shown in figure 25.

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.

a literation with the second

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 onehalf 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

615654- 45----6

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 crode 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 The procedure of starting contour operamidway between terraces. tions 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, When this method is used, runoff is led from and drilling operations. 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 case.

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.

-		Land	slope	Surface	Corn	Illofal	Surfac	e ranofí	Soil loss	Density	
number	vertical spacing	Before terrac- ing	After terrac- ing ¹	soil depth ²	yield per acre 3	rain- fall	Total	Percent- age of rainfall	în runofî per sere	runoft per acre- inch	
4 N 5 N 5 N 3 G 4 G 5 G 5 G	Feet 3 5 7 5 7 9	Percent 6, 3 7, 4 6, 8 12, 4 13, 9 13, 2	Percent 0.8 9.7 8.2 18.0 18.4 16.0	Percent 97 83 55 75 89 100	Bushels 49, 2 45, 6 41, 0 30, 0 46, 0 57, 0	Inches 255, 54 255, 54 255, 54 258, 74 258, 74 258, 74	Inches 21, 97 32, 06 26, 16 42, 04 40, 15 30, 55	Percent 8, 6 12, 5 10, 2 16, 6 15, 5 11, 8	Tons 4, 386 0, 866 9, 835 10, 172 10, 486 9, 982	Tons 0. 200 . 214 . 376 . 237 . 261 . 327	

TABLE 32 .- Variable factors, and total soil losses and runoff from terrace spacing study, 1982-40

The land slopes after terracing were calculated, not measured.
 Surface soil depth is 9 inches.
 A verage 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 acce-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 This fact may indicate that the widest intervals on each percent. slope are excessive. The variation in runoff density is illustrated in figure 29. Increases in density were greatest when the terraces were

TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE





84

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. 1.11

A CALLER AND

86 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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.



Total soil loss in runoff increased logarithmically with terrace grade. Increasing the channel grade from level to 8 inches per 100 fect 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 onehalf 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-This has been the most satisfactory method of establishing hour. 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 Breaks occuring in the seeding were then repaired by the seeded. 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 torraced 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 The depth of surface soil ranged from 0 to 12 inches and aver-1930. aged 8 inches. The average land slope was 7.0. The watershed has a bluegrass terrace outlet, received lime and fertilizer, and is contourfarmed 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-S 1

	Rain- fatt		Ru	nofT		0-3	14.4-	Viald 2		
Стор		Am	Amount		itage of Mail	per i	loss here	i)er acre		
		1) -2	D-3	D-2	D-3	32-2	D-3	D-2	D-3	
Corn Oats Wheat	Inches 28, 28 20, 62 31, 49	1nches 3.84 2.00 5.75	Inches 4, 60 3, 55 8, 48	Percent 13.6 6.8 18.3	Percent 16.3 12.0 26.9	Tons 0,71 .32 1,13	Tons 41.83 20.53 36.62	Bushels 26 *36 15	Bushels 21 39 14	
Clover and timothy	26.33	1.52	2.08	5. S	7.9	. 03	2.08	Tons 1.7	Tons 1.6	
Rotation average	28.93	3. 28	4.68	11.4	10.2	. 55	25.26			

1D-2 is farmed on the contour and has been limed, and commercial fertilizer is applied on the small grain.]

1 D-3 is formed with field boundaries and has not received soil treatments.

 $^{\circ}$ Jost forment wan neur nonnammes and not recorved son treatments. $^{\circ}$ Jost for each erop 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 . $^{\circ}$ O at so a terrace ridge lodged during 1938, resulting in high introxing baryes, while that on D-3 without soil treatment did not lodge and therefore harvesting loss was negligible.

INVESTIGATIONS IN EROSION CONTROL

Ø

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.





'90 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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.

INVESTIGATIONS IN EROSION CONTROL

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 stripcropped plots was also the dominating factor in the amount of soil loss experienced.

91

			l i 1≀u	noff	gn		'rop yiek	ls
Plot No,	Стор	Crop Rain- fall Amount of		Percent of rain	loss per acre	Corn per acre	Mea- dow per acre	Wheat, per acre
], 3, 5], 3, 5], 3, 5	Corn, clover-timothy, wheat Wheat, corn, clover-timothy ! Clover-timothy, wheat, corn !	Inches 26, 88 26, 88 26, 88	Inches 2.01 2.16 1.95	Percent 7.5 8.0 7.3	<i>Tops</i> 0, 20 . 63 1, 62	Bushets 25.7 16.5 17.8	Tous 1, 30 1, 43 1, 54	Bushets 11.1 11.5 0.2
1, 3, 5 2, 4, 6 2, 4, 6 2, 4, 6 2, 4, 6	Average strip-cropped plots Wheat Corn Clover-thiothy	26, 88 26, 88 26, 88 26, 88	2, 04 2, 11 2, 20 1, 70	7.6 7.8 8.5 6.7	. 85 . 41 5. 15 . 18	20.0	1, 42	11.0
2, 4, 6	Average contoured plots	26, 58	2. DG	7.7	1. 91	21.8	1.34	11.3

TABLE 34.—Average rainfall, runoff, soil loss, and crop yields from the contour stripcropped and contoured plots of series 5 for the 6-year period 1930-41

3 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 1J-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 TILLACE

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

tillage	ractors		terraces 4, 5 and 6 N	terraces 3, 4, and 5 G	Ratio G/N
1031 contour tillage on G, cor- rected for slope difference with N terraces.	ill: inches f: inches ent. ss; tons per acre.		30, 47 12, 00 40 4 27	30, 47 9, 27 30 1, \$1	0.77
Operation across N terraces	yield: bushels per	nere	36. 6	41.5	1. 22
with N terraces. Operation across N terraces.	ent ss: tons per acre. yield: bushels per	nere	40 -4-27 36, 6		30 1. \$1 44. 5

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	Стор	Rain- full	toin- Ann Row direction		որք առե	Soil loss per- uere	Con- tour, up- and-down hill				
1936 1937 1938 1030 1040 1941 1942 1 1942 1 Total all years	Corn Corn Corn Corn Wheal Meadow Corn	Inches 24, 16 21, 86 26, 19 26, 75 27, 67 34, 62 32, 77 194, 02	(Up and down (Contour (Up and down (Contour (Up and down Contour (Up and down Contour (Up and down Contour (Up and down (Contour (Up and down (Contour (Up and down (Contour (Up and down (Contour) (Up and down (Contour)	Inches 1, 02 0, 13 2, 35 3, 30 2, 07 , 53 3, 61 4, 19 2, 68 2, 25 1, 86 4, 20 3, 76 18, 10 14, 54	Per- cent 4, 2 0, 5 10, 8 15, 8 7, 9 2, 0 18, 1 15, 2 9, 4 2, 5 8, 5 8, 5 8, 5 8, 5 12, 9 11, 5 9, 3 7, 5	Tons 1, 55 0, 05 1, 33 .95 11, 65 .22, 400 19, 38 7, 19 .92 .02 .04 4, 83 2, 09 .42 .02 .04 .95 .04 .95 .04 .05 .02 .05 .05 .05 .05 .05 .05 .05 .05	Ratio 0.03 0.74 .06 .06 .06 .06 .43 .48				

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 upand-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 soilloss 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.

			Soil loss pe				her gero	Crop yiel	d per nere
Year	Стор	Water- shed	Rainfall	Ru	notť	Amount D-1 6 D-3		Total yield divided by total arca	Total yield divided by area ia crops (
H835 1936 1937 1938 1930 1930 1941 1942 1935–49	(Wheat Onts Mendow Corn Onts Whent Mradow Corn Oats		36, 07 36, 07 24, 77 24, 25 21, 63 21, 63 25, 62 26, 69 27, 69 28, 17 35, 64 34, 81 34, 80 33, 20 33, 89 230, 89	Inches (0.3) (1.54 (1.94 (2.00) (3.50) (3.50) (3.50) (3.65	Percent 29 8 8 9 16 3 5 15 7 7 7 8 8 20 7 7 8 14 16 14 16	Tons 16.07 47.38 11 85 19.71 19.71 19.71 20.3 25.55 0.8 25.55 0.8 25.55 0.8 25.55 0.8 25.55 0.8 25.55 0.8 2.03 2.03 2.03 1.35 2.03	<pre> 0.36 13 .09 .00 .03 .02 .02 .02 .02 .02 .11 </pre>	Bushcls or lons { 20, 1 38, 0 { 1, 83 1, 66 35, 2 33, 9 40, 9 50, 0 50, 00, 00, 00, 00, 00, 00, 00, 00, 00,	Busheis or fons 25. 0 38. 0 1. 83 1. 66 43. 7 33. 7 50. 0 0. 8 9. 0 1. 03 3. 84 9. 2 8. 3 31. 9 27. 8

TABLE 37.—Soil loss, runoff, and crop yields from a watershed with contour tillage and other practices (D-7) and a watershed farmed with field boundaries (D-8)

4 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 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 percept 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





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 contourfurrowed 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.

96

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

		Rainfall				Runoff					
Bluegrass pasture watersheds	Date of storm	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	Infiltra- tion Index per bour
Pa-A, torraced Pa-B, undisturbed Pa-C, undisturbed Pa-A, terraced Pa-B, undisturbed Pa-C, contour furrowed 4 Pa-B, undisturbed Pa-B, undisturbed Pa-A, terraced Pa-A, terraced Pa-A, terraced Pa-A, terraced Pa-A, terraced Pa-B, undisturbed Pa-B, undisturbed Pa-C, contour furrowed 4	June 21, 1939. June 21, 1930. June 21, 1930. June 9, 1941a. m. June 9, 1941p. m. June 9, 1941p. m. October 30, 1941. October 30, 1941.	$\begin{array}{c} In ches \\ 2.03 \\ 2.03 \\ 2.03 \\ 1.62 \\ 1.62 \\ 1.62 \\ .66 \\ .66 \\ .66 \\ 1.98 \\ 1.98 \\ 1.98 \\ 1.98 \end{array}$	Inches 4, 20 4, 20 4, 22 4, 32 4, 32 1, 68 1, 68 36 .36 .36	Inches 3.36 3.36 2.80 2.80 1.13 1.13 1.13 2.33 .28 .28 .28	Inches 2,50 2,50 1,74 1,74 .85 .85 .22 .22 .22	Inches 0. \$2 .37 .55 .68 1.01 1.17 .33 .39 .67 .42 .62 .74	<i>Inches</i> 1.67 .73 1.35 .76 1.56 .40 .27 .60 .25 .08 .10 .09	Inches 1.65 .64 1.31 .73 1.50 .40 .27 .49 .25 .08 .10 .09	Inches 1.43 .61 1.08 .64 1.27 .39 .25 .43 .25 .08 .10 .09	Inches 1.10 .49 .80 .92 .36 .23 .35 .25 .08 .10 .09	Inches 1.40 2.25 1.83 .40 .18 .12 .30 .00 .12 .09 .08

615654

Terraced bluegrass pasture watershed of 2,026 acres, and 13-percent slope.
 Undisturbed bluegrass pasture of 5,563 acres and 9,5-percent slope.
 Bluegrass pasture watershed of 1.074 acres, and 11-percent slope before placement of contour furrows.
 Bluegrass pasture watershed of footnote ⁵ after placement of contour furrows.

56

15



0.3

Picture - in seas in some

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 S 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 dovelopment of erosion control practices by field trial is the end product of escarch 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. ...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. and the second description (submodely a second of the second second second second second second second second s

100 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

Field	Area (acres)	Year started	Rotation (kind)	Soil treatmont	Control practices
Ĺ	13.1	1932	Corn, small grain, meadow.	2 tons per acts of barn- yard manure sp- piled hefore corn, 200 pounds per acre of 20-percent super- phosphate applied with small grain.	Diversion ditch at top of slope. 2.S acres of permanent allalia above diversion ditch and im- mediately below. 8.7 acres in rotation striperopping: 1.6 acres in permanent grass, in- cluding; small strip to mark boundaries of cultivated strips and correction areas.
ր Բ Չ	18, 0 34, 0 46, 0	1934 1935 1938	(Corn, hurvested for grain, Small grain, pastured off, Mendow, pastured and restdue plowed tun- der in the spring pre- ceding the following corn crop. Crops of the rotation on each field are one year out of plase to provide year around grazing.	4-12-4 fertilizer ap- plied at the rate of 150 pounds her acre with small grain seuding.	(Four terraces upon upper reaches of slope. Approximately 9 acres cultivated (including ter- races and strips below terraces). 9 acres in permanent buffer strips and grassed waterways. 14 acres cultivated between per- manent buffer strips. 20 acres in permanent grass and water- ways (all small, severely croded, concave areas upon which water concentrates have been loft in permanent grass). Two terraces on the upper reaches of slope. Two diversion dykes at 10-foot vertical intervals. Permanent grass left on irregu- lar neas above diversion dykes. Point rows thus clininated. 20 acres in rotation. 26 acres in permanent grass.

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

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 stripcropping, 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 croded 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 smallgrain 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

.104 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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

INVESTIGATIONS IN EROSION CONTROL

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 erop 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 scedings 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

106 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 \mathbf{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 mendow 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. ý



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 crosion 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 croded down to the subsoil in 1930. The plots of series 2 comprise the detail study, and a naturally croded 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

INVESTIGATIONS IN EROSION CONTROL

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	40Average rainfall, surface runoff	, soil loss, and crop yields from i	realed 1
	and unircated subsci	l plots, 1932-40	

		n- Rain-		Surfac	e runofi				Green sticki pos		
Crop	Num- ber vears		Amount		Percent fal	ol rain- i	off fiet 801 1052	n run-	acre		
			Untreat- ed plot	Treat- ed plot	Untreat- ed plot	Treat- ed plot	Untreat- ed plot	Treat- ed ploi	Unireat- ed plot	Treated plot	
Corn Oats First-year meadow Second-year meadow.	2 2 3 2	Inches 20, 46 32, 79 27, 27 27, 18	Inches 6.02 8.61 1.92 6.02	Inches 4.87 6.42 .30 2,95	Percent 20.4 20.3 7.0 25.5	Per- cent 16. 5 10. 6 1. 3 10. 9	Tons 28, 54 39, 32 . 69 1, 03	Tons 14. 69 13. 59 . 08 . 65	Bushcis or tons 1.1 3.9 .50 .40	Bushels or tons 0.8 16.6 1.08 .70	
Rotation average		29, 18	5.87	3, 65	20.1	12, 5	17-40	7, 25			

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 acro with each oats seeding.

110° TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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.

		Vours		Ru	noff	- Soil loss	0	
Plot	Стор	(num- ber)	Ruinfall	Amount	Percent of rainfall	in runoff per acre	yield per acre	
4 5 6	Corn Oats Clover-timothy Rotation average Corn Sweet clover Rotation average Corn Oats Sweet clover Rotation average Rotation average	33 30 33 30 33 33 33 33 33 33 33 33 33 3	<i>Iuches</i> 28. 15 27. 67 31. 0B 28. 96 28. 96 28. 96 28. 95 27. 67 31. 06 28. 15 27. 67 31. 06	Inches 5.15 4.77 3.76 4.71 4.49 4.02 2.16 3.56 4.86 4.17 2.45 3.83	Percent 19.9 17.2 12.1 16.3 16.0 14.5 7.0 12.3 17.3 15.1 7.9 13.2	Tons 17, 13 9, 23 2, 30 9, 58 19, 53 7, 26 7, 5 9, 18 15, 53 7, 48 , 40 7, 94	Bushels or tons 20,6 0,79 15,8 23,5 Under 17,3 28,0 Under	

 TABLE 41.—Average rainfall, surface runoff, soil loss, and crop yields from organic mailer treatments on subsoil plots, 1932-40 1

¹ All plots were limed at the rate of 3 tons per acre in 1030 and received 189 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-timethy 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 vielded 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 fortilizers are necessary, except in those instances where an abundance of barnyard manure is availa-These severely eroded lands have produced the best returns ble. when utilized for meadow crops or pasture.

					Rur	Sollors		
Plot	Cropping system	Soil treatment	Years incl.	Rain- full	Amount	Percent of rain- fall	in run- off	
				Inches	Inches	Percent	Tans	
- 13	Corn ennually	250 nounds per aere, 4-12-4	32-39	21.01	7, 19	24.8	43.83	
- <u>1</u> 2	Corn, annually	8 tons per acre, manure annu-	33-35	129.01	15.41	1 18.6	30.36	
	Social Company	ally.					}	
4	Corn. oats, meadow	Lime, 188 pounds per acre,	32-40	28,96	4.71	16.3	9,58	
•		4-12-1 on oats.				1 10 6		
3	Corn, oats, meadow,	Lime, 250 pounds per aere,	32-49	29.18	3.65	32.5	7.25	
_	mendow.	4-12-1 on pats.	ac 10	DE CO	7.0.10	+ • • •	10.04	
8	Oats-Korean lespedeza	125 pounds per acre. 0-20-0	30-10	- 20, 79	- 210	- 0,1		
7	Grass-legume mixture	Lime, 188 pounds per acre, 4-12-4 in 1931.	3240	28.96	1.40	4.8	.09	
			•	. I	1			

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

Adjusted to be comparable with Plot B, on the basis of a straight-line relationship for the 3 years plot Was in this system.
 Previous treatment of 8 tons of manure annually during the 3-year period, 1033-35, when the plot was

in continous corn.

112 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 crossosted 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 $1\frac{1}{2}$ 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:

Rotation of corn, wheat, mendow 2 years— Surface soil without treatment	Bushels
Subsoil without treatment	20.5
Subsoil with lime and 4-12-4 fertilizer with the oats	34.6
Rotation of corn, cats, 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 sweet-	
clover plowed under	44.0
Subsoil limed, 0-20-0 fectilizer 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 4-12-1 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 scepy but fertile field drainageways. For drainageways in severely croded 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 scepage. 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 croded 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

615654-45-----8



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 soll 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, croded 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 reseaded, 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.

116 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 laving 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.

118 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

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 fortilizer 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 $2 \ge 12$ 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 sandasphalt 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.

120 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

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 (SS)." 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 glaced 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. Ponos 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 fect 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



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 1

n,

1







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 $4 \ge 4$ 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.

	Structures		1	Draina	uge		Cost 1			rus-	-so
Kind	Description	lustallation date	Number	Area	Vertical drop	Original	Ma na opup e.L.	Anticipated 85	Life, years	Protection, feet-ne years	Cost, dollurs, feet-aci yuxrs
Temporary thecks	Discarded oak posts, wire, and brush Hedge posts, wire, and brush Double hedge posts, wire, and brush	1931 1935 1932	С С	Aleres 8 15 30	17 15 2}4	Dal- lars 11, 25 136, 10 31, 60	Dol- lurs 30, 37 13, 75 S, 75	Dol- lurs 10.00 25.00	$\frac{12}{20}$	1, 632 4, 500 1, 875	0. 032
Permanent and Semi-permanent	Creesole dipped 3-in. plank dam Rubble-masonry dam Rubble-masonry dam Asphalk and sant fanne G-	1932 1935 1935		17 26 0	6 4½ 4	70, 23 97–58 31, 70	0 0 0	0 5.00 2.00	1S 30 35	1, 836 3, 510 840	. 038 . 029 . 040
	4 in, (hick) Asphalt and sand flume (3- 4 in, thick) Unformed concrete flume	1936 1936	1	11 25	8 #1/2	2900 97, 97	(3, 00 45, 55	10.00 10.00	10 12	880 2, 184	. 059 . 070
	(4-6 in, thick). Unformed concrete side spillway (1½-2 in, thick). Concrete drop-inlet flume	1932 1932	1	19.6 19	5 13	33, 15 99, 00	15, 25 15, 00	15.00	20 5	1, 960 1, 235	.032 .092
	(3-4 in, thick). Corrugated sheet-metal flume (wooden frame- work). Sheet-metal flume	1937		19 19,6	14 7 6	126.00 22.00	0 0	15.00	25 3	6, 650 412	.021 .053
	Detention reservoir ()-foot sewer tile) Drop - inlet culvert (cor- rugated)	1936 1930		10 29 65	0 14 12	251,65 251,65	น 5.00 50.00	15.00 15.00	12 25 30	1, 050 10, 150 23, 400	.017
	Drop-inlet culveri (con- crety)	1934	1	100	8	625, 02 i	Û	50. 00	50	JO, OUG	.017

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

¹ Costs shown do not include placing of earth fills.

126 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 I 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.

and the second s				A CONTRACTOR OF A CONTRACT OF				
Lowtion	Drainage	Total	Specification fe	ns, lower 200 et				
	firen	length	Cross-see- Grade per tion area foot		i) be of milne			
Pa-B Pa-C Field P Field Q: 3 north 3 sonth 4 south	Acres 2.8 2.1 1.5 1.0 5.4 4.0 4.1	Feet (950) 410 325 530 1, 350 1, 350	Square peet 5 7 10 9 18 15 13	Foot 0.017 .010 .005 .005 .001 .005	Bluegrass pasture. Bo, Combination concrete and sod. Grassed waterway. Sod channel, Do, bo,			

TABLE 44.—Station	diversion	dikes
-------------------	-----------	-------

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 fect vertically below the ridge top. It has performed satisfactorily without scouring or silting of the channel and without erosion in the outlet.

- 127

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, \mathbf{F} , \mathbf{L} , and \mathbf{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 \mathbf{L} and \mathbf{Q} .

From this experience with diversion dikes, it is apparent that their operation, without excessive maintenance, requires an area of grasabove 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 pratically the same as for terraces.

HYDRAULIC STUDIES

Studies of the retarding influence of vegetation on the flow of watehave 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,

$$V = \frac{1.486}{n} R^{36} S^{11}$$

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 retarnance coefficient has been used as a gage of channel roughness.

Retardance of bluegrass terrace outlets.—Data secured prior to 19% on bluegrass terrace outlets on slopes ranging from 7 to 12 percent, consisted of peak discharge rates and maximum depth of flow reading, 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 that 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 recorde, s 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, whe bluegrass was at its maximum growth stage. For shallow flows the grass remained erect and created excessive turbulence. Values of nboth 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

INVESTIGATIONS IN EROSION CONTROL

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



R-Hydroulic radius in feet

- (1) Terrace channel 4-1-Mature second-year timothy meadow, 6/21/39
- (2) Terrace channel 4-1-Mature wheat, 6/9/41
- (3) Terrace channel 4~I→Corn 4 inches high, 6/10/40
- (4) Bluegrass terrace outlet D-2- Heavy bluegrass at maximum growth stage, 6/9/41

FIGURE 49.-Relardance 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 γ folded 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

ないというないないないないないないないないないないです。

÷.....

130 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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 straightrow 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.

132 TECHNICAL BULLETIN 883, U.S. DEPT. OF AGRICULTURE

		Desired		Ru		
Watershed designation	Major practice t	Period of records	Rainfall	Amount	Percent of rainfall	Soil loss per acre
Pa-A Pa-B D-3 I-58 Pa-B IJ-3 IJ-1 IJ-1 IJ-1 IJ-1	Bluegrass, terraced Bueerass, untisturbed Rotation, no supplemental practices Alfalfa 1st. 5 years, Oats-lespedeza 2d 5 years, ⁴ Bluegrass, undisturbed Rotation, no supplemental practices Rotation, contoured Rotation, sontoured Rotation, sontoured Rotation, sontoured	Years 1934-12 1934-12 1933-12 1933-12 1933-12 1935-12 1935-12 1935-12 1935-12	Inches 29, 45 29, 26 29, 41 29, 71 29, 71 29, 47 28, 86 28, 86 29, 32 28, 87 28, 77	Inches 2, 36 2, 58 4, 96 3, 82 2, 59 4, 67 3, 91 3, 17 3, 27	Percent 8.0 8.8 16.9 12.9 8.8 16.1 13.7 10.8 11.4	Tons ² 0, 94 ⁴ , 62 26, 98 3, 18 ⁴ , 60 25, 26 2, 76 1, 69 55

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

² 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 distorbed in terracing.

Includes guily erosim prior to 1030.
 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 upand-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 15minute 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 rules of runoff from 79 storms 1 from a cultivated and a pasture watershed during the 7-year period, 1983-40

Range of ranoff in inches per bour	Cultivated watershed D-3	Pasture watershed Pa-B	Range of runoff in inches per bour	Cultivated watershed D-3	Pasture watershed Pa-B
0-0,-1;: 0, 50-, 90 1, 00-1, 40 1, 50-1, 90	Number 45 11 3 9	Number 69 3 4 2	2,00-2,40 2,50-2,50 3,00-1,99	Number 5 4 2	Number 0 i - 0

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

INVESTIGATIONS IN EROSION CONTROL

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 1	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:

 $\begin{array}{c} X^1 = -.58 + .16X^2 - .49X^3 + .79X^4 + .14X^3 \\ \text{Cultivated watershed D-3:} \\ X^1 = -.1.11 + .29X^2 - .15X^3 + .85X^4 + .73X^3 \end{array}$

in which

 X^{1} = maximum rate of runoff in inches per hour.

 $X^2 = 5$ -minute rainfall intensity in inches per hour.

 $N^3 = 15$ -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:

Binegrass Pasture B. $S = \pm 0.39$ R = 0.60Cultivated 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

134 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

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



Frequency - (years)

FIGURE 51.—Maximum rate of runoff from a cultivated and a bluegrass-pasture watershed for different frequencies of 5-, 15-, and 30-minute rainfalt 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

⁴ ZINGG, A. W. 1941 HYDROLOGIC STUDIES. COMPILATION OF RAINFALL AND RUNOFF FROM WATERSHEDS OF SHELBY MAM AND RELATED SOLS, CONSERVATION EXPERIMENT STATION, BETHANY, MO. SCS-TP-30 Supplements 1 and 2. [Mineographed.]

INVESTIGATIONS IN EROSION CONTROL

data; correlation of rainfall intensity and previous rainfall with the maximum rate of runoff, for 79 storms selected by use of the Weather Burean 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 Λ_i 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)

	Rainfall.	Amount of rain- fall	Time of	Average rainfall intensity during	Maxi- mum	Coeffi-	Total	Reten- tion	Effec- tive	Crop and soil c	Crop and soil condition factors influence	
storm	total amount	during rise of hydro- graph	graph rlso	time of hydro- graph rise (1)	rate of runoff (Q)	of runofi (C)	amount of runoff	of runoff (R)		Crop kind	Crop growth (height)	Soil condition
9-13-34 5-1-35 5-31-35 6-1-35 6-1-35 6-20-35 6-20-35 6-23, 21-39 6-23, 40 Average	Inches 1. 95 1. 22 . 04 1. 05 . 03 2. 37 1. 26 2. 19 1. 92 1. 54	Inches 0, 95 .64 .68 .44 .42 .79 .52 .50 .49 .60	Minutes 13 13 14 12 14 12 14 12 13 14 12 13 13 14 12 13 14 12 13 14 12 13 14 12 13 14 12 13 14 15 15 13 14 15 15 15 15 16 17 17 17 17 17 17 17 17 17 17	Inches per hr. 4.41 2.04 2.22 2.29 3.16 2.39 3.75 2.45 2.95	Inches per hr. 1:59 1:00 .93 1:23 .59 1.67 .31 1.00	0.36 .21 .33 .45 .41 .39 .25 .45 .13 .33	Inches 0.69 .22 .45 .87 .57 .38 .45 .57 .38 .45 .23 .63	Inches per hr. 1.96 2.15 1.05 .10 .40 .75 1.08 1.60 1.87 1.22	Inches per hr. 2.45 2.12 1.85 2.12 1.80 2.41 1.31 2.15 58 1.73	Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass	<i>Inches</i> 4 to 6 in	Surface soil moist, subsoil dry. Soil moist. Soil wet. Soil saturated. Soil wet. Soil wet. Surface soil moist.
					NORMAI	BLUEG	RASS PA	STURE V	WATERS	ited (Pa-B)		
9-13-34 5-1-35 5-31-35 6-17-35 6-20,21-35 6-23-40 Average	1. 95 1. 22 . 94 1. 05 . 93 2. 37 1. 20 2. 19 1. 92 1. 54	$\begin{array}{c} 0.82\\ .46\\ .65\\ .46\\ .62\\ .66\\ .48\\ .79\\ .44\\ .60\end{array}$	11 8 13 13 21 12 12 12 13 10 13	4, 45 3, 46 3, 02 2, 11 1, 77 3, 28 2, 30 3, 65 2, 66 2, 98	0. 21 .09 1. 55 1. 43 1. 70 1. 75 1. 20 .73 .18 .98	0.05 .03 .51 .08 .96 .53 .50 .20 .07 .39	0.07 .03 .50 .93 .76 1.48 .61 .37 .10 .54	4. 10 3. 36 . 90 . 06 . 14 . 64 . 64 . 67 2. 40 2. 46 1. 64	$\begin{array}{c} 0.35\\ .10\\ 2.12\\ 2.05\\ 1.63\\ 2.64\\ 1.72\\ 1.25\\ .20\\ 1.34\end{array}$	Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass Bluegrass	4 to 6 in	Surface soil molst; subsoil dry. Soil molst. Soil seturated. Soil saturated. Soil saturated. Soil wet. Soil wet. Surface soil molst. Surface soil molst.

•

CONTOUR CROPPED WATERSHED (D-1)												
9-13-34 5-1-35 6-1-35 6-17-35 6-17-35 6-20-35 6-20,21-39 (-23-40 Average	$\begin{array}{c} 1.95\\ 1.22\\ .94\\ 1.05\\ .93\\ 2.37\\ 1.26\\ 2.19\\ 1.92\\ 1.54 \end{array}$	$\begin{array}{c} 0, 39 \\ .37 \\ .49 \\ .29 \\ .32 \\ .54 \\ .23 \\ .35 \\ .30 \\ .36 \end{array}$	5 69 57 95 57 6	$\begin{array}{c} 4.\ 73\\ 3.\ 68\\ 3.\ 27\\ 3.\ 52\\ 2.\ 74\\ 3.\ 60\\ 2.\ 73\\ 4.\ 20\\ 2.\ 57\\ 3.\ 45\\ \end{array}$	$\begin{array}{c} 2.38\\ 1.34\\ 3.18\\ 2.14\\ 3.05\\ 2.68\\ 1.61\\ 3.18\\ 1.44\\ 2.33\end{array}$	$\begin{array}{c} 0.50\\ .36\\ .97\\ .61\\ 1.11\\ .74\\ .59\\ .76\\ .56\\ .69\\ \end{array}$	$\begin{array}{c} 0.73\\ .26\\ .70\\ .84\\ .89\\ 1.63\\ .54\\ 1.72\\ .73\\ .89\end{array}$	$\begin{array}{c} 1,87\\ 2,03\\ ,40\\ ,12\\ ,02\\ ,51\\ ,91\\ ,42\\ 1,08\\ ,82\end{array}$	$\begin{array}{c} 2.86\\ 1.65\\ 2.87\\ 3.40\\ 2.72\\ 3.09\\ 1.82\\ 3.78\\ 1.49\\ 2.63\end{array}$	Plowed on S/20; disc on J(1, Dril) wheat 10/5 Wheat Wheat Wheat Wheat Wheat Clover	Coming up 6 to 8 in	Surface soil moist; subsoil dry. Soil moist. Soil wet. Soil saturated. Soil wet. Soil wet. Soil wet. Soil wet. Soil wet. Soil wet. Soil moist.
TERRACED CROPPED WATERSHED (D-2)												
9-13-34 10-19-34 5-1-35 -31-35 -1-35 -1-7-35 -20,21-39 -20,21-39 -20-40 A verage	$\begin{array}{c} 1.95\\ 1.22\\ .94\\ 1.05\\ .03\\ 2.37\\ 1.26\\ 2.19\\ 1.92\\ 1.54\end{array}$	0.75 .42 .73 .50 .62 .70 .65 .84 .56 .64	10 7 16 16 21 13 18 15 15 15 15	$\begin{array}{r} 4.48\\ 3.64\\ 2.72\\ 1.87\\ 1.77\\ 3.23\\ 2.17\\ 3.34\\ 2.23\\ 2.83\end{array}$	$\begin{array}{c} 2, 20\\ ,38\\ 1, 21\\ ,94\\ 1, 34\\ 1, 48\\ ,51\\ 2, 36\\ ,53\\ 1, 22\\ \end{array}$	$\begin{array}{c} 0.49\\.10\\.44\\.50\\.76\\.46\\.24\\.71\\.24\\.44\\.44\\.44\end{array}$	0.06 ,21 ,55 .81 .73 1.49 .43 1.56 .59 .81	1.37 2.26 $.77$ $.16$ $.17$ $.51$ 1.27 $.00$ 1.25 $.93$	$\begin{array}{c} 3.11\\ 1.38\\ 1.95\\ 1.71\\ 1.60\\ 2.72\\ .90\\ 2.74\\ .98\\ 1.90\end{array}$	Plowed 8/20; disc on 9/11 Drill Wheat 10/5 Wheat Wheat Wheat Wheat Clover	Coming up 6 to S in	Surface soil moist; subsoil dry. Soil moist. Soil saturated. Soil saturated. Soil wet. Soil wet. Soil wet. Soil wet. Soil moist.
CROPPED WATERSHED (D-3)												
9-13-34 5-1-35 6-1-35 6-17-35 6-26-35 6-20, 21-39 6-23-40 A verage	$\begin{array}{c} 1.95\\ 1.22\\ .91\\ 1.05\\ .05\\ 2.37\\ 1.26\\ 2.19\\ 1.92\\ 1.54\end{array}$, 02 , 61 , 34 , 29 , 29 , 52 , 10 , 30 , 28 , 42	14 12 5 6 8 4 4 4 6 7	4.36 3.03 3.40 3.52 2.90 3.89 2.44 4.50 2.75 3.42	2.48 2.03 4.02 2.50 2.72 2.48 1.45 3.36 1.53 2.57	.57 .07 1.36 .71 .94 .64 .59 .75 .56 .75	$1.01 \\ .47 \\ .79 \\ .72 \\ .78 \\ 1.42 \\ .45 \\ 1.73 \\ .83 \\ .91$	$1.27 \\ 1.27 \\ .20 \\ .27 \\ .12 \\ .70 \\ 1.18 \\ .40 \\ .97 \\ .71$	3.09 1.76 3.20 2.78 3.19 1.26 4.10 1.78 2.71	Corn	5 feet Poor crop mature 2 inches 12 inches 30 inches Mature Mature Cut and shocked	Surface soil moist; subsoil dry. Soil wet. Soil saturated. Soil saturated. Soil wet. Soil wet. Soil wet. Soil wet. Soil moist.

137

 TABLE 47.—Study of 9 intense storms occurring from July 1, 1984, to December 31, 1940, inclusive, Soil Conservation

 Experiment Station, Bethany, Mo.—Continued

 CONTINUOUS ALFALFA WATERSHED (I-58)

138

-TECHNICAL BULLETIN 883, U.

S. DEPT.

OF AGRICUL/TURE

Date of storm	Rainfall, total amount	Amount of rain- fall during rise of hydro- graph	Time of hydro- graph rise	Average rainfall intensity during time of hydro- graph rise (I)	Maxi- mum rate of runoff (Q)	Coeffi- cient of runoff (C)	Total amount of runoif	Reten- tion rate index (R)	Effec- tive rain- fall (I-R)	Crop and soil condition factors influencing runoff		
										Crop kind	Crop growth (height)	Soil condition
9–13–34	Inches 1.95	Inches 0.82	Minutes 11	Inches per hr. 4.45	Inches per hr. 0.67	0. 15	Inches 0.26	Inches per hr. 3.40	Inches per hr. 1.05	Alfalfa	Inches 12 inches	Surface soil moist:
$\begin{array}{c} 10-19-34 \\ 5-1-35 \\ 5-31-35 \\ 6-1-35 \\ 6-17-35 \\ 6-26-35 \\ 6-20, 21-39 \\ \end{array}$	$1. 22 \\ . 94 \\ 1. 05 \\ . 93 \\ 2. 37 \\ 1. 26 \\ 2. 19$.57 .49 .35 .40 .52 .23 .40 .52 .23 .40 .52 .23 .40 .52 .23 .40 .52	11 9 7 10 8 5 6	$\begin{array}{r} 3.13\\ 3.27\\ 3.04\\ 2.40\\ 3.89\\ 2.73\\ 4.00 \end{array}$	$1.74 \\ 3.52 \\ 1.93 \\ 2.53 \\ 2.30 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ 3.00 \\ 1.57 \\ $		$ \begin{array}{r} .37 \\ .75 \\ .90 \\ .90 \\ .46 \\ .62 \\ .62 $	$ \begin{array}{r} 1.57 \\ .28 \\ .08 \\ .02 \\ .67 \\ .65 \\ \end{array} $	$1, 56 \\ 2, 99 \\ 2, 96 \\ 2, 38 \\ 3, 22 \\ 2, 08 \\ 2, 08 \\ 3, 100 \\ 1, 100 \\$	Cut alfalfa 9/19 Alfalfa Alfalfa Alfalfa Cut alfalfa 6/8 Alfalfa	Stubble 6 to S in 18 inches 18 inches 4 inches 10 inches	subsoil dry. Soil moist, Soil wet. Soil saturated. Soil saturated. Soil wet. Soil wet.
6-23-40	1, 92 1, 54	. 42 . 47	9 8	2, 80 3, 30	1. 05 2. 14	. 38	.44 .81	. 35 1, 47 . 97	3.45 1.33 2.34	Oats lespedeza	Mature 4 to 6 in Shocked. Heavy young growth.	Soil wet and packed. Soil moist.
ROTATION STRIP-CROPPED WATERSHED (IJ-J)												
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	Surface soil moist:
10-19-34	1, 22	.37	6	3.68	. 73	. 20	. 13	2.66	1.02	meadow. Strip-cropped with corn, soyheans, wheat and		subsoil moist.
5-1-35	. 94	. 58	11	3. 19	3, 00	. 94	. 61	. 61	2.58	Strip-cropped with corn, soybeans, wheat and		Soil wet.
5-31-35	1,05	. 33	6	3. 29	2, 54	. 77	. 93	. 07	3, 22	meadow. Strip-cropped with corn	Soupeone wheat and	Coll cofumeted
6-1-35	. 93	. 40	10	2,40	2.64	1.10	, 81	. 08	2.32	meadow.	sorboone wheat and	Son saturated.
6-17-35	2.37	. 52	8	3, 89	2.24	. 58	1,16	1.02	2.87	meadow.	soubcans, wheat and	Son saturated.
6-26-35	1.26	. 22	4	3. 31	1.73	- 52	66	55	2.01	meadow.	soybeans, wheat and	Soil wet,
6-20, 21-39 6-23-40 Average	2.19 1.92 1.54	. 40 . 44 . 46	6 10 8	$\begin{array}{c} 4.\ 00\\ 2.\ 66\\ 3.\ 43\end{array}$	3. 12 1. 12 2. 07	$.78 \\ .42 \\ .63$	$1.72 \\ .42 \\ .76$.41 1.50 1.08	3, 59 1, 16 2, 35	meadow. Strip-cropped with corn, c Strip-cropped with corn, c	soyocans, wheat and pais, and meadow pais, and meadow	Soil wet. Soil wet. Soil moist.
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	water-
sheds for 9 storms	

	Relati	igh to	Average ranking					
Watershed	1	3	3	 	5	6	7	for 9 storms
Pa-A /'a-B	2 4 1 1 1	3 J 2 I J I	1 1 3 1 2		2 4 1 1	2 1 4 2		2 1 5 3 7 6 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 g	iven in table	48		-	

		Q=a+b1		Q=a-{-b (I-It)			
w storsnoa	"	6	t }	a	U	71	
Pa-A. 1 Pa-B. 1 D-1 1 D-2 1 D-3 1 I-66 1 IJ-1 1	$\begin{array}{c} -0.41 \\ 2.38 \\ 1.35 \\ .09 \\ .40 \\ 1.86 \\ 2.42 \end{array}$	0,48 47 28 40 64 09 10	0, 8t 58 15 50 54 22 10	0.03 .03 .37 	0, 56 71 75 81 76 1, 01 70	0.86 96 85 .92 .75 .84 .84	

¹ Coefficient of correlation 5-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 However, the density of runoff continued to rise for apparticles. proximately 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 Accumulative soil loss in tons per acre is plotted in the lower feet. 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

142 TECHNICAL BULLETIN \$\$3, U. S. DEPT. OF AGRICULTURE

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:

 $y = 1.85 N^{-8}$

where y—soil loss in runoff in pounds per cubic feet, and X—the rate of runoff in cubic feet per second.

LITERATURE CITED

(1) BAVER, L. D.

1935. SOIL EROSION IN MISSOURI. Mo. Agr. Expt. Sta. Bul. 349, 66 pp., illus.

(2) -----.

1.

AGGREGATE ANALYSES AS AN AID IN THE STODY OF SOIL STRUCTURE RELATIONSHIPS. Amer. Soc. Agron. Jour. 24: 920-930, illus. 1931.

- (4) BENNETT, H. II.
- 1939. SOLL CONSERVATION. 993 pp., illus. New York and London. (5) ---- and CHAPLINE, W. R.
- 1928. SOIL EROSION A NATIONAL MENACE. U. S. Dept. Agr. Cir. 33, 36 pp., illus. (6) Browning, G. M.

1937. CHANGES IN THE ERODIBILITY OF SOILS BROUGHT ABOUT BY THE APPLICATION OF ORGANIC MATTER. Soil Science Soc. Amer. Proc. 2: 85-90, illus.

- (7) DISERER, E. G. and YODER, R. E. 1936. SHEET BROSION STUDIES ON CECIL CLAY. Ala, Agr. Expt. Sta. Bul.
- 245, 52 pp., illus. (8) DULEY, F. L. and HAYS, O. E.
 - 1932. THE EFFECT OF THE DEGREE OF SLOPE ON RUNOFF AND SOIL EROSION. Jour, Agr. Res. 45: 349-360, illus.
- (9) and MILLER, M. F.

1923. EROSION AND SURFACE RUNOFF UNDER DIFFERENT SOIL CONDITIONS. Mo. Agr. Expt. Sta. Res. Bul. 63, 50 pp., illus.

(10) GRAHAM, E. R.

1941. ORGANIC COLLOIDAL ACIDS AS FACTORS IN THE WEATHERING OF ANORTHITE. Soil Science 52: 291-295.

- (11) HAYNES, J. L. 1940. GROUND RAINFALL UNDER VEGETATIVE CANOPY OF CROPS. Amer. Soc. Agron. Jour. 32: 176-184.
- (12) HOLMAN, A. T.
 - 1937. TERRACE CROSS-SECTIONS AS INFLUENCED BY SOIL, CROPS, LAND SLOPE, AND FARM MACHINERY. Amer. Soc. Agr. Engin. Jour. 18:5-8.
- (13) MARR, JAMES C.
- 1941. MORE RATIONAL "NORMAL" PROPOSED. Amer. Soc. Agr. Engin. Jour. 22: p. 315.
- (14) MEYER, ADDENI F.
- 1917. The elements of hydrology. 487 pp., illus. New York.
- (15) MIDDLETON, H. E., SLATER, C. S., and BYERS, H. G.
 - 1932. PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE BROSION EXPERIMENT STATIONS. U. S. Dept. Agr. Tech. Bul. 316, 51 pp.
- SLATER, C. S., and BYERS, H. G. (16) ••••
 - 1934. PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS, SECOND REPORT. U. S. Dept. Agr. Tech. Bul. 430, 63 pp.
- (17) MILLER, M. F., and KRUSEKOPF, H. H.
- 1929. THE SOLLS OF MISSOURI. Mo. Agr. Expt. Sta. Bul. 264, 120 pp., illus.
- (18) MUSGRAVE, G. W.
- 1935. THE INFILTRATION CAPACITY OF SOILS IN RELATION TO THE CONTROL OF SURFACE RUNOFF AND EROSION. Amer. Soc. Agron. Jour. 27:336-345, illus.
- (19) ----- and Norros, R. A.
- 1937. SOIL AND WATER CONSERVATION INVESTIGATIONS AT THE SOIL CONSERVATION EXPERIMENT STATION CLARINDA, IOWA. U. S. Dept. Agr. Tech. Bul. 558, 182 pp., illus.

7

Ş.

144 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

and the second second second

(20)	Neal, J. H.
, ,	1938. THE EFFECTS OF DEGREE OF SLOPE AND RAINFALL CHARACTERISTICS ON RUNOFF AND SOIL EROSION. Mo. Agr. Expt. Sta. Res. Bul. 280, 47 pp
(21)	PEELE, T. C.
	1937. THE EFFECT OF LIME AND ORGANIC MATTER ON THE ERODIBILITY OF CECIL CLAY. Soil Sci. Soc. Amer. Proc. 2: 79-84.
(22)	RAMSER, C. E.
	1917. PREVENTION OF EROSION ON FARM LANDS BY TERRACING. U. S. Dept. Agr. Bul. 512, 40 pp., illus.
(23)	SHARP, A. L., and HOLTAN, H. N.
	1940. EXTENSION OF GRAPHIC METHODS OF ANALYSIS OF SPRINKLED PLOT
	HYDROGRAPHS TO THE ANALYSIS OF HYDROGLAPHS OF CONTROL
	Inion Trans 21 (2): 558-570
(24)	SMITH, D. D.
1 ,	1938. EXPERIMENTAL STUDIES IN TERRACING. Amer. Soc. Agr. Engin.
	Jour. 19: 63-66.
(25)	
(0.0)	1941. INTERPRETATION OF SOIL CONSERVATION DATA FOR FIELD USE. Amer. Soc. Agr. Engin. Jour. 22: 173-175.
(26)	and WOLFE, E.
(07)	Soil Conserv. 4: 12-13.
(27)	1040 where method for which we have a hurble to be the second
	AND FARM MANAGEMENT PRACTICES ON SOLL PROSION AND CROD
	VIELDS. Soil Sci. Soc. Amer. Proc. 5: 372-376.
(28)	
	1936. THE USE OF BLUEGRASS SOD IN THE CONTROL OF SOIL EROSION,
(00)	U. S. Depf, Agr, Farmers' Bul, 1760, 13 pp., illus.
(29)	WALKER, R. H., SHO BROWN, P. E.
	1950. Som EROSION IN 10WA. TOWR Agr. Expt. Sta. Spec. Rpt. 2, 47
(30)	WHITT, D. M.
	1941. THE ROLE OF BLUEGRASS IN THE CONSERVATION OF THE SOIL AND
	ITS FEBTILITY. Soil Sci. Soc. Amer. Proc. 6: 309-311.
(31)	and Swanson, C. L. W.
	1942. EFFECT OF BROSION ON FERTILITY CHANGES IN THE SHELBY LOAM
(32)	WOODEWER C. M.
(02)	1937. LINEAR CHANGES IN THE SHELBY LOAM PROFILE AS A RUNOTION
	OF SOIL MOISTURE. Soil Sci. Soc. Amer. Proc. 1: 65-70.
(33)	WOOLEY, J. C., CLARK, W. M., and BEASLEY, R. P.
	1941. THE MISSOURI SOIL SAVING DAM. Mo. Agr. Expt. Sta. Bul. 434,
(0.4)	²³ pp., illus.
(34)	YARNELL, D. G.
	Pub 204 68 pp. illus
(35)	Zinge A. W.
(00)	1940. DECREE AND LENGTH OF LAND SLOPE AS IT APPECTS LOSS IN BUN-
	OFF. Amer. Soc. Agr. Engin, Jour. 21: 59-64.
(36)	
	1940. AN ANALYSIS OF DEGREE AND LENCTH OF SLOPE DATA AS APPLIED
(07)	TO TERRACING. Amer. Soc. Agr. Engin. Jour. 21: 99-106.
(67)	
	LANDS ADDEr Son Age Engin Jour 23, 93-94
(38)	
	1942. TERRACE GRADES ON THE SHELBY LOAM AS THEY AFFECT SOIL AND
	WATER LOSSES. Amer. Soc. Agr. Engin. Jour. 23: 159-160.
1201	and Warmer D. M
(99)	1949 DISTRUCTION OF COMMUNICATION ON RADIATION OF COMMUNICATION OF $COMMUNICATION OF COMMUNICATION OF COMMU$
	SOL. Amer. Soc. Agr. Epsin. Jour. 23: 126-123.

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.

145

615654-45-----10

TARLE 50.—Description of the experimental plots from which soil and mater li

ζ.

	f records	Enderl	Dire. 31, 1049	Do.	.) <u>)</u> o,		.Da.	Do.	De.	lu operation.	Ja.		1)a.	.D0,	7)a.	Da.	.nct	-201		.DO.	The	
	Period o	Regan	Ане. 1930	do do	do	do	do		do	Spring 1932	- da			op	do		do	ej.		do	Surine 1835	
	Sojl treatment		None	(10	do.	8 tons of line per acre in 1930; 250 pounds of 20-bereent superplayesplore on wheat	3 tous of thue per nere in 1930; 250 pounds of 20-percent superplusifing every	lifree years, None	Desurfaced	Desturfaced and spacked 3 inches deep 250 pounds of 4-12-4 broadenst an- numby: meadow established than serve	us No. 7. Dustrificed and spaded 7 fuelles drept 20 prainfact of 4-12-4 fuellizer hrad-	Philliphic activities and the second			Desitificent; 3 tous of little in 1940; 250 potadisat j=12-4 fertilizer meenting only.	Desurfacet; 3 tons of lime in 100; 188 poundsof 4-12-4 fortilizer preceling and	Desurfaced: 3 tans of line in 1936, 188 pounds of 1-12-1 fertilizer proceeding:	unts. Desurfacedi; 3 tons of lime in 1930; 1885	pounds of 20-percent superplues hate furceeding conts; S hous of manure pre- ceeding corts, every fall of 1911.	Desturfacent: 3 tons of time in 1930; 158 pounds of i=12-4 fertilizer in 1031, [Anil]	Spuded RHI for corn in 1012. Destriated: 5 tons of mumire murinily: 1	changed to ants-lespedeza 1636, 125 pounds of 20-percent superplues/dante
	Cropping praedice		(Corn continuously	3-year rolation of cara, wheat, and clowe-fimothy.	do	(ta	Vistonuluos enution	Pluegrass continuously Fullow	d0	COFRECORDINGUES AGE TOTE AND A DE NO. T. DE NO. T.	Corn continuously: after 1839 same as No. 7 except hay removed,	4-Year rotation of corn, cats, clover-	timothy, and clover-timothy.	Unsthy, and clover-timathy,	timotity, and clover-timothy.	ergur funden of corn, onts, and	5-Yelf folmuni of corn, only, and swortchover.	do.		o lover and grass muxure of time of the other sweetelover, alsthe, red elever and second seco	Corb continues y uza	
	A verage slope		Percent		•	_	9 6									5.5						
	Soll		Shelby sift loam	9		(10		do	Shullve due basis		e	Shelby silt loam	Shelloy clay loam.	da 1								
	Aren	ļ	0.00 0.00	ē	ō	1		55	01		. 01255	6010	0103	EIIIO.	5010.	11510		. 0103	£010.		80.	
	Leugth		Nect 145, 2 72, 11	e 4	leir.			5 1 21	 सङ्घ		2	SO	7	ź	9	9		F.	5		9%	
	WIdth		N 99	• •			,		50 50 		2	J0.50	10.50	10, 50	10.50	10 [.] 20		97 97	11,50		10.50	
	Plot Series No.				-	Ξ							-		~	e		-		-		
[No.		- 61	~ -	-			w on g	-		=	-	¢1	~				0	t	· ,	2	- ,

146 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

-1)		10.50	125 125	. 03013	Shelby silt loam		4-year rotation of corn, soybeans	16 tons of manure annually 200 pounds of 20-percent superphosphate	Jan. 1933 Nov. 1931	Dec 31, 1939 Do. 3
B		10.50	125	. 03013			clover-timothy, ¹ 4-year rotation of corn, drilled soy- beans, wheat and clover-tim-	200 pounds of 20-percent superphosphate on wheat.	do	Do. 5
1		10. 50	125	. 03013	tlo		othy. ¹ 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	\$.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.	(l0	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	đo	Do.
4		10.50 10.50	125 125	. 03013	do		Fallowdo	4 tons of oats straw each fall at spading	do	Dec. 31, 1935 Do. Do.
67		10.50 10.50 (243.67	125 125 270	. 03013 , 03013 2, 267	do do. Grundy-Shelby silt		3-year rotation of corn, wheat, and	None. None. 150 pounds of 4-12-4 fertilizer with wheat;	July 1934	Do. In operation ⁶
2		*43. 67	270	2, 267	loam. do		on a separate strip. 3-year rotation of corn, wheat, and	do	do	Do.7
3		243.67	270	2, 267	do		on a separate strip. 3-year rotation of corn, wheat, and		do	Do.
4	5	43.67	270	2, 267	do	6,6	on a separate strip. 3-year rottaion of corn, wheat, and	do	do	Dali
5	(*)	243.67	270	2. 267	do		3-year rotation of corn, wheat, and clover-timothy with each crop	do	do	.Do.6
6		243.67	270	2, 267]	on a separate strip. 3 year rotation of corn, wheat, and clover-timothy.	dø	Spring 1932	Do. 7
121	9	60 60 (28	229 229 90	. 3415 . 3424 . 0564	Shelby silt loam dodo	} 11.6	Pasture, grazed moderately Pasture, grazed intensively Continuous corn; after 1939 wheat,	None. do	Fall, 1933	Do. In operation
51-53	15	2 28 2 28	180 270	.1142 .1721	do	**********	meadow, corn. do do	dodo	do	Do. Do. Do.
4 5	(1)	² 28 28	180 90	, 1142 , 0564	do	••••••••••••••••				Do.

1 The plot was fallow in 1931. 3 Gelb multislot divisor units were on these plots after June 1935. 4 Concrete tank. 4 Soil and water losses were secured in spring and summer of 1940 with Plot A disked and 2 tons per acre ont straw mulch and Plot B disked only. 4 Continued planted up and down hill in 1942, followed by wheat and meadow 1 year. 4 Continued planting on contour with corn in 1942, followed by wheat and meadow 1 year.

INVESTIGATIONS IN EROSION CONTROL

Terrace No.	Length	Grade per 100 feet	Ver- tical	Ter- race	Land	Sell	Cropping practice	Soll treatment	Period o	of records	
			ing	slope	siope				Began	Ended	
1-H	Feet 876	Inches Variable 1-2-3-4	Fect 5	Per- cent 10.0	Per- cent 6.4	Shelby loam	Corn, oats with sweet-	4 tons of lime per acre in 1930; 200	March 1936	Dec. 31 1941	
2-11 3-11	1,050 1,050	Variable 0-1-2-3-t do	5 5	11.7 11.9	5,3 8,5	do	clover: the sweetclover was turned under. do Corn, soybeans, wheat,	pounds of 20-percent super- phosphate per acre on oats. 200 pounds of 20-percent super-	Spring 1932	Do. Do.	
4-H	1, 050	do	5	12, 9	9, 6	do	elover with timothy.	phosphate per acre with wheat in the fall of 1932. 3 tons of lime per acre in 1935; 200 pounds of 4-12-4 fertilizer per	do	Do.	
5-11	1, 050	do	5	13.6	9,7	do	đo	acre with wheat in the fall of 1935. 2.5 tons of lime per acre in 1934-35; 200 pounds of 4-12-4 fertilizer her uere with wheat in the fall	do	Do.	
6-H	1,050	do	5	13, 9	9.8	do	do	of 1934. 200 pounds of 20-percent super- phosphate per acre with wheat in the foll of 1933	do	Do.	
2-G	650 700	Uniform, 4	6 5	16.0 18.7	12.0 12.4	do	Alfalfa, onts-lespedeza 1938-39. Corn. oats, clover with	3 ions of line per acre in 1933; 300 pounds of 4-12-4 fertilizer per acre in 1933. 200 pounds of superphosenbate per	Nov. 1932	Dec. 31, 1939	
4-G 5-G 2-I	700 700 1, 375	do do Variable, 0-1-2-3-4-5	7 9 5	17.6 16.1 11.6	13.9 13.2 7.9	do do do	timothy. do do Corn, corn, oats, clover	acre on onts. do do do	Joing 1931	Dec. 31, 1940 Do. Do. Dec. 31, 1938	
4-T 5-C 6-C	2,450 1,200 1,200	do Uniform, 8	5 5	12.1 16.3	8.4 10.9	do do	with timothy. do Corn, onts, clover with timothy.	do do	Jan, 1932	Do. Dec. 31, 1940	
7-C 8-C. 9-C. 10-C	1,200 1,200 1,200 1,200 1,200	Uniform, 4 Uniform, 2 Level Variable, 1-2-3-4	5 5 5 5	$ \begin{array}{r} 10.0 \\ 17.5 \\ 15.9 \\ 16.8 \\ 17.7 \\ \end{array} $	11.7 10.8 11.1 11.8	do do do do do	do do do do	do do do do	Spring 1931 Jan. 1932 Spring 1931 do	Do. Do. Do. Do.	
2-N 4-N 5-N 6-N	836 1,040 1,040 1,040	Level Uniform, 4 do do	4 3 5 7	$11.2 \\ 11.0 \\ 9.8 \\ 8.4$	6.5 6.3 7.4 6.8	Grundy loam Shelby loam do do	do do do		Mar, 1936 Spring 1931 do	Do. Dec. 31, 1938 Dec. 31, 1940 Do.	
Area 7-CN (3 terraces).	725 1, 315	Level	4 5.5	13.1 17.0	8.2 9.1	do do 	do	do tio	Oet. 1, 1932 Apr. 1933	Do. Dec. 31, 1938 Do.	

TABLE 51.—Description of the terraces for which soil and water losses were measured 1

1 Measuring equipment consists of either 1- or 2-foot Parshall flume, float water stage recorder, silt box, and Ramser silt sampler.

148 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

					Terraces	and the second sectors	an en		Period o	f records
Watershed designation	Land slope	Area	Soil	Length	Grade per 100 feet	Ver- tical spac- ing	Cropping practice	Soil treatment	Began	Ended.
Pasture A t Pasture B	Per- cent 13,0 9.5	Acres 2.03 3 5.56	Shelby loam	Feet : 1, 710	<i>Inches</i> Variable, 0-1-2	Feel 0	Bluegrass pasture, excellent vegetation. Bluegrass pasture, excellent	None: 4-12-4 fertilizer on terrace channels and ridges. None: 4-12-4 fertilizer in waterway	Jan. 1, 1934 Jan. 1, 1932	In operation. Do.
Pasture C ‡	11.0 9.1	1, 97 2, 11	do do	2, 950	Level 7.	1	vegetation. Bluegrass pasture, excellent vegetation. Alfalfa: oats-lespedesa be- gan 1938.	None 3 tons of lime per acre in 1932; 200 pounds of 20-percent superphos-	Apr. 1, 1937 Jan. 1, 1933	Do. Do.
IJ-1	9, 2	2.13	do				Corn, onts, clover with	phate per arre in 1932; 250 pounds of 4-12-4 fertilizer per acre in 1933; 125 pounds 0-20-0 per acre with onts-lespedeza. 2.5 tons of lime per acre on strip C in 103:1 - 54 tons per acre on strip C in	July 1, 1933	Do.
Del	6.5	7.51	do				Corn. oats. wheat, clover	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, 19347	Do.
B-24 D-3	7.0 6.7	8. 03 • 4. 49	do do	³ 5, 050	3	5	with timothy. do - do - ³	pounds of 4-12-4 fertilizer per acre on wheat; 125 pounds of 20-percent superphosphate on oats. do 150 pounds of 20-percent superphos- phate per acre on oats before 1939.	July 1, 1934 July 1, 1932	Do. Do.

TABLE 52.—Description of the watersheds for which soil and water losses were measured

Pasture A contains six terraces that discharge into a common outlet.
 Total length of the six terraces on pasture A.
 The area of pasture B was 6.52 acres until the fall of 1935.
 Field D-2 contains eight terraces that discharge into a common outlet.
 Total length of the eight terraces on field D-2.
 2.12 acres prior to fall of 1938.
 Contour furrows constructed by Wooley furrowing machine in Nov. 1939
 Gorn, corn, oats, clover prior to 1937.
 4.85 acres prior to May 1934.
 Corn, soybeans, wheat, clover with timothy prior to 1936.

INVESTIGATIONS IN EROSION CONTROL

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 o	puarter	Second quarter		Third quarter		Fourth quarter		Total		Cropping	
Y car	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1931 1932 1933 1934 1935 1936 1936 1938 1937 1938 1939 1940 Total	Inches 0.17 .47 0 .02 .91 3.56 3.78 0 .75 1.16	Pounds 0 1, 806 0 15, 050 1, 570 1, 570 8, 200 0 9, 270 0, 570 42, 596	Inches 0.78 1.34 .70 2.85 11.31 .46 .53 1.13 5.10 1.70	Pounde 47, 315 38, 786 14, 945 110, 845 190, 045 5, 345 21, 065 33, 410 183, 410 46, 430	Inches 5.27 2.94 8.42 3.46 .44 2.42 .18 3.11 1.61 .82	Pounds 103, 565 62, 505 53, 675 4, 365 11, 660 2, 250 49, 730 49, 730 2, 020	Inches 7.07 .29 4.04 .40 1.11 .13 .40 .88 .17	Pounds 60.454 2,102 30,805 2,735 24,070 830 8,075 275	Inches 13. 20 5. 04 9. 41 10. 37 7. 55 4. 67 4. 64 8. 34 8. 34 3. 85	Poinds 211, 334 105, 349 130, 350 105, 515 212, 105 42, 645 31, 535 84, 000 244, 085 55, 205	Corn	Tons or bushels 20.0 44.1 43.7 0 17.8 0 41.6 4.5 16.8 22.2
Äverage	1.08	42, 320	23, 60	69,173	28.07 2.87	448, 505	14,84	129, 546 12, 954	80, 28 8, 03	1, 312, 303 131, 230	******************	
					PLOT 2							
1031 1032 1033 1034 1035 1036 1037 1039 1039 1040	$\begin{array}{c} 0.17\\.23\\0\\.05\\1.25\\2.49\\3.53\\0\\.98\\1.09\end{array}$	$\begin{array}{c} 0\\ 534\\ 0\\ 0\\ 7, 530\\ 230\\ 1, 120\\ 0\\ 4, 670\\ 1, 610\end{array}$	$\begin{array}{c} 0.80\\ 1.65\\ .82\\ 2.92\\ 8.53\\ .77\\ .67\\ 1.28\\ 5.45\\ 2,10\\ \end{array}$	$\begin{array}{c} 37,414\\ 31,311\\ 12,650\\ 95,160\\ 138,030\\ 7,890\\ 13,850\\ 27,830\\ 142,450\\ 38,780\end{array}$	$\begin{array}{r} 4.78\\ 3.63\\ 8.89\\ 3.91\\ .54\\ 3.23\\ .31\\ 2.89\\ 1.52\\ 1.11\\ \end{array}$	76, 499 63, 760 86, 850 50, 810 2, 670 13, 270 1, 710 26, 880 26, 775 3, 660	7.44 .35 .34 4.55 .64 1,37 .18 .54 .80 .18	$54, 426 \\ 2, 256 \\ 0 \\ 25, 760 \\ 2, 010 \\ 16, 480 \\ 20 \\ 670 \\ 3, 100 \\ 320$	$\begin{array}{c} 13. \ 19 \\ 5. \ 86 \\ 10. \ 05 \\ 11. \ 43 \\ 10. \ 96 \\ 7. \ 86 \\ 4. \ 69 \\ 4. \ 71 \\ 8. \ 75 \\ 4. \ 48 \end{array}$	168, 339 97, 861 99, 500 171, 730 150, 240 37, 870 16, 700 55, 380 176, 900 43, 770	Corn Corn Corn Corn Corn Corn Corn Corn Corn Corn	20.7 36.7 49.3 0 16.7 0 35.0 5.0 11.8 26.4
Total A verage	9.79 .98	15, 694 1, 569	24. 99 2, 50	33, 365 3, 337	30. 81 3. 08	352, 279 35, 228	16.39 1.64	105, 042 10, 504	81.98 8.20	1,018,380 101,838		
					PLOT 3							
1931 1932 1933 1934 1935	0.20 .14 0 .02 .75	0 8 0 3,360	0.93 ,20 ,04 1,54 10,71	29, 679 12 10 2, 870 17, 900	4.44 .96 2.07 4.02 .02	56, 309 3, 159 370 43, 610 0	5.12 0 3.48 0	21, 882 0 15, 260	10.69 1.30 2.11 9.06 11.48	107,960 3,179 380 61,740 21,260	Corn	30.6 30.9 1.61 0

PLOT 1

0

1936 1937 1938 1939 1939 1940 Total A verage	1.68 2.51 0 .67 .54 6.51 .65	70 190 230 40 3,898 390	$ \begin{array}{r} .03 \\ .43 \\ 3.06 \\ 3.55 \\ 1.37 \\ \hline 21.86 \\ 2.19 \\ \end{array} $	10 2, 530 24, 850 2, 240 7, 580 87, 681 8, 768	.12 .31 3.36 .51 1.16 16.97 1.70	40 1,090 4,310 70 1,660 110,708 11,070	.03 .16 .04 .01 0 8.84 .88	0 10 0 0 37, 162 3, 716	$ \begin{array}{r} 1.86 \\ 3.41 \\ 6.46 \\ 4.74 \\ 3.07 \\ \overline{54.18} \\ 5.42 \\ \end{array} $	120 3, 820 29, 170 2, 540 9, 280 239, 449 23, 945	Meadow Corn Wheat Meadow Corn	1,72 37.0 4,0 1.10 26.1
		р нат С.			PLOT 4							1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.
1931 1932 1933 1934 1935 1936 1936 1937 1938 1939 1938 1939 1940 1940 1940 1940 1940 1940	$\begin{array}{c} 0.03 \\ .13 \\ 0 \\ .03 \\ .41 \\ 2.07 \\ 2.52 \\ 0 \\ .31 \\ 1.05 \\ \hline 6.55 \\ .66 \end{array}$	0 397 0 250 60 180 0 10 510 1,407 141	$\begin{array}{c} 0, 01 \\ .17 \\ .20 \\ 2.48 \\ 5.33 \\ .31 \\ .11 \\ .05 \\ 4.15 \\ 2.76 \\ \hline 15.57 \\ 1.56 \end{array}$	0 10 410 24, 140 610 160 20 38, 330 6, 330 70, 410 7, 041	$1.18 \\ 05 \\ 0.89 \\ 2.75 \\ 01 \\ 1.86 \\ 05 \\ 11 \\ 1.33 \\ .37 \\ 14.60 \\ 1.46 \\ 1$	3, 869 3 55, 180 2, 870 0 6, 110 50 50 8, 960 200 77, 292 7, 729	$\begin{array}{c} 3.19\\ 0\\ .11\\ 1.92\\ 0\\ .76\\ .01\\ 0\\ .26\\ 0\\ \hline \\ 6.25\\ .63\\ \end{array}$	2, 621 0 200 0 1, 410 0 710 0 710 0 - 4, 941 494	$\begin{array}{r} 4.41\\ .35\\ 7.20\\ 7.18\\ 5.75\\ 5.00\\ 2.69\\ .16\\ 6.05\\ 4.18\\ \hline 42.97\\ 1.30\\ \end{array}$	$\begin{array}{c} 6,490\\ \pm10\\ 55,590\\ 27,210\\ 650\\ 8,190\\ 390\\ 70\\ 48,010\\ 7,040\\ \hline 154,050\\ 15,405\\ \end{array}$	Wheat	41.4 1.63 43.3 8.7 1.38 0 20.7 1.48 21.4 10.0
					PLOT 5							
1931 1032 1033 1034 1035 1036 1037 1038 1039 1039	0.03 .14 0.06 .12 3.03 3.29 0.06 .68 .99	0 13 0 0 70 1,220 0 1,620 100	$\begin{array}{c} 0.03 \\ 1.66 \\ .23 \\ 1.60 \\ 5.68 \\ .22 \\ 1.55 \\ .99 \\ 5.83 \\ 1.48 \\ \hline 10.27 \end{array}$	0 9,321 140 510 8,060 240 10,250 8,920 38,380 880	0.61 2.81 2.60 .12 .07 3.02 .62 3.54 1.14 .07	1, 21230, 3266601902, 3102, 31024, 4802, 2000	4,92 0 0 1,15 ,02 1,20 0 2,01 ,26 0 7,59	2, 217 0 120 70 4, 790 0 10 140 0 7, 247	5.59 4.61 2.83 2.03 5.89 7.47 5.48 4.54 7.91 2.54	$\begin{array}{r} 3,429\\ 39,660\\ 800\\ 820\\ 8,320\\ 7,410\\ 12,120\\ 34,400\\ 42,340\\ 880\\ \hline \end{array}$	Meadow Corn Meadow Corn Wheat Corn Wheat Meadow	2.68 49.7 10.6 .34 15.0 22.5 .57 4 1.7 .99
Average	8. 34 . 83	3,033 303	19.27	7,670	14.60	6, 322	7. 58 . 76	7,347 735	49.79	15,018		

č

See footnotes at end of table.

INVESTIGATIONS IN EROSION CONTROL

	1. A.			1	PLOT 6							
	First o	juarter	Second	quarter	Third	juarler	Fourth quarter		Total		Cropping	5
Yoar	Runofi	Soil loss	Runoff	Soil loss	Runoft	Soil loss	Runoft	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
931	Inches 0.01 .07 0 .03 .28 2.25 3.71 0 .01 .95	Pounds 0 6 0 10 150 2,010 0 1,680 140	Inches 0.01 1.30 .05 1.51 5.24 .05 .59 .75 4.64 1.71	Pounds 0 10,017 10 930 12,950 0 2,470 8,890 50,110 1,940 87,377	Inches 0.47 1.52 2.80 .05 1.77 .68 2.47 1.32 .32	Pounds 795 9,856 1,050 220 180 3,180 920 22,660 5,630 0 44,491	Inches 2.79 0 1.46 0 .93 .08 .01 .32 0	Pounds 1, 175 0 0 150 0 5, 540 0 250 0 7, 125	Inches 3. 28 2. 89 2. 85 3. 06 5. 57 5. 00 5. 06 3. 23 6. 89 2. 98 40, 81	Pounds 1, 970 19, 879 1, 060 1, 300 13, 140 8, 930 5, 400 31, 550 57, 670 2, 080 142, 989	Meadow Corn Wheat Meadow Corn Wheat Meadow Wheat Meadow	Tons or bushels 3, 14 51, 6 24, 1 .52 12, 9 31, 7 1, 54 1, 0 1, 6 .8
Total. Average		4,000	1.58	8,738	1.15	4, 450	. 60	712	4.08	14, 299		-
					PLOT 7							
1931	$\begin{array}{c} 0 \\ 0 \\ 0 \\ .04 \\ .74 \\ 1.45 \\ 2.20 \\ 0 \\ .63 \\ .83 \end{array}$	0 1 0 0 10 30 160 0 10 40	$\begin{array}{c} 0.\ 03\\ .31\\ .02\\ 1.\ 57\\ 6.\ 15\\ .02\\ .06\\ .03\\ 1.\ 29\\ .07\\ \end{array}$	0 18 0 240 10 40 10 140 0	$\begin{array}{c} 0.54\\ .04\\ 2.33\\ .05\\ .01\\ .04\\ .03\\ .04\\ .02\\ 0\end{array}$	$\begin{array}{c} 548\\ 2\\ 510\\ 130\\ 0\\ 50\\ 30\\ 10\\ 0\\ 0\\ 0\\ 0\\ 0\\ \end{array}$	0.57 0 0 1.18 0 0 .01 0 0 0 0	253 0 200 0 0 0 0 0 0 0 0 0	$1.14 \\ .37 \\ 2.35 \\ 2.84 \\ 6.90 \\ 1.51 \\ 2.36 \\ .07 \\ 1.94 \\ .90$	$\begin{array}{r} 801\\ 21\\ 510\\ 390\\ 250\\ 90\\ 230\\ 230\\ 150\\ 40\\ \end{array}$	Alfaifa do do do do do do do do do	- 2, 21 - 5, 68 - 2, 56 - 3, 00 - 1, 88 - 2, 9 - 3, 0 - 4, 3 - 4, 3
Total Average	5.97	$251 \\ 25$	9.49 .95	518 52	3. 10 . 31	1,280 128	1.76 18	453 45	20.38 2.04	2, 502 250		-
					PLOT 8				<u></u>			<u> </u>
1931 1632 1933	0.21	0 13 0	0.06 .31 .02	0 40 0	$\begin{array}{c} 0.52\\ 6\\ 2.70\end{array}$	934 8 360	4.11 0 0	816 0 0	4.90 .47 2.72	$1,800 \\ 61 \\ 360$	Bluegrass ² do	

TABLE 53. -Seasonal and annual runoff and soil loss i and crop yields from control plots 1 to 10 of plot series 1, 1932-40 2-Continued

1934 1935 1936 1937 1938 1939 1939 1940 Total A verage	. 06 .10 2.10 2.43 0 .71 .93 6.64 .66	0 0 30 00 10 0 113 11	1.50 5.26 .02 .04 .04 1.27 .08 8.60 .56	$\begin{array}{c} 170\\ 220\\ 10\\ 10\\ 10\\ 40\\ 0\\ \hline \\ 500\\ 50\\ \end{array}$.05 .01 .05 .0 .02 0 .02 0 .02 0 .3.44 .34 PLOT 9	170 0 40 0 0 0 0 0 0 1,562 150	$ \begin{array}{c} 1.54\\ 0\\ .01\\ .06\\ 0\\ 0\\ 0\\ 5.72\\ .57\\ \end{array} $	90 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	3, 15 5, 37 2, 18 2, 53 0, 07 2, 00 1, 01 24, 40 2, 44	430 220 80 70 10 50 0 3,051 308	do
1031 1032 1032 1033 1034 1035 1036 1036 1037 1038 1039 1040	$\begin{array}{c} 0.14\\ .01\\ 0\\ .40\\ 1.97\\ 2.68\\ 0\\ 1.02\\ 1.74\\ \hline 7.96\\ .80\\ \end{array}$	0 3 0 0 11, 200 3, 140 4, 770 4, 810 6, 650 30, 573 306	$\begin{array}{c} 0.03\\ 1.75\\ .88\\ 2.26\\ 14.15\\ .95\\ .98\\ 2.03\\ 5.94\\ 3.07\\ \hline \end{array}$	$\begin{array}{r} 27,409\\ 33,309\\ 17,620\\ 61,560\\ 260,430\\ 8,460\\ 22,100\\ 59,180\\ 158,840\\ 46,230\\ \hline \\ 605,408\\ 69,541\\ \end{array}$	$\begin{array}{c} \textbf{6.44}\\ \textbf{4.76}\\ \textbf{9.88}\\ \textbf{3.86}\\ \textbf{.94}\\ \textbf{2.94}\\ \textbf{.93}\\ \textbf{3.89}\\ \textbf{1.84}\\ \textbf{1.89}\\ \hline \textbf{37.37}\\ \textbf{3.74} \end{array}$	$\begin{array}{c} 135, 520\\ 132, 743\\ 271, 060\\ 84, 740\\ 15, 130\\ 22, 180\\ 12, 010\\ 92, 900\\ 37, 300\\ 6, 780\\ \hline \\ 810, 753\\ 81, 075\\ \end{array}$	2.90 .33 0 .04 .33 0 .33 .68 .04 .911 .91	$\begin{array}{r} 47,551\\ 3,955\\ 0\\ 23,940\\ 250\\ 5,450\\ 0\\ 5,450\\ 0\\ 770\\ 4,720\\ 0\\ \hline \\ 86,636\\ 8,664\end{array}$	10.476.8510.7610.0215.536.694.596.259.486.7487.388.74	210, 870 170, 100 288, 650 170, 240 287, 010 39, 230 38, 970 152, 940 205, 670 59, 660 1, 623, 370 162, 337	Fallow
1931 1932 1933 1934 1935 1936 1937 1938 1939 1939 1939 1940 Total	$\begin{array}{c} 0.38\\ .03\\ 0\\ .03\\ .35\\ 4.95\\ 4.77\\ 0\\ 1.66\\ 3.06\\ \hline 15.23\\ 1.52\\ \end{array}$	0 10 0 2,130 3,500 10,750 9,030 11,870 37,290 3,729	$\begin{array}{c} 0.03\\ 1.98\\ .69\\ 2.94\\ 12.94\\ 12.94\\ .71\\ 1.32\\ 6.13\\ 3.27\\ \hline 30.84\\ 3.08\\ \end{array}$	0 14, 258 10, 050 60, 860 212, 480 3, 650 15, 070 22, 030 131, 230 31, 280 500, 908 50, 091	PLOT 10 5.54 3.47 10.25 2.83 .67 79 3.06 1.53 1.39 31.80 3.18	111, 476 70, 576 203, 320 42, 970 5, 070 13, 010 5, 590 46, 720 25, 720 6, 690 531, 142 53, 114	2.87 .20 0 4.93 .09 .64 0 .14 .15 0 9.02 .90	36, 415 2, 025 0 17, 080 230 0 610 1, 540 0 60, 860 6, 086	S. 82 5. 68 10. 94 10. 73 14. 05 8. 69 6. 27 4. 52 9. 37 7. 72 8. 68	147, \$\u00f31 \$6, \$69 213, \$70 120, 910 23, 120 31, 410 69, 360 167, 520 49, 840 1, 130, 200 113, 020	Fallow

Ų,

Sandan Berten and Bertan Burner Bertan Bertan Barren Bertan Bertan

Soil loss in pounds per acre, water loss in inches per acre.
 Bluegrass established by seeding with timothy and not harvested until 1935.

INVESTIGATIONS IN EROSION CONTROL

154 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

 TABLE 54.—Average seasonal and annual runoff and soil loss 1 from plot series 1 for 10-year period 1931-40
 Y

ł

Plat	First	marter	Second	quarter	Third	quarter .	Fourth	quarter	Tu	ital
	Rimon	Soil loss	Книол	Soit loss.	Runoff	soit loss;	Runoff	Soil loss	Runoff	Soil toss
1	Inches 1,08 .98	Tona 2, 126 , 785	Inches 2, 50 2, 50	Tons 34,586 27,268	Inches 2,87 3,08	Tons 22,425 17,614	Inches 1.49 1-64	Tons 6, 478 5, 252	Inches 8.03 8.20	Tons 05.015 50.019
3, 4. 5, } (corn), }	. 64) . 5 3	.016 .288	1, 73 2, 57	5.415	2,65 1,55	11, 449	1.60	1,968	5, 98 5, 61	15, 848
3, 4, 5,} (mendow), }	, 73 - N	. 115	1,39	; 711 ; • • • • •	.43	. 130	. 62	. 1)7	3.17	1.073
6	- 79 - 60 - 67 - 79 1. 52	. 135 . 200 . 013 . 005 1. 520 1. 565	1, 60 , 95 , 86 3, 30 3, 68	4, 369 (027 025 34, S1S 25, 046	1, 46 1, 14 , 32 , 35 3, 74 3, 15	3, 101 2, 225 , 064 , 078 40, 537 26, 558	, 15 , 56 , 18 , 58 , 91	367 356 023 045 4,332 3,043	4, 98 4, 08 2, 05 2, 46 8, 74 8, 69	7.511 7.150 127 156 81.216 50.513

1 Soll 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 iv-year period, 1981-40

CORN YEARS

	First	quarter	secon	l quarter	Third	quarter	Fourt	h qua, ter	 T	otal	Stold
Year	Pun- off	Soil loss	Run- off	Soil loss	Run- off	Soil loss	Run- off	Soil loss	Run- off	Soil loss	per acre
		, ,				,	<u> </u>			·	
	Inches	Pounds ;	Inches	Pounds.	Inches	Pounds	Inches	Pounds	Inches	Pounds	hushels
1931	0,20	0	0.73	29, 679	4.41	56, 399	5.12	21, 562	10, 69	107.969	30.4
1932	- 14	13	<i>.</i> 6	9,321	2.81	30, 326	0		4.61	39,660	49.7
1933	<u> </u>	· () ·	(<u></u>)	410	6, 89	55,180	.11	: e.	7,20	1 55, 590	43.3
1934	02	0	0.54	2,870	4.112	43,610	3.48	15,260	9.06	-61,740	, ù
1076	21.	;	5.155	8,660	- 07	194	. 02	. TL 1	5.89	\$, 320	15.0
1027	1 2.07	100	3I	010	1.86	6, 140	. 76	1,410	5.00	8, 190	0
1038	1 2.51	101	. 43	2,340	.31	1,090	. 16	10	3,41	3,520	37.0
1939	· "31	10	1 15	38 330	0.01	20,470	.01	-10	-1.54	. 34,400	4.0
1940	54	. 40	1.37	T 350	1+3-5	1 660	U	· - 211	0.07	45,010	21,4
								14	3.07	9,480	20, 1
Total	5.91	313	16.23	105.310	26.43	225, 995	9,92	39 352	59 59	376 970	,
A verage	. 50	31	1.62	10,531	2.64	22.900	. 60	3.935	5.95	37, 697	
				:							,
				WHE	AT AT	ARS					
					··· - · ·						
1931	0.03		0.01		1 117			0.00.			·
1932	1.1	2	90		1.13	3, 303	3, 19	2,621	4, 41	0, 100	41.4
1933		6	- 59	เม่ต์	- 1 KO	0,100	X		1,00	3, 1, 11	00.0
1934	. (3	ű	2.48	24, 140	4, 75	2 570	1 99	900		07.000	10.0
1935	. 75	3, 300	10.71	17,9441	- 12	-,	1.0-	200	11.45	21, 210	19.6
1936	3.03	70	. 22	240	3.02	2.310	i, 20	4, 790	7.47	7 410	
1937	2.52	150	. 11	160	. 05	50	.01	ü	2.69	390	20.7
1938	0	u	3. (4)	24.850	3, 36	4,310	. 64	10	6,46	29, 170	4.0
1939.	- 68	1,620	5.53	38, 380	1.14	2,200	. 26	I 10	7.91	42, 340	1.7
1846	1,05	510	2,76	6, 330	. 37	200	0	0	4.48	7,040	10.0
(Pot of	C fel			110 120							
A VOLGOO	0,20	01.140	23, 01	112,102	30,40	19,628	6, 62	7, 761	55. 9L	145, 289	*******
- A SCIAGE STOL			- - , 00	11.410	1.00	1, 11,-1	. 00	714	0, 39	14,529	
				MEAD	OW Y	EARS					
1021	0.09		6.425	·							
1991	0.03	; (). • ••••••	0.03		0. 61	1,212	4.92	2, 217	5,59	3, 429	2. (8
1932	10	397	- 14	10	. 65	3	11		. 35	-110	1.63
1071	 00	· .	- 04	510	$= 2.0_{\rm f}$	170			2.11	350	1.61
1035	41	่าณ์	5 23	100	- 12	10-1	1:10	120	2.03	520	- 34
1936	1.68	70	113	. 10	19	ŭ.	" 07	1	0.10	100	1.05
1037	3, 29	1.200	1.55	10, 250	62	650	100	- <u>n</u>	. 1.60 2.19	12 120	1.12
1038	0	. <u>0</u> .	.05	20		50	0	ă	16	70	1.49
1939	. 67	230	3.55	2,240	, 5L	70	. di	ö	4.74	2,540	1 10
1940	. 99	110	1.45	770	. 67	Ű	0	ö	2.54	850	. 09
(D		· · · · · · · · · · · · · · · · · · ·		e de la companya de l		·					
Total	7.20	2, 277	13. 53	14, 220	4, 29	2, 585	0.13	2,337	31, 51	21, 419	·
Average	1 73	: 22S -	1.35	÷ 1,422	- 13	259	. 61	234	3.15	2,142	·

¹ Soil loss in pounds per acre, water loss in inches.

						PLOT A							مر میکیود و آمر
		First (poarter	Second	quarter	Third	quarter	Fourth	quarter	Ťc	tal	Croppir	Ig
	Year	Runoff	Soil lass	Runoff	Sail loss	Runoff	Soil loss	Runoff	Sail lass	Runoff	Sail loss	Crop kind	Yield per acre
1932 1933. 1934 1935. 1936. 1937. 1938. 1939		<i>Inches</i> 0 0 1,56 0 4,31 0 .65	Pounds 0 0 9, 875 0 6, 175 0 3, 092	Inches 2,45 1,28 2,96 13,51 1,36 1,18 2,02 6,15	Pounds 67,028 25,273 87,527 160,867 11,299 16,192 28,804 122,905	Inches 6, 17 9, 91 3, 97 72 3, 23 , 65 2, 56 1, 27	Pounds 127, 097 145, 963 44, 353 3, 571 17, 371 2, 414 22, 015 14, 848	Inches 0.87 .03 4.13 .27 .79 0 .46 .75	Pounds 2,853 0 6,909 85 4,749 0 705 1,546	Inches 9,49 11,22 11,06 16,06 5,38 6,14 5,04 8,85	Pounds 196, 978 171, 236 138, 789 174, 401 33, 410 24, 781 51, 584 142, 391	Fallow Corn do do do do do do do	Tons or bushels 9,0 0 21,1 0 28,1 4,8 1,4
	Total Average	6.55 .82	19, 142 2, 303	30, 91 3, 86	519, 895 64, 987	28, 48 3, 56	377, 632 46, 829	7.30 .91	16, 910 2, 114	73. 24 9. 16	933, 579 116, 697		
	analas () <u>analas provinsi dalam sugali</u> suga ana (1922) kanada <u>ngan ja</u> (1976)				1	PLOT B	ا بید بر با بعومحند	, en fi			میں ہے۔ میں پیفرینہ	وموجد ومنار المراجع والمحاد	e e e e e e An an
1932 1933 1934 1935 1936 1937 1938 1939		0 0 0 .43 0 3.54 0 .12	0 0 8,026 0 5,538 0 279	1,99,943,3611,08,63,891,554,83	$\begin{array}{c} 29,672\\ 21,407\\ 46,673\\ 154,667\\ 4,705\\ 16,773\\ 22,884\\ 110,983\end{array}$	3.60 9.39 3.15 .43 2.58 .34 2.61 1.31	96, 485 78, 736 41, 659 1, 777 9, 298 821 21, 904 17, 901	0. 13 . 02 2. 53 . 05 . 81 0 . 48 . 74	$1,371 \\ 0 \\ 2,192 \\ 16 \\ 4,072 \\ 0 \\ 686 \\ 1,976$	$5.72 \\10.35 \\0.04 \\11.99 \\4.02 \\4.77 \\4.64 \\7.00$	$127,528\\100,143\\90,524\\164,486\\18,135\\23,132\\45,474\\131,139$	Fallow Corn do do do do do do do do	$ \begin{array}{c} 28,7\\0\\16,5\\0\\30,2\\3,2\\3,7\\\end{array} $
	Total. Average	4, 09 , 51	13, 843 1, 730	25. 27 3. 10	407, 824 50, 978	23, 41 2, 93	268, 581 33, 573	4.70 .59	10, 313 1, 287	57, 53 7, 19	700, 561 87, 750		
Se traduce	an faile an	19. ga in in 1044 in - 6144				PLOT 1							
1932, 1933 1934, 1935, 1936,		0 0 0 0 0 0	0 0 0 984 0	0 .03 .84 14.05 0	41 0 2, 378 47, 003 10	0 1.68 5.30 .57 .25	0 1,036 31,148 47 99	0 0 5.51 ,23 ,14	0 0 7, 568 0 99	0 1, 71 11, 71 15, 45 , 39	41 1,036 41,094 48,034 208	Meadowdo Corn Oats Meadow	0.68 1.76 0 30.0 1.21

ب

155

۱.,

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

		First o	uarter	Second	quarter	Third	quarter	Fourth	quarter	'rc	otal	Cropping	; ;
- 11-1 - 11-1 - 11-1 - 11-1	1.CBF	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per ncre
1937. 1938 1939 1940		Inches 1.04 0 .50 .14	Pounds 5 0 3, 191 36	Inches .07 .89 5.17 .92	Pounds 52 11, 295 48, 562 342	Inches .06 3.58 1.30 .01	Pounds 21 31,004 4,077 5	Inches 0 .54 .25 0	Pounds 0 544 SS 0	Inches 1, 17 5, 01 7, 22 1, 07	Pounds 78 42, 843 55, 918 383	Mendow Corn Oats Mendow	Tons or bushels 1, 13 .5 2.5 .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. 1933 1934 1935. 1936. 1937. 1938 1939. 1940.		$ \begin{array}{c} 0 \\ 0 \\ 0 \\ 2 \\ 99 \\ 0 \\ 39 \\ 36 \\ \end{array} $	0 0 0,760 0 871 0 1,865 93	$1.23 \\ .08 \\ 3.33 \\ 0.09 \\ .01 \\ .47 \\ .77 \\ 5.04 \\ 1.68 \\ 1.68 \\ 1.23 \\ 1.08$	$1, 037 \\ 0 \\ 29, 350 \\ 80, 492 \\ 36 \\ 1, 669 \\ 7, 300 \\ 61, 751 \\ 880 \\ 880$	1.3710.012.45.11.70.302.871.3S.02	$\begin{array}{c} 740\\ 1,528\\ 32,971\\ 88\\ 280\\ 57\\ 25,459\\ 6,263\\ 31 \end{array}$	0 2.17 0 .3S 0 .41 .02 0	0 0 18, 591 0 451 0 461 31 0	$\begin{array}{c} 2.\ 60\\ 10.\ 09\\ 7.\ 95\\ 10.\ 39\\ 1.\ 09\\ 3.\ 76\\ 4.\ 08\\ 6.\ 83\\ 2.\ 06\end{array}$	$\begin{array}{c} 2,377\\ 1,528\\ 80,912\\ 87,340\\ 767\\ 2,597\\ 33,220\\ 69,910\\ 1,004 \end{array}$	Mendow do Coru Onts. Mendow. do Corn. Onts. Mendow.	$\begin{array}{c} 0.\ 67\\ .\ 74\\ 0\\ 6.\ 5\\ .\ 66\\ .\ 06\\ 2.\ 1\\ 1.\ 3\\ .\ 16\end{array}$
	Total.	4.33	9, 589	22.30	183, 115	19.21	67, 417	3,01	19, 534	48.85	279, 655		
••••••	n an	ار. مورد به محمد مکن	a da ang ang ang ang ang ang ang ang ang an	n an	en strand i	PLOT 3	en en en L'arrende					ی را بیند میشد محمد در با مراد میشد است. از این	
1932. 1933. 1934. 1935. 1936. 1937. 1938. 1939. 1940.		$\begin{array}{c} 0 \\ 0 \\ 0 \\ .22 \\ 0 \\ 3.44 \\ 0 \\ .36 \\ .50 \end{array}$	0 0 4,771 0 1,819 0 1,616 62	$\begin{array}{c} 0.\ 04\\ .\ 03\\ 1.\ 68\\ 7.\ 80\\ 0\\ .\ 08\\ .\ 90\\ 3.\ 76\\ .\ 52\\ \end{array}$	58 124 3, 947 31, 318 5 109 3, 617 15, 235 217	$\begin{array}{c} 0 \\ 2.34 \\ 2.00 \\ 0 \\ .03 \\ 0 \\ 2.47 \\ .62 \\ 0 \end{array}$	0 3, 539 18, 026 0 67 0 21, 491 1, 409 0	$\begin{array}{c} 0 \\ 0 \\ 2 \\ . 43 \\ 0 \\ . 01 \\ 0 \\ . 20 \\ 0 \\ 0 \end{array}$	$\begin{array}{c} 0\\ 0\\ 11,479\\ 0\\ 42\\ 0\\ 176\\ 0\\ 0\\ 0\\ 0\end{array}$	$\begin{array}{c} 0.01\\ 2.37\\ 6.11\\ 8.08\\ .04\\ 3.52\\ 3.63\\ 4.74\\ 1.02 \end{array}$	$\begin{array}{c} 88\\ 3, 663\\ 33, 452\\ 36, 080\\ 114\\ 1, 928\\ 25, 284\\ 18, 260\\ 270\end{array}$	Meadow do Corn Onts. Meadow do Corn Onts. Meadow	$1, 47 \\ 1, 16 \\ 0 \\ 26, 7 \\ 1, 08 \\ .36 \\ 1, 6 \\ 6, 4 \\ .60$
	Total	4, 52	8,268	14, 03	54, 660	7.46	44, 532	2,64	11,697	29. 55	119, 157		

- . - A

1932 1933	0 0 0 2, 28 0 2, 93 0 . 01 . 87 4. 09	0 0 2, 207 0 2, 741 57 2, 461 7, 466	$\begin{array}{c} 0.05\\ 82\\ 1.89\\ 8.96\\ .21\\ .79\\ .82\\ 4.58\\ 1.88\\ \hline 20.00 \end{array}$	93 969 29, 417 10, 443 549 5, 156 716 67, 438 7, 408 122, 189	0 7,78 2,16 0 1,23 ,26 1,15 .77 .14 13,49	0 \$1,493 5,424 0 1,622 145 \$60 5,905 124 32,579	0 .21 3.37 0 .70 .01 0 .50 0 4.79	0 2, 507 0 6, 632 5 0 1, 109 0 10, 253	$\begin{array}{c} 0.05\\ 8.81\\ 7.42\\ 9.24\\ 2.14\\ 3.99\\ 1.97\\ 5.86\\ 2.59\\ 42.37\\ \end{array}$	93 10, 462 37, 348 12, 650 8, 803 8, 047 1, 582 74, 509 9, 993 172, 487	Mendow Corn Onts Meadow Corn Onts Meadow Corn Onts	1.47 23.6 3.6 .30 47.8 .55 13.9 10.4
			an a		PLOT 5		an a					
1932 1933 1934 1935 1936 1937 1937 1938 1939 1939 1939 1940 Total	* 0 0 23 2,58 0 .79 3.60	0 0 870 0 1, 985 0 0 2, 916 5, 771	$\begin{array}{c} 0\\ .37\\ 2.15\\ 6.00\\ .32\\ .77\\ .62\\ 4.66\\ 1.44\\ 16.93\end{array}$	$\begin{array}{c} 41\\ 1,476\\ 21,404\\ 2,891\\ 974\\ 4,850\\ 684\\ 75,664\\ 7,203\\ 115,247\end{array}$	$\begin{matrix} 0 \\ 4.79 \\ 1.28 \\ 0 \\ 1.40 \\ .41 \\ .02 \\ .68 \\ .37 \\ -9.04 \end{matrix}$	0 24, 085 2, 052 0 1, 974 311 10 6, 805 306 36, 536	0 09 1 22 01 58 04 0 . 49 0 2. 43	0 0 1, 503 0 4, 964 57 0 1, 130 0 7, 654	0 5, 25 5, 65 0, 81 2, 39 3, 80 -, 64 5, 83 2, 60 	$\begin{array}{r} 41\\ 25,534\\ 25,859\\ 3,761\\ 7,912\\ 7,203\\ 694\\ 83,689\\ 10,485\\ 165,208\end{array}$	Meadow Corn Oats Meadow Corn Oats Meadow Corn Oats	32.1 3.2 0 52.6 15.4 14.7
	بیر بچوندیوشنده				PLOT 6							
1032 1033	0 0 0 2,47 0 2,47 0 ,18 ,93 3,90	0 0 798 2,637 0 52 1,948 5,435	0.08 .55 3.67 6.85 .50 .68 .00 4.41 .52	41 1, 604 23, 437 1, 465 1, 176 3, 399 99 60, 601 1, 135	0 6,76 1,30 0 .92 .29 0 .54 .02 9,\$3	0 20, 809 2, 331 0 1, 637 166 0 4, 667 57 29, 667	0 .11 2.62 0 .39 .01 0 .22 0 3.35	0 736 0 4,444 5 0 373 0 5,558	$\begin{array}{c} 0.08\\ 7.42\\ 7.59\\ 7.17\\ 1.81\\ 3.45\\ .09\\ 5.35\\ 1.47\\ 34.43\\ \end{array}$	$\begin{array}{r} & 41\\ 22,503\\ 35,504\\ 2,263\\ 7,357\\ 6,207\\ -99\\ 65,693\\ 3,140\\ 142,707\end{array}$	Mendow Corn Meadow Corn. Oats Mendow Corn Oats Oats	30.4 4.3 0 55.0 12.6 24.8

PLOT 4

See footnote at end of table.

INVESTIGATIONS IN EROSION CONTROL

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

	First (narter	Second	quarter	Third	quarter	Fourth	quarter	т	otal	Croppin	K
Year	Runoff	Soil loss	Runoff	Soll loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1932 1933 1934 1935 1936 - 1937. 1937. 1938 1930 1940 T ^o tal. Average	<i>Inches</i> 0 0 0 0 81 0 14 39 1, 34 15	Pounds 0 0 0 176 21 36 233 20	Inches 0.09 07 2.29 0.3.49 0 0.04 02 1.51 0 7.51 .83	Pounds 119 0 435 217 0 10 0 0 0 0 0 781 87	Inches 0 1, 57 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Pounds 0 446 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	<i>Inches</i> 0 2, 13 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Pounda 0 0 135 0 0 0 0 0 0 0 0 0	Inches 9,09 1,64 4,43 3,49 0 .85 .02 1,65 .39 12,56 1,40	Pounds 119 446 570 217 5 186 0 21 36 1,600 178	Mendow	Tons or bushels
					PLOT 8		· · · · · · · · · · · · · · · · · · ·			• • • • • • • • • • • • • • • •		
1930. 1937. 1938. 1939. 1940. 1940. Total. A verage .	0 2. 84 0 . 80 . 59 4. 29 . 86	0 S, 005 0 383 36 S, 424 1, 685	0, 25 1, 31 80 2, 73 .01 5, 10 1, 02	544 6, 482 1, 549 2, 093 0 10, 668 2, 134	$0.25 \\ 01 \\ 05 \\ 46 \\ 0 \\ .77 \\ .15$	$244 \\ 93 \\ 52 \\ 192 \\ 0 \\ 581 \\ 116$	0.32 0 0 0 0 0 0 0 0	2, 741 0 0 0 2, 741 518	0.82 4,16 .85 4.05 .60 10.48 2.10	3,52914,5801,6012,66836 $22,4124,483$	Onts: lespedeza do do do do	0.8 1.04 2.32 ,91 1.64

PLOT 71

1 Soil loss in pounds per acre; water loss in inches.

This plot was not harvested.

158 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

	First o	unrter	Second	quarter	Third	quarter	Fourth	quarter	То	tul	Croppin	g
Year	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runofi	Soil loss	Crop kind	Yield per acre
933 1934 1935 1936 1937 1937 1938	<i>Inches</i> 0 44 0 1,65 0 0 7	Pounds 0 6, 802 933 0 176	Iuches 0, 29 1, 48 8, 50 - 64 - 58 1, 58 5, 05	Poands 4, 100 39, 286 80, 870 6, 926 11, 822 33, 741 436, 316	Inches 6, 47 3, 70 16 1, 36 1, 36 17 3, 09 , 52	Pounds 51, 181 53, 355 889 6, 782 784 49, 187 5, 769	Inches 0.06 2.42 0 .31 0 .27 .17	Pounds 1, 850 2, 204 0 339 282	Inches 6, 82 7, 60 9, 19 2, 31 2, 40 3, 49 5, 81	Pounds 55, 581 94, 491 88, 561 15, 002 13, 539 83, 277 142, 543	Corn Corn Corn Corn Corn Corn Corn Corn	Tons or bushels 50.1 0 10.0 0 30 7 37.9
Total Average	2.16 .31	7, 911 1, 130	$\begin{array}{c}18,21\\2,60\end{array}$	$313,061 \\ 44,723$	15, 47 2, 21	168, 247 24, 035	3. 23 46	4, 675 668	39, 07 5, 58	493, 894 70, 556		
					PLOT 1					nel e e Le constant Alton de le t		
833 934 935 936 937 937 938 	0 76 0 3, 17 .00 .07	0 0 16, 750 9 7, 985 0 196	$\begin{array}{c} 0.87\\ 3.30\\ 10.52\\ .75\\ .82\\ 1.37\\ 5.51\end{array}$	$\begin{array}{c} 11,503\\ 48,000\\ 171,950\\ 9,184\\ 23,203\\ 38,465\\ 179,550\end{array}$	14. 07 4. 58 58 1. 84 24 3. 51 88	84, 228 70, 583 2, 297 7, 702 701 55, 716 12, 121	$\begin{array}{c} 0.16\\ 2.35\\ 0.03\\ 55\\ 0\\ .55\\ 0\\ .56\\ .77\end{array}$	0 3, 062 0 3, 024 0 748 3, 327	$\begin{array}{c} 12.10\\ f0.23\\ 17.89\\ 3.14\\ 4.23\\ 5.44\\ 7.23\end{array}$	95, 731 121, 645 190, 997 19, 910 31, 859 04, 929 195, 194	Corn Corn Corn Corn Corn Corn Corn Corn	56.0 0 8.5 0 31.8 2.3 8.2
Total Average	4.00 .57	24, 031 3, 562	29, 14 4, 16	481, 855 68, 835	$\frac{22.70}{3.24}$	233, 348 33, 335	4, 42 . 61	10, 161 1, 451	60. 26 S. 61	750, 295 107, 185		
				1	чот л	an anna a'				fan de troch Service Altre de		
932. 933. 934. 935. 936. 936. 937. See footnote at and of table	0 0 0 12 0 2,40	0 0 139 0 3,694	1.54.921.523.13.901.55	34, 748 8, 991 1, 069 16, 805 11, 765 26, 005	0, 09 4, 89 , 47 , 10 4, 25 , 88	$\begin{array}{c} 31, 816\\ 5, 405\\ 233\\ 604\\ 23, 050\\ 604\end{array}$	0 .00 1.64 .12 1.46 .08	0 472 847 27, 083 113	2, 53 5, 51 3, 63 3, 47 6, 61 4, 91	66, 564 14, 396 1, 774 18, 395 61, 898 30, 416	Soybeans Oats. Meadow. Corn Soybeans Oats	$\begin{array}{c c} 2.15 \\ 34.8 \\86 \\ 15.6 \\ 0 \\ 71.6 \end{array}$

TABLE 57 .- Runoff and soil loss ' by seasons and years, and crop yields from plots .1-1, 1, A, B, 2, and 3 of series 3 PLOT A 1

Ð

159

1

\c

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

	First q	uarter	Second	quarter	Third	quarter	Fourth	quarter	To	tal	Cropping	
Year	Runofí	Soll loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soll loss	Crop kind	Yield per acre
103\$ 1930	Inches (1 . 11	Pounds 0 30	Inches 1, 47 5, 62	Pounds 1, 745 47, 035	Inches 1, 25 . 87	Pounds 512 5, 253	Inches 0.03 .71	Pounds 7 -1, 119	Inches 2.75 7.31	Pounds 2, 264 53, 440	Meadow Corn	Tons or bushels 0.87 26, 1
Total Average	2.63 .33	3, 863 483	$\begin{array}{c} 16.65\\ 2.08\end{array}$	148, 166 18, 521	13.70 1.71	67, 477 8, 435	4.04 .50	29, 641 3, 705	37.02 4.63	249, 147 31, 143		
<mark>en negocijan po svojen svoje</mark> na svoje na poslava svoje po negocija po kontra na svoje na svoje na svoje na svo Na		la services e e e e			ргот в				n en lan en la general. Tr	en former en der er bleider partiet. Eine der eine der er bestehen er bei der eine der er bestehen der er bestehen er bei der er bestehen		
1932 1933 1934 1934 1935 1935 1936 1937 1938 1938 1939	0 0 0 0 0 1.93 0 .05	$egin{array}{c} 0 \\ 0 \\ 0 \\ 126 \\ 0 \\ 1,142 \\ 0 \\ 20 \end{array}$	$1.43 \\ .13 \\ 1.96 \\ 4.03 \\ .85 \\ .28 \\ .26 \\ 5.19$	33, 907 292 3, 005 32, 055 17, 617 654 219 38, 885	0.27 3.90 .08 .37 2.28 .16 .54 .54	1,009 2,065 17 1,842 10,936 93 485 2,467	0 0 1.89 .33 .53 .04 0 .33	0 163 2,025 5,762 60 0 342	1,70 4,03 3,93 4,81 3,96 2,41 ,80 6,11	34, 916 2, 357 3, 185 36, 048 34, 315 1, 955 704 41, 714	Soybeans Wheat Meadow Corn Soybeans Wheat Meadow Corn	2: 54 20. 5 1. 08 14. 5 0 2: 15 1. 43 13: 4
Total Average	2,00 ,26	1, 288 161	14, 13 1,77	126, 634 15, 830		18, 914 2, 364	3.42	5, 388 1, 045	27, 75) 3, 47	19, 399		********
and a second					PLOT 2	ina constant of a second	and an internet of	an a		and the second		
1032 1033 1034 1035 1036 1037 1038 1039 1039 1030 1031 1032 1036 1037 1038 1030 1031 1032 1033 1034 1035 1037 1038 10300 1040 1041	0 0 0 0 0 0 0 0 1.45 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		$\begin{array}{c} 0.31\\ .19\\ 1.39\\ 2.85\\ .10\\ .74\\ .04\\ .05\\ .06\end{array}$	$196 \\ 1,597 \\ 7,205 \\ 347 \\ 371 \\ 7,351 \\ 30 \\ 10,629 \\ 50 \\ 50 \\ 50 \\ 50 \\ 50 \\ 50 \\ 50 \\ 50$	$\begin{array}{c} 0 \\ 4,50 \\ ,79 \\ 0 \\ .40 \\ .20 \\ 0 \\ .02 \\ 0 \\ 0 \\ 0 \end{array}$	$\begin{array}{c} 0\\ 10, 297\\ 4, 296\\ 0\\ 1, 569\\ 0\\ 53\\ 13\\ 0\\ 0\end{array}$	0 0 1.03 .02 .14 0 .02 0 .11	$ \begin{array}{c} 0 \\ 133 \\ 13 \\ 1, 789 \\ 0 \\ 27 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0$	$\begin{array}{c} 0.31 \\ 4.78 \\ 3.21 \\ 2.96 \\ .73 \\ 2.39 \\ .04 \\ 4.30 \\ .10 \\ .21 \end{array}$	$\begin{array}{r} 196\\ 12,504\\ 11,634\\ 420\\ 3,729\\ 7,842\\ 30\\ 10,709\\ 202\\ 50\end{array}$	Meadow. Corn. Onts	1.6975.210.31.34089.21.0836.646.61.73
Total.	1, 64	5 42	9.98	28, 005	6, 09	16,987	1.32	1,962	19.03	47, 496		

Č.

160 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

	strange and an internet of the second statement of the	 	1. S.	1								and the second	
615654451	1032 1033 1034 1036 1036 1037 1038 1039 1040 1041 1041 1041 1041 1042 1042 1042 1042 1042 1053 1052	0 0 550 0 1.95 0 .01 .56 .04	0 0 574 0 1,374 0 0 717 0	$\begin{array}{c} 0.23 \\ .33 \\ 2.31 \\ 7.34 \\ .23 \\ 1.30 \\ .24 \\ 4.82 \\ 1.85 \\ .84 \end{array}$	$\begin{array}{c} 106\\ 2,115\\ 19,077\\ 765\\ 504\\ 16,946\\ 140\\ 23,144\\ 4,266\\ 103\\ \end{array}$	$\begin{matrix} 0 \\ 5.08 \\ 2.77 \\ 0 \\ 1.63 \\ .62 \\ .31 \\ .58 \\ .28 \\ 0 \end{matrix}$	$\begin{array}{c} 0\\ 20,200\\ 4,752\\ 0\\ 4,321\\ 358\\ 50\\ 1,564\\ 132\\ 0\\ \end{array}$	0 0 3.38 0 .73 .02 0 .53 0 .53 0 .53	0 341. 0 S, 652 33 0 707 0 10	$\begin{array}{c} 0.\ 23\\ 6.\ 31\\ 8.\ 40\\ 7.\ 84\\ 2.\ 59\\ 3.\ 89\\ .\ 55\\ 5.\ 94\\ 2.\ 69\\ 1.\ 72\end{array}$	$\begin{array}{c} 106\\ 22, 324\\ 24, 170\\ 1, 339\\ 13, 567\\ 18, 711\\ 190\\ 25, 415\\ 5, 115\\ 113\\ \end{array}$	Mendow Corn Meadow Corn Oats Corn Corn Oats Meadow	$\begin{array}{c} 1, 06\\ 56, 9\\ 10, 9\\ 1, 56\\ 0\\ 57, 1\\ 1, 03\\ 11, 1\\ 29, 6\\ .12\end{array}$
-	Total. Average	3.06 .31	2, 665 266	19.40 1.95	67, 346 6, 735	12, 17 1, 22	31, 386 3, 139	5, 50 . 55	9, 743 974	40. 22 4. 02	111, 140 11, 114	*****	********

¹ Soil loss in pounds per acre; runoff in surface inches.

0 :

14

INVESTIGATIONS IN EROSION CONTROL

161

PLOT 3

162 TECHNICAL BULLETIN \$83, U. S. DEPT. OF AGRICULTURE

TABLE 58.—Runoff and soil loss by scasons and years and crop yields for contour-cropped plots 2, 4, and 6 of series 5, by individual crops by a 3-year rolation, 1936-41

	First (quarter	Second	quarter	Third	quarter	Fourth	quarter	Тс	otal	Yield
Yest	Run- off	Soil loss	Run- off	Soll loss	Run- off	Soil loss	Run- off	Soil loss	Run- off	Soil loss	nere
1936 1937 1938 1939 1949 1941 1°otal	Inches 0 3.08 0 .30 .41 0 3.79	Pounds 0 874 0 19 0 902	Inches 0 .31 .30 3.27 1.68 1.64 7.48 1.95	Pownds 0 1, 089 1, 221 34, 373 10, 755 6, 614 54, 052 0 000	Inches 0, 10 * 0 . 23 . 62 . 07 0 1. 02 17	Pounds 88 3 147 4, 377 32 0 4, 407 774	Inches 0.03 0 0 0 1.45 1.45 25	Pounds 16 0 2,207 2,223 2,223	Inches 0, 13 3, 39 .53 4, 10 2, 44 3, 09 13, 77 2, 30	Pounds 104 1,906 1,358 38,759 10,806 8,821 61,824 10,304	Tonn or bushets 0 39, 1 16, 9 16, 4 31, 6 16, 8
Average	.03	150 PLOT	4. WHI	EAT OC	CUPY	ING EN	STIRE	PLOT			<u> </u>
1936 1937 1938 1939 1940 1940	0 2,76 0 .05 .43 .74	0 182 0 36 713 74	0 .04 .47 2.40 .22 1.47	0 26 518 1,757 137 159	0.55 0 .87 .33 .02 1.74	. 136 0 345 198 2 25	0.40 0 0 0 0 0	309 0 0 0 0	1.04 2.80 1.34 2.87 .67 3.95	445 208 1, 163 1, 991 852 288	22.0 22.3 3 38.5 5.6 18.0 3 22.5
Totai.	3. 98 . 66	1,005 .168	4.60 .78	2,927	3.51 .58	706 11\$	- 49 - 0\$	309 52	12.67 2.11	4, 947 825	
PL0'	r 6, Ki	ED CLC	VER 2	AND TI	моти	1Y 0CC	บย้างเร	VO EN1	TRE P	LOT	
1930 1937 1938 1939 1939 1940 1941	0 3.28 0 	0 979 0 36 1 9	0 7, 28 0 3, 09 00 , 54	0 406 293 160 26	0, 22 *, 16 0 -, 23 0 0	19 -10 0 8 0 0	0, 24 0 0 0 1, 17	100 0 0 0 0 0 36	0.46 3.72 0 3.54 .92 1.86	119 1, 425 8 337 161 71	L. 40 L. 39 L, 40 - 57 - 74 2, 01
Total A verage,	3.97	1,025	4. S1 . S0	893 140	. 61 . 10	i 67 11	1.41 .24	$136 \\ 23$	10.80 1.80	2, 121 351	:

L

PLOT 2, CORN OCCUPYING ENTIRE PLOT

Soil Joss in pounds per acre, water loss in surface inches.
Box leaked.
Wheat, winter-killed; onts, seeded in spring. "Yield is for onts.

TABLE 59.—Runoff and soil loss ' 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

νÃ,

Year	First (warter	Second	quarter	Third	quarter	Fourth	quarter	Tota	1	Ŷ	ields per ac	re
	Runoff	Soll loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Corn	Wheat	Meadow
1936 1037	Inches 0 3.16 0 .16 .19 .10	Pounds 0 636 0 30 30 30 3	<i>Inches</i> 0 . 12 . 20 2. 64 . 02 1. 39	Pounds 0 41 1, 121 9, 714 4, 418 1, 419	Inches 0.36 0 .23 .31 0 0	Pounds 148 0 176 636 0 0	Inches 0, 17 0 0 0 0 1, 69	Pounds 119 0 0 0 0 944	Inches 0, 53 3, 28 , 49 3, 11 , 21 3, 18	Pounds 267 677 1, 297 10, 380 4, 448 2, 366	Bushels 0 41.8 14.3 6.3 33.7 10,5	Bushels 18.9 17.0 238.3 5.3 17.7 222.5	Tons 1. 84 1. 36 2. 23 . 81 . 90 2. 10
Total A verage	3.61 ,60	609 116	4, 43 . 74	16, 713 2, 785	. 90 . 15	960 160	1.86 .31	1, 063 177	10. 80 1. 80	19, 435 3, 239			
		P	LOT 3, W	пелт о	CCUPYI	NG LOW	ER STRI	P					
1036 1037 1038 1039 1040 1941	0 2.99 0 .16 .40 .14	0 264 0 73 234 23	$\begin{array}{r} 0\\ .32\\ .16\\ 2.69\\ 1.00\\ 1.64\end{array}$	0 289 241 1, 205 220 539	0. 21 .06 .27 .36 .01	33 17 67 80 1 0	0, 23 0 0 0 1, 44	95 0 0 0 0 67	$\begin{array}{r} 0.44\\ 3.37\\ .43\\ 3.21\\ 1.41\\ 3.22\end{array}$	$128 \\ 570 \\ 308 \\ 1,358 \\ 404 \\ 629$	0 53. 1 17. 8 8. 1 55. 4 19. 9	28.8 18.8 35.8 3.6 16.6 222.5	1.36 1.60 1.97 .47 .69 1.73
Total. Average	3.69 .62	594 99	5. 81 . 97	2; 503 417	.91 .15	198 33	1.67 ,28	162 27	12.08 2.01	3, 457 576		• • • • • • • • • • • • •	
	PLO.	r 5, RED	CLOVET	AND T	мотну	OCCUPY	ING LO	WER STI	RIP		l light of the second		
1936 1937 1938 1939 1940 1941	0 2.90 0 .38 .18 .52	0 814 0 26 11 27	$0\\.15\\.16\\2.98\\1.29\\1.57$	0 174 77 4, 391 386 633	0.01 .06 .20 .29 0	4 12 52 246 0 0	0.07 0 0 0 0 2.17	10 0 0 0 711	$\begin{array}{c} 0.08\\ 3.11\\ .36\\ 3.65\\ 1.47\\ 4.26\end{array}$	14 1,000 129 4,663 397 1,371	0 36.0 14.7 19.3 15.1 13.8	18, 9 23, 1 2 41, 6 8, 2 20, 7 2 22, 5	1.53 1.38 1.74 .57 .77 2.57
Total Average	3.98 .66	878 146	6.15 1.02	5, 661 944	. 56 . 09	314 52	2. 24 . 32	721 104	12.93 2.16	7, 574 1, 262			*******

PLOT 1, CORN OCCUPYING LOWER STRIP.

1 Soil loss in pounds per acre, runoff in surface inches.

0

² Wheat, winter-killed; oats, planted in spring. Yield is for oats.

INVESTIGATIONS IN EROSION CONTROL

TABLE 60.-Seasonal and annual soil and water losses 1 and grazing data, from bluegrass pasture plots 1936-41

SERIES 9, PLOT 1

Yadı	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Unit 2 tusture	Chànge in animal
A (24)	Runoff	Soil loss	Runoff	Soll loss	Runoff	Soil loss	Runoff	Soft loss	Runoff	tunoff Soil loss		per acre
1036 1037 1038 1039 1040 1040 1041 Yotal Average	Inches 0, 88 3, 15 0 , 21 0 0 4, 24 , 71	Pounds 9.0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Inches 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Pounds 0 2 1 0 0 0 0 3 . 50	Inches 0 0 0 .87 .15	Pounds 2 0 0 123 125 20, 83	Inches 0 0 0 0 0 0 0 0 0 7 .07	Pounds 1 0 0 0 0 1 .17	Inches 0.88 3.15 0 .26 0 .94 5.23 .87	Pounds 12 2 1 0 0 123 138 23	Da ys 121 154 141 98 129 36	Pounds 145 384 141 57 190 255
			SERI	ES 9, PL	от 2				ا مغیر منتخب کا این این این این این ا			
1036 1037 1038 1030 1030 1040 1041	1.40 2.36 0,15 0,29	33.0 0 0 0 0	0 .01 .03 2.29 .24 2.02	0 8 3 14 11 214	0 0 0 .0: 0		0 .01 0 0 .22	1 0 0 0 10	1.40 2.38 .03 2.48 .27 2.53	37 8 3 20 13 224	95 275 203 157 218 89	134 51 213 -07 -080 -586
Total. A veräge	4.20 .70	33.0 5.50	4, 59 . 77	200 41,67	.0. .0	1.83	. 23 . 04	1. \$3	1,52	50, 83	[

Soil loss in pounds per acre; runoff in inches.
 A unit pasture day is equivalent to the grazing of 5 sheep for 1 day.

		······		PLOT 1,	90 FEET	LONG		100 A				
1 -	First o	juarter	Second	quarter	Third	quarter	Fourth quarter		Total		Croppin	g
i cin	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1934 1935 1936 1937 1938 1939 1940 Total Average	Inches 0 .78 0 3.20 0 .30 1.51 4.37 .73	Pounds 0 3, 370 0 7, 312 0 2, 570 2, 110 132, 520 2, 209	<i>Inches</i> 1.37 8.03 .07 .02 .93 4.04 .37 14.82 .2.41	Pounds 2, 553 62, 643 429 126 18, 525 73, 530 371 157, 806 26, 301	Inches 1, 15 0 1, 54 , 27 2, 18 , 80 , 28 6, 22 , 99	Pounds 3,961 292 6,223 619 19,917 10,137 92 41,149 6,858	Inches 2.79 .01 .60 .06 .02 .08 0 3.56 .59	Pounds 5, 285 18 7, 302 340 11 517 0 13, 563 2, 277	Inches 5.31 8.82 2.21 3.55 3.13 5.31 2.16 28.33 4.72	Pounds 11, 799 66, 323 14, 044 8, 307 38, 453 86, 754 2, 573 225, 770 37, 628	Corn	Bushels 0 24.2 0 37.1 7.1 37.5 17.3
				PLOT 5,	90 FEET	LONG	******					<u> </u>
1934	0 .32 0 3.48 0 .23 .36	0 2, 693 0 6, 853 0 2, 163 848	2.07 6.72 .5 .02 .70 3.59 .55	$16,764 \\ 81,420 \\ 626 \\ 76 \\ 16,504 \\ 69,883 \\ 754$	$\begin{array}{r} 0.96 \\ .03 \\ .75 \\ .09 \\ 1.46 \\ .63 \\ .17 \end{array}$	$\begin{array}{r} 6,215\\ 239\\ 2,347\\ 195\\ 14,167\\ 10,482\\ 51 \end{array}$	2. 26 0 . 39 . 03 . 02 . 08 0	4, 549 21 3, 443 122 7 285 0	5. 29 7. 07 1. 19 3. 62 2. 18 4. 53 1. 08	27, 528 84, 373 6, 416 7, 276 30, 678 82, 813 1, 656	Corn	0 41.2 0 50.9 16.1 43.6 19.0
Total. Average	4.03 .67	11,739 1,956	13. 15 2. 19	185, 273 30, 879	3,92 .65	33, 645 5, 608	2.78 .46	8, 427 1, 571	23, SS 3, 98	239, 084 39, 847		
				PLOT 2, 1	SO FEET	LONG		······				<u>.</u>
1034 1035 1036 1037 1038 1039 1039 1040 Total A verage	0 .44 0 3.10 0 .32 .76 3.86 .64	$\begin{array}{r} & 0 \\ 4,732 \\ 0 \\ 16,539 \\ 0 \\ 6,948 \\ 6,803 \\ \hline 28,219 \\ 4,703 \\ \end{array}$	0.93 8.57 .04 0 .82 3.73 .22 14.09 2.35	3, 485 166, 481 678 49 38, 455 174, 251 345 383, 402 63, 900	1.04 0 .85 .17 1.57 .57 .33 4.20 .70	12,7342794,54552028,24015,19793 $61,52710,255$	$1,96 \\ 0 \\ .41 \\ .02 \\ .03 \\ .06 \\ 0 \\ \hline 2,48 \\ .41 \\ .41$	10, S20 0 10, 669 145 10 337 0 21, 981 3, 664	$\begin{array}{r} 3.93\\ 9.01\\ 1.30\\ 3.29\\ 2.42\\ 4.68\\ 1.31\\ \hline 24.63\\ 4.11\\ \end{array}$	27, 039 171, 402 15, 892 17, 259 66, 714 196, 733 7, 241 495, 129 82, 522	Corn	32.3 0 44.6 12.6 38.9 23.6

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 PLOT 1, 90 FEET LONG

103

See footnotes at end of table.

INVESTIGATIONS IN EROSION CONTROL

165

\$

TABLE 61.-Secsonal and annual runoff and soil loss 1 and crop yields, from length of slope plots 1 to 5 of plot series 15, 1934-402-Continued PLOT 4, 180 FEET LONG

	First quarter		Second quarter		Third quarter		Fourth quarter		Total		Cropping	
Year	Runoff	Soi! loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Crop kind	Yield per acre
1934 1935 1936 1937 1938 1938 1939 1940 1940 Total Average	Inches 0 .43 0 3.14 0 .28 .53 3.85 .64	Pounds 0 8,093 0 14,926 0 0 8,038 5,035 31,057 5,176	Inches 1.60 8.20 .02 0 .78 3.80 .70 14.49 2.42	Pounds 6,995 187,492 46 31,052 149,034 1,006 375,454 62,576	Inches 1.58 .20 1.01 .14 1.55 .73 .36 5.21 .87	Pounds 11, 942 774 7, 303 269 19, 822 16, 812 156 56, 922 9, 487	$\begin{tabular}{ c c c c c c c c c c c c c c c c c c c$	Pôunds 19,550 138 8,924 71 46 482 0 29,209 4,868	Inches 6.68 9.03 1.56 3.20 2.38 4.91 1.59 27.85 4.64	Pounds 38,487 196,495 17,062 15,312 50,920 174,366 6,197 402,642 82,107	Corn	Bushels 0 25.0 0 42.0 17.9 32.6 15.8
*				PLOT 3,	270 FEE4	LONG						V##
1934 1935 1936 1937 1938 1939 1039 1940 Total Average	0 61 0 3.45 0 .35 1.66 4.41 .74	0 10, 730 0 22, 030 0 10, 390 22, 217 43, 150 7, 192	1.34 7.95 .08 0 .80 4.71 .70 14.88 2.48	$13, 129 \\ 203, 002 \\ 1, 836 \\ 44 \\ 38, 851 \\ 257, 797 \\ 2, 233 \\ 514, 659 \\ 85, 776 \\ \end{array}$	$1,52 \\ .05 \\ 1.18 \\ .12 \\ 1.56 \\ .60 \\ .49 \\ \hline 5.03 \\ .84$	16, 175 790 6, 732 328 30, 653 18, 114 270 72, 892 12, 149	4, 58 09 50 03 03 06 0 5, 29 88	21, 810 109 15, 944 278 36 179 0 38, 356 6, 393	7.44 8.70 1.76 3.60 2.39 5.72 2.85 29.61 4.94	51, 114 214, 631 24, 512 22, 680 69, 540 286, 580 24, 720 669, 057 111, 510	Corn	0 25.1 0 41.3 18.4 32.1 20.9

Soil loss in pounds per acre, water loss in surface inches.
 Corn years, 1934 through 1939. All plots were in wheat in 1940 and are not totaled or averaged with the corn years.

INVESTIGATIONS IN EROSION CONTROL

	Ru	noll					
Year	Amount	Maximum rate per hour	Soli loss per acre	Стор	Crop yiel	ld per acro	
933	Inches 7.52	Inches 1.97	Tons I, 49	Oats 1	Tons	Buthels	
34	7.67	ч. 30	1, 24	Alfalfa	0,00		
35	10.75	I. S 4	. 91	Alfalfa.	. 90		
30	.97	. 16 54	.00	Alfalfa	1.48		
38	1, 15	. 95	. 22	fOats	1. 20	42	
39	4, 31	4, 10	. 36	Oats		17	

TABLE 62.—Annual soil and water losses and crop yields from lerrace 2-G, cropped to alfalfa 1933-37 and to oats-lespedeza 1938-39

tAlfalfa was established with oats as a nurse crop in the spring of 1933 and was not harvested. 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

			Corn			Onts							
Yoor		Ru	noff			1	Ru	noff					
	Terraced orea	Amount	Maxi- num rate per hour	Soil loss per acre	Crop yield per acre	Terraced area	Amount	Maxi- mum rate per hour	Soil loss per acre	Crop yield per acre			
1932 1933 1935 1935 1936 1937 1930 1930 1940 1941	1-Л 2-Д 2-Ц 2-Ц 1-Ц 2-Ц 1-Ц 2-Н 2-Н 2-Н	Inches (1) 6,00 (1) 7,82 3,41 3,32 .93 4,39 2,57 3,88	Inches (1) L,41 (1) .94 .30 .21 2.85 L,22 1,19	Tons 0.319 .104 .129 .125 .144 .261 .751 .509	Busheis 24.6 8.2 0.0 40.1 12.2 14.7 34.8 10.4	2-П 1-НЫ 2-НЦ 2-НЦ 1-НП 1-НП 1-НП 2-ПЦ 2-ЦЦ 2-ЦЦ 2-ЦЦ 1-ЦЦ 2-ЦЦ	Inches 2.05 (1) 7.27 (1) 2.87 3.06 .91 5.22 1.52 2.86	Inches 0.44 (1) 3.50 (1) 48 1.78 2.20 2.20 .03 .42	Tons 0.530 6.560 .315 .193 .131 .574 .116 .116	Busheis 45.9 8.0 60.6 65.2 51,1 10.3 35.9 42.7			

¹ Not measured.

168 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

			Corn			Soybeans					
		Rn	noff				Ru	noif			
X ent	Terraced area	Amount	Maxi- muni rate per hour	Soil loss per sere	Crop yield per , acre	Terraced area	Amouni	Maxi- mum rate per bour	Sall loss per acre	Crop yield per ucre	
1932 1933 1934 1935 1936 1938 1938 1938 1938 1940 1941	6-H. 5-JJ 4-H. 3-H 6-H. 5-JJ. 4-H. 3-H. 3-H. 6-JJ. 5-H	Inches 4, 42 10, 68 12, 82 5, 97 3, 95 2, 92 1, 24 4, 41 2, 54 5, 99	Inches 1, 95 2, 47 2, 08 , 93 , 98 , 70 3, 28 1, 35 1, 78	Tons 8, 260 4, 373 3, 282 8, 750 1, 048 1, 378 640 3, 748 1, 020 1, 205	Bushels 22.4 35.5 0 7.2 0 42.8 12.9 31.8 35.4 17.1	3-11 6-11 5-11 3-11 6-11 5-11 5-11 6-11 6-11	Inches 3.03 7.50 11.01 10.42 3.88 3.47 2.98 6.66 2.29 4.50	Inches 2, 60 1, 95 3, 21 1, 89 - 52 - 20 - 37 3, 09 1, 29 1, 45	Tons 4. 157 9. 842 5. 883 3. 924 1. 305 700 1. 055 4. 457 1. 292	Tons 2.10 2.14 .41 .06 0 .97 .97 .90 1.04 .75	
			Wheat				1	leadow	•		
1932 1933 1934 1935 1936 1937 1935 1949 1940	5-11. 3-31. 6-11. 5-11. 3-11. 3-11. 6-11. 3-11. 5-11. 5-11. 5-11. 5-11. 5-11. 3-11. 3-11.	5.21 8.10 90.68 11.69 3.79 3.07 2.23 4.81 1.15 3.41	$\begin{array}{c} 1.60\\ 1.78\\ 2.93\\ 1.19\\ .54\\ .62\\ .30\\ 2.49\\ .59\\ \end{array}$	$\begin{array}{c} 2.609\\ 2.159\\ 2.117\\ 2.161\\ .230\\ .406\\ .271\\ .598\\ .131\\ .170\end{array}$	$\begin{array}{c} 14.7\\ 23.0\\ 13.0\\ 18.7\\ 30.0\\ 21.4\\ 10.7\\ 8.4\\ 22.4\\ 141.7\end{array}$	4-H 4-H 3-H 5-H 3-H 3-H 3-H 5-H 5-H 5-H	3, 25 5, 64 6, 02 8, 84 4, 05 4, 05 4, 63 1, 60 2, 22	$1,50 \\ .94 \\ 2.91 \\ .03 \\ .35 \\ 1.07 \\ .13 \\ 2.20 \\ .35 \\ .23$	$\begin{array}{c} 0.416\\ .377\\ 3.524\\ 1.227\\ .032\\ .488\\ .034\\ .200\\ .233\\ .033\end{array}$	0.77 -77 -41 1.33 1.22 -41 1.97 0.78 1.05	

 TABLE 64.—Annual soil and water losses and crop yields from designated terraced areas in a 4-year rotation corn, soybeans, wheat, and meadow

¹ Seeded to oats after wheat winter-killed.

TABLE 65 .- Annual soil and water losses and crop yields from terraces of various vertical spacing

Terrace 3-O.5-foot vertical interval on a 12,4 percent i	Terrace 4-G, 7-foot vertical interval on a 13.9 percent
slope	slope

······································											
	Run	οlΣ					Run	olĭ			
Year	Amount	Maxi- mum rate per hour	Sofi loss per nere	Стор	Crop yield per aerc	Ƴear	Amount	Maxi- mum rate per hour	Soil loss per acre	Crop	Crop yield per acre
1932 1933 1934 1935 1935 1936 1938 1938 1939	In.2.895.470.3510.021.253.761.745.152.41	In. 1. 13 .94 3. 63 2. 40 .05 1. 64 .54 3. 00 1. 70	Tons 0, 393 229 3, 148 3, 653 008 1, 256 269 280 936	Oais Meadow, Corn, Onis, Meadow, Corn, Oais, Meadow, Corn,	Bu. or lons 43.9 1.05 0 30.3 1.20 30.8 44.6 0 41.2	1032 1933 1934 1935 1937 1937 1938 1939 1940	<i>In.</i> 2, 14 4, 49 9, 52 10, 65 1, 35 3, 74 1, 25 4, 31 2, 70	<i>I</i> n. 0. 62 , 89 3. 21 2. 36 , 10 1. 40 . 30 3. 03 1. 70	Tons 0, 407 , 431 2, 517 4, 025 , 609 1, 526 , 196 , 231 1, 102	Oats Meadow Oorts Meadow Corn. Oats Meadow Corn.	Bu. or tons 43.9 1.68 0 34.5 1.67 42.3 43.1 0 49.7

¥.,

¢

INVESTIGATIONS IN EROSION CONTROL

TABLE 65.—Annual soil and water losses and crop yields from terraces of various vertical spacing—Continued

Terrace 5-G, 8-foot vertical interval on a 13.2 percent | Terrace 5-N, 5-foot vertical spacing on a 7.4 percent slope

				, 							
	Run						Run	Ito			
Year	Amount	Maxi- fuuni rate per hour	Soil loss per aere	Стор	Crop yield per acre	Year	Amount	Maxi- mum rate per bour	Soil loss per acre	Сгор	Crop yield per acre
1932 1033 1934 1935 1036 1937 1938 1938 1939 1940	/n. 1,56 3,32 7,74 8,35 1,02 3,20 .55 3,10 1,71	$\begin{array}{c} fn,\\ 0,46\\ ,76\\ 3,02\\ 2,01\\ ,05\\ 1,37\\ ,24\\ 2,62\\ 1,58\end{array}$	Tons 0.329 .215 3.371 3.368 0 1.602 .054 .114 .899	Oats Meadow Corn Oats Mendow Corn Oats Atendow Corn	Bu.or fons 43.9 1.68 0 41.7 2.20 50.3 41.4 0 57.6	1932 1933 1934 1035 1036 1937 1938 1938 1940	In. 1.777 3.222 7.73 9.75 9.75	<i>In</i> . 0, 21 . 50 2, 18 1, 52 . 34 . 15 . 05 2, 58 1, 01	2 ons 0, 131 . 205 2, 505 3, 002 . 009 . 220 . 030 . 174 . 500	Oats Corn Oats Meadow Corn Meadow Corn	Bu. or lons 59.6 1,73 0 39.5 1.87 40.7 0 51.1
Terence	4-N, 3-fot	ot vertio slo	al inter pe	wai on a 6.3 p	errent	Terrace	6-N, 7-for	ot verii sle	ent spac ope	ring on a 6.8 p	ercent
1932 1933 1934 1935 1936 1937 1938 1938 1939 1940	2, 56 1, 13 3, 75 5,90 1,01 2,12 53 3,37 1,54	$\begin{array}{c} 0.41 \\ -26 \\ 1.50 \\ 1.98 \\ -67 \\ -23 \\ -11 \\ 2.23 \\ -86 \end{array}$	$\begin{array}{c} 0,245\068\\ 1,100\\ 2,051\024\193\035\329\281 \end{array}$	Oats Mendow Corn Oats Corn Oats Meadow. Corn Vorn	62, 4 1, 73 0 31, 1 1, 28 44 1 39, 1 0 54, 3	1932 1933 1934 1935 1935 1935 1937 1938 1939 1940	1.44 2.24 6.47 8.24 1.77 .25 3.33 1.54	0.40 .01 .176 .178 .23 .27 .08 2.51 J.10	0. 201 . 156 4. 570 3. 730 . 006 . 302 . 026 . 213 . 631	Oats. Meadow Oats Meadow Corn Oats Meadow Corn	59.6 J.73 0 40.6 1.49 36.7 36.5 0 45.4

TABLE 66.—Annual soil and water losses and crop yields from terraces of various channel grades

 Terrace 5-C; channel µ 	grade, S i	inches per	100 feet	(Tern
--	------------	------------	----------	--------

2

Terra	ce 5-C; ch	annel g	rade, S i	inches per 100) feet	Terrace 7-C; channel grade, 4 inches per 100 feet						
	Ru	off					Run	off				
Year	Amount	Maxî- muni rate per hour	Soil loss per acre	Crop	Crop yiekt per acre	Year	Amount	Maxi- mum rate per hour	Soil Ioss Per acre	Стор	Grop yield per acre	
1932 1933 1934 1935 1935 1936 1937 1939 1939 1940	<i>In.</i> 4, 19 4, 84 5, 72 12, 33 4, 07 3, 87 2, 72 5, 14 1, 14	In. 3.30 1.44 2.40 2.40 .29 2.06 2.23 .36	Tons 7, 167 . 057 . 901 14, 598 . 598 . 340 5, 319 . 980 . 013	Cora Onis Meadow Corn Onts Meadow Corn Onts Aleadow	Bu. or tons 27.5 04.1 .85 5.0 5.5 .61 5.6 24.1 1.31	1932 1033 1934 1935 1936 1936 1938 1938 1940 1940	In. 3.94 4.03 9.41 2.56 3.41 2.02 4.87 .08	<i>fn</i> , 2, 55 .71 2, 13 1, 96 , 49 .17 1, 03 1, 92 .17	Tons 2,913 ,424 ,692 5,586 ,159 ,090 1,850 ,556 ,004	Corn Oats Oats Meadow Corn Oats Meadow	Bu. or (ous 27.5 04.1 .06 8.0 67.8 .67 13.7 24.1 1.31	
Terras 1032 1933 1034 1035	ce 6-C; ch 3, 50 4, 02 5, 71 10, 32	3. 00 . 87 2. 10 2. 04	nde, 6 i 3. 335 , 419 , 525 4. 929	Corn Oats Meadow	27.5 64.1 .83	Terrace	7-C North	n; chann	el grado	e, level (overto	opping)	
1936 1937 1938 1930 1940	3.08 3.51 2.25 4.40 1.01	, 54 , 16 1, 60 2, 01 , 26	. 177 . 163 3. 004 . 486 . 005	Oats Meadow Corn Oats Meadow	48, 6 55 10, 4 24, 1 1, 31	1034 1935 1930 1937 1937 1938	3, 05 4, 34 1, 35 3, 56 , 17	2, 10 1, 14 1, 06 .07 .25	.760 2.040 .090 .270 .170	Mendow Corn Oats Meadow Corn	8.0 57.9 3.30 14.3	

Ð

'n

170 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

TABLE 66.—Annual soil and water losses and crop yields from terraces of various channel grades—Continued

1

11

1.2

Terrace 8-C; channel grade, 2 inches per 100 feet [Terrace 10-C; elannel grade, variable 1 to 4 inches per 100 feet

-											
	Run	n					Rur	ofī			
Year		Maxi- mum rate per	Soil loss per acre	Crop	Crop yleid per sere	Yenr	Amount	Maxi- mum rate per hour	Soil loss per aere	Сгор	Crop yleid per sere
		non									Bu. or
1632 1933 1934 1935 1936 1938 1939 1939 1940	In. 3.03 3.71 4.51 0.74 2.21 3.28 1.54 3.00 .73	$\begin{array}{c} hr.\\ 2.05\\ .40\\ 1.40\\ 1.54\\ .25\\ .21\\ .38\\ 1.23\\ .12\end{array}$	Tons 0. 95% . 308 . 202 3. 143 . 049 . 102 . 801 . 330 . 003	Gorn Oats Corn Mendow Corn Oats Meadow	Bu. or lous 27.5 64.1 .83 8.0 65.2 .71 21.1 24.1 1.31	1032 1933 1935 1936 1938 1938 1939 1930	/n. 2.84 2.51 2.45 10.44 1.01 3.60 1.18 J.20 .00	In. 2,42 ,38 1,68 2,23 ,15 ,78 1,25 ,10 2-N; ch	Tons 2, 218 201 , 388 5, 272 , 056 , 120 1, 028 , 209 , 001	Corn Oals Oals Onts Meadow Oals Meadow ade, level	Lons 27.5 64.1 1.09 8.0 51.1 .77 28.5 24.1 1.31
	Terrace	9-C; ch	nnnel gr	ade, level			1	1	<u> </u>		
1932 1933	1, 59 2, 56	0.51 .30	0. 626	Corn Onts	27.5 64.1	1036 1037 1938	0.64	0.01	. 150 . 010	Corn Qaįs	1.54 54.8 42.0
1934	2.96 9.09	1.02	2.646	Corn	99 . S.O		Terrace	8-N; ch	nnne) gr	ade, level	
1937 1938 1939 1940	3. 18 3. 2. 23 2. 23 31	.13 .14 .76 .02	. 143 . 202 . 088 . 000	Mendow Corn Outs Mendow	23.6 24.1 1.31	1933 1934 1935 1936 1937 1938	$\begin{array}{c} 1,25\\ 2,03\\ 4,20\\ ,76\\ 2,25\\ ,26\end{array}$	0.32 .70 .54 .03 .03 .12	0.060 1.140 .600 .010 .110 .030	Mendow Corn Oats Mendow Corn Oats	1. 19 0 31. 2 1. 43 40. 5 39, 2

TABLE	67.—Annual	soil	and	water	losses	and	crop	yiclds	from	lerraces	oſ	various
					leng	ths		•				

Terrace 2-I, terrace length, 1,375 feat							Terrace 4-1; terrace length, 2,450 feet							
Year	Run	φſΓ					Runoff							
	Amount	Maxi- mann rate per hour	Soil loss per acre	Стор	Crop yield per nere	Year	Amount	Maxi- mum rate per hoar	Soil loss j#'r ncre	Стор	Crop yield per acre			
1934 1935 1935 1937 1938	Inches 1, 76 5, 84 1, 26 3, 43 , 64	Inches 0.62 1.36 .25 .41 .21	Ton\$ 0.98 4.29 .34 1.54 .14	Mendow Corn Onis Meadow	Bu. or lons 1, 18 22, 4 0 61, S 1, 64	1934 1035 1936 1937 1937	Inches 4, 95 10, 69 3, 50 3, 29 1, 47	Inches 1, 80 1, 91 , 62 1, 02 , 37	Tons 1, 34 10, 86 1, 29 2, 08 , 17	Meadow Corn Coru Onts Meadow	Hy.or lons 0.77 13.7 0 68.6 1.53			

INVESTIGATIONS IN EROSION CONTROL

TABLE 68.—Annual precipitation, runoff, soil loss, and crop yields from terraced blucgrass 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]

			Runofī		Grazing	
Year	Rainfall	Amount	Percent of rainfall	Maximum rate per hour	Soil loss per acre	animal- unit-days per acré
1934 1935 1936 1937 1937 1939 1939 1940 1941 1941	<i>Inches</i> 31, 18 37, 33 24, 11 21, 54 27, 23 27, 27 27, 27 35, 41 32, 90	Inches 4, 48 7, 92 64 2, 99 .06 .08 .41 1, 91 1, 86	Percent 14, 4 21, 2 2, 7 13, 7 , 2 3, 6 1, 5 5, 4 5, 7	Inches 1,59 1,22 ,02 17 ,14 1,59 ,31 ,76 ,17	Tons 7, 134 1, 183 000 014 003 -021 0 .037 .052	Days 82.3 1J.7.0 50.3 28.2 79.1 82.0 101.1

¹ Terraces were constructed in the fall of 1933. ¹ Area consisted of 2.117 acres prior to August 12, 1938, on which date the outlet was relocated. ² Pastures were grazed with horses, cattle and sizep in 1936 and cattle thereafter. The fenced grazing area is 1.61 acres. Fence was installed May 10, 1936.

TABLE 69.—Annual precipitation, runoff, soil loss, and crop yields from normal bluegrass pasture watershed (Pa-B)

[Area 5.563 acres: 4 average slope 9.5 percent]

			Runoff		Grazing ²	
Year	Rainfall Amoun		Percent of rsinfall	Maximum rate per hour	Soll loss per acre	animal- unit-days per acre
1932	Inches 27, 96 31, 37 31, 18 37, 33 24, 11 21, 84 26, 51 26, 59 27, 84 35, 03 32, 63	Inches 0, 70 2, 73 2, 83 9, 96 90 3, 37 01 59 -38 2, 06 2, 17	Percent 2.6 8.8 0.1 26,7 3.7 15.4 0 2.2 1.4 8.4 8.7	Inches 0,21 1,23 2,55 1,76 ,12 .03 0 .73 ,18 1,56	Tous 0, 920 1, 342 1, 875 3, 259 , 073 , 125 0 . 043 . 003 100 069	Days 75,8 45,7 62,3 46,3 102,4 104,0 108,4

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 borges, 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 contourfurrowed bluegross pasture $(Pa-C)^1$

[A rea, 1.074 acres; average slope, 11.0 percent; 7950 feet of contour furrows placed at 1-foot vertical intervals]

:			fcunofi		Grazing ²		
Year	Rainfall	Amount	Percent of rainfall	Maximum raie per hour	Soil loss per acre	animal- unit-days per acre	
1037 * 1938 1639 1640 1641 1642	Inches 16, 03 27, 23 27, 27 27, 79 35, 41 32, 90	Juckes 0, 34 , 33 1, 13 . 47 3, 22 2, 93	Percent 2.0 1, 2 4, 2 1.7 9, 1 8, 9	Inches 9. (1 10 1.30 16 .40 .29	Tons 0.049 .006 .035 .020 .136 .000	Days 59.5 59.0 34.6 56.9 71.0 103.5	

¹ Contout furrows were constructed on Nav. 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.

³ The pasture was grazed with entitle. 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 calcudar year only. Total rainfall for the year was 21.84 inches.

172 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

. TABLE 71.—Annual precipitation, runoff, soil loss, and crop yields from cultivated watershed (D-3)

[Area, 4.485 acres; | average slope 6.7 percent; control practices, none (farmed with field boundaries]

	Rainfall	ļ	Runofi			Cropping 2	
Year		Amount	Percent of rainfall	Max- imum rate per hour	Soit loss per acre	Crop kind	Yield per acre
1932 3	Inches 17, 65 31, 37 31, 18 36, 07 24, 25 21, 68 26, 22 27, 09 28, 17 34, 89 33, 20	<i>Inches</i> 0, 38 6, 02 6, 18 11, 54 2, 00 3, 50 1, 22 5, 41 2, 17 5, 69 5, 89	Percent 2,2 19,2 19,8 32,0 8,2 16,1 4,7 20,0 7,7 16,3 17,7	Inches 0, 10 2, 97 2, 46 4, 62 15 91 2, 66 3, 36 1, 53 3, 55 2, 72	Tous 0, 910 27, 731 40, 015 47, 380 880 19, 712 2, 625 25, 845 3, 275 63, 935 38, 443	Meadow. Corn Corn Oats. Meadow. Corn Oats Wheat Meadow. Corn Oats Oats Oats	Tons or hushels 0.43 28.0 (9 38.0 1.66 33.9 50.0 9.0 1.5 8.3 27.8

Area reduced from 4.847 to 4.485 acres on May 11, 1934.
 Rotation was corn, corn, oats, clover and finothy previous to 1937 at which time it was changed to corn, oats, where the set of the set of the set of the set.
 Data cover last 6 months of year only; total for the year was 27.36 inches.

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, grossed 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]

	1		Runoff			Cropping 3	
Year	Raintall	Amount	Percent of rainfall	Max- imum rate per bour	Soli loss per acre	Crop kind	Viela per acre
1934 4 1995	<i>Inches</i> 21, 20 36, 07 24, 77 24, 63 26, 63 26, 68 27, 62 35, 04 32, 89	<i>Inches</i> 5.93, 10.31 4.04 71 3.65 1.93 5.03 3.65	Percent 27.9 28.6 7.8 18.5 2.7 13.7 13.7 14.4 11,1	Inches 2,35 3,18 1,34 1,24 3,18 1,43 2,77 17 77	Tous 24, 040 16, 040 113 1, 825 1, 825 1, 825 1, 825 1, 825 1, 825 1, 776 1, 378 1, 378 1, 378	Onts	Tons or bushels 49.0 20.1 1.83 35.2 40.0 7.9 1.78 7.9 25.7

¹ Cultivation lines deviated from the contour by as much as 5% at a few points prior to 1039. The lines were relaid on an approximate terrace spacing and grade in the fall of 1935. 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 solid and - netro 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 tens per acre in 1930, and 125 pounds per acre fertilizer applied with each small grain erop]

			Runoff			Cropping 1			
Year	Rainfall	Amount,	Percent of rainfall	Max- imum rate per hour	Spil loss per acre	Crop kind	Yield per acre		
1934 ¹ 1935 1926 1937 1938 1938 1939 1940 1941 1941	Inches 21, 26 36, 07 24, 28 21, 62 26, 21 26, 21 26, 71 27, 50 34, 88 32, 83	Inches 5, 37 7, 97 1, 37 2, 99 2, 99 3, 52 3, 52 1, 66 4, 68 3, 29	Percent 25.3 22.1 5.6 13.8 2.7 13.2 6.0 13.4 13.4	Inches 2, 19 1, 48 , 14 , 14 2, 36 , 53 2, 07 , 29	Tons 4, 545 1, 625 , 006 , 203 , 055 , 632 , 045 1, 123 , 581	Onis. Whent. Mendow Corn Onts Whent. Mendow Corn Onts	Tona or bushels 40.5 20.5 1.66 40.7 41.0 9.5 1.68 12.0 30.9		

Practices were initiated in 1930 before installation of measuring equipment.

•

1

Э

Protation of corr, oats, wheat, clover and timothy mendow.
 Protation of corr, oats, wheat, clover and timothy mendow.
 Measurement for last 6 months of year only. 'Potal 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, 2.1)2 acres; average slope 9.1 percent; soil treatment, limed 3 tons per acre in 1932, 250 pounds per acre of 4-12-4 (ertilizer with original alfalfa seeding, 125 pounds per acre of 0-20-0 fertilizer annually with

			Ranof			Cropping				
)"enr	Rainfull	Amount	Percent of minfall	Max- imum rate per bour	Soil loss per acre	Crop kind	Yield per nere			
1033 1034 1035 1035 1035 1037 1038 1038 1038 1039 1040 1041 1041 1041 1042 104 10 1042 1042 1044 1042 1044 104	Inches 31.37 31.18 36.07 24.73 22.01 20.82 27.69 28.17 35.12 33.92	Inches 5.84 4.75 12.57 2.40 2.37 3.36 .73 2.03 2.39	Percent 15.6 15.2 34.9 3.5 10.9 5.8 J2.1 2.6 5.3 7.0	Inches 2.06 3.50 3.52 .00 .22 2.34 3.99 .41 .70 2.20	Tons 9, 885 6, 309 7, 634 . 002 292 6, 416 8, 10 . 056 . 026 . 026 . 324	Alfalfa do d	Tons or bushels 0.24 1.47 1.75 1.00 1.03 44.7 (?) 16.8 37.1 .89 37.1 .99 27.2 .71			

⁴ Continuous alfalfa was plowed out in the fall of 1937 and a small grain-lespedera annual rotation is now being studied. ⁴ No harvest.

وأستعلقه فالمتاب المتارينية والمترافية والمترافية

174 TECHNICAL BULLETIN 883, U. S. DEPT. OF AGRICULTURE

TABLE 75.—Annual precipitation, runoff, soil loss, and crop yields from rotation strip-cropped watershed (IJ-1)¹

[Area, 2.128 acres; average slope 9.3 percent; strip erapping, contour cultivation, grassed waterway; soil treatment, 200 pounds per acro of 0-20-0 fertilizer with each small grain seeding]

ないとうないというというというという

· ·	Rainfall		Ru	noc		
.Year		Amount	Percent of rain- fall	Maximun ho	i rale j#r ur	Gropping—klud and yield per sere ?
1933 3	Inches 21.39	Inches 5.08	Percent 23.4	Inches 1,-14	Толя 22. 594	Upper two strip seeded to meadow, no yickl; corn 14.5 bu; soybeans, 3.17 tons.
1934	31. I S	2.58	8.3	2,95	7. 395	Cl and 14 1.4 tons; corn, no harvest;
1935	36.07	10. 91	30.3	3,00	10, 186	Corn 3.5 but soybeans 1.02 tons; wheat
1936,	24, 73	1. 42	5.7	. 09	. 018	Oats 60.2 bu; corn, no harvest; cl and
1937	22.01	3.17	14.4	. 1,35	1 639	Claud t 1.95 ton; outs 57.4 bu; carn 59.6
1938	26.82	.49	. LS	. 42	. 088	Corn 9.1 bit; c) and $t + 1.40$ (ons; oats
1930	27,69	3, 42	12.4	3,12	, S7-I	Oats 19.6 hu; corn 40.3 bu; cl and 1 + no
1940	28.17	2.19	7.8	1, 12	. 853	Cl and t i 2.6 tons; onts 40.2 bu; corn
1941	35.12	1.77	6 G	1.31	. 192	Corn 11.8 hu; cl and t 1 2.26 tons; oats
1942	33, 92	1.08	ā. S	. 55	.118	Oats 39.4 bu; corn 73.6 bu; cł and t 1 2,37 tons.
	<u>.</u>	·				

The watershed was cropped in four strips of corn, soyheans, 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, outs, clover and timothy in 1936 and a small strip at the bottom of the slope retired to permanent hay.
* Crops and yields given in the sequence of their position from the top to the bottom of the slope.
* Data cover has 6 months of the year only. Total for the year was 31.37 inches.
* 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

		ation [0,25 Min.	0.50 M	0.50 Min.		0.75 Min.		Min.	1,50 Min.	
Year	Total amo	Total dure	Amount.	Amount	TYING	Amount	Time	Amount	J'ime	Amount	Time
1031 1032 1933 1934 1935 1036 1038 1938 1939 1931 1932 1934 1935 1937 1938 1930 1941	11. 42.10 27.36 31.37 31.18 36.07 21.72 26.16 26.84 27.76 31.62	Min, 26, 162 11, 372 0, 967 12, 737 17, 109 10, 759 11, 031 12, 972 12, 503 16, 823 19, 045	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	115, 64 110, 57 14, 83 12, 18 8, 12, 18 1, 7, 21 0, 5, 30 8, 10, 91 2, 11, 08 3, 8, 71 4, 10, 80	801 371 679 427 643 450 273 521 487 412 531	12, 61 9, 68 13, 58 11, 18 10, 54 4, 88 4, 40 9, 33 9, 43 7, 39 8, 94	517 253 325 325 376 215 176 365 319 277 317	10, 38 8, 75 12, 09 10, 19 9, 41 3, 91 3, 21 7, 52 8, 51 6, 01 7, 05	342 232 416 251 261 141 128 235 251 472 220	7, 12 7, 40 9, 12 8, 79 8, 20 2, 27 1, 81 5, 31 4, 73 5, 23	174 166 251 181 220 60 46 123 164 106 126
INVESTIGATIONS IN EROSION CONTROL

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	7'jmë	1unóuty	Time	Amount	'l'ine	Amount	J'ime	Amount	Time	Amount	The	Amount	Time	Amount	Tíme
5, 21 5, 76 7, 58 7, 48 6, 07 1, 58 1, 55 3, 95 4, 80 4, 01 4, 02	100 115 186 138 126 35 34 75 104 78 82	3. 51 4. 00 3. 71 5. 16 4. 55 . 79 . 48 2. 26 2. 26 2. 25 2. 38	54 64 59 76 78 13 7 32 38 39 39	$1, 66 \\ 1, 14 \\ 1, 70 \\ 3, 15 \\ .92 \\ .81 \\ .27 \\ 1, 55 \\ .68 \\ .73 \\ 1, 06 \\ $	19 13 22 40 13 4 20 7 10 13	0.85 02 61 .83 .20 .09 .59 .68 .50	8 10 5 8 2 1 7 7 7 6	0. 67 .40 .39 .46 .20 .15 .15	0 4 3 4 2 	0, 27 . 29 . 16 	2 2 1 	0. 14 .29 .16 .15 .15	1 2 1 1 	0, 15 . 16 	1 1

TABLE 77.---A mount 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 .					Duration	0.25 Min.		0.50 Min.		0.75 Min.		1.00 Min.		1.50 Min.	
				Amount		Rate	Time	Rate	The	Rate	Time	Rute	Timo	Rate	Time
Janua Febru March April May, Juay July Augus Septer Octob Nover Decen	ry ary l nber nber nber nber	· · · · · · · · · · · · · · · · · · ·		In. 11. 76 6, 27 12. 07 25. 51 38, 59 30, 66 25. 35 41. 58 35. 26 17. 82 11. 03 11. 03	Min. 11, 102 6, 413 11, 152 16, 609 8, 731 6, 390 13, 055 11, 753 8, 369 17, 296 11, 081	0. 48 . 21 3. 72 0. 35 10. 66 25. 51 15. 28 26. 20 18. 88 7. 90 0. 91 . 81	71 33 414 1,565 1,484 765 1,558 1,371 641 748 45	0, 10 2, 15 7, 05 15, 67 122, 52 13, 97 23, 05 14, 48 5, 75 3, 70 5	7 5 141 309 793 977 520 1,052 1,052 318 237 39	0. 07 1. 32 5. 97 12. 74 19. 57 12. 82 20. 04 12. 85 4. 25 2. 79 52	-1 59 484 671 406 748 490 172 145 16	0,07 .02 5.18 10,63 17,82 11,45 16,64 11,07 3.69 2.09 .42	4 127 320 524 318 516 375 127 75 9	0.80 4.41 8.71 13.05 8.13 13.04 7.85 2.20 1.08 .40	21 102 228 332 202 314 205 55 24 8
Tota			-	294, 85	141, 525	134.94	9, 374	109.34	5,064	83. 02	3, 385	79, 98	2, 442	61.15	l, 49L
2.00 Min. 3.00 Min.				4.00	Min.	5.00	Mîn.	0.00	Min.	7.00	Min.	\$.00	Mîn.	0.00	Min.
Rate	Time	Tate	Thine	Rate	Thine	Rate	Time	Tate	7'irne	Rate	Thue	Rate	1'lme	Rate	'Thrue
0.51	10 75	0.41	7	0.07		0. 53		0. 16	4	: 0. is		0.16		0.16	
7.08 11.27 7.24 9.79 5.77	$158 \\ 237 \\ 140 \\ 200 \\ 118 $	4, 26 6, 60 4, 61 5, 42 4, 17	71 107 74 80	1, 13 2, 69 1, 52 2, 95 2, 02	14 34 19 37 26	.35 1.03 .72 1.57 24	4 10 7 17 2	20 50 63 24	2 5 6 2 1	. 29 . 13 . 14	2	.29	2	. 15	1
1.61 .78 .34	34 13 6	, 97 , 70 , 22	19 11 3	- 47 - 22	73						<i>*</i>				
48. 05	901	20, 06	460	12, 11	152	4,77	46	2, 27	20	. 87	G	.74	5	. 46	3

U. S. GOVERNMENT PRINTING OFFICE: 1940

175

END