SOIL AND WATER RESEARCH ON A CLAYPAN SOIL

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SOIL AND WATER RESEARCH ON A CLAYPAN SOIL

A Compilation of Results of Research Conducted at Midwest Claypan Experiment Farm McCredie, Mo. 1937–1962

By V. C. JAMISON, D. D. SMITH, and J. F. THORNTON

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SUMMARY OF RESULTS

Runoff and Erosion.—Soil and water losses from a sloping claypan soil[1] depend on both its cover and surface conditions. The surface condition, including cover density and soil aggregate stability, is related to soil fertility.

In earlier studies conducted at relatively low soil fertility levels, grasses and sod crops in rotations appeared to be essential to soil and water conservation on Mexico silt loam and similar soils. However, the increased use of lime and fertilizer and the return of heavier crop residues to the soil have reduced the erosion hazard on these claypan soils of the Midwest. Although soil losses from a sloping claypan soil producing continuous corn with a full-fertility program are still higher than those from corn in a rotation, the hazard is largely confined to the period from seedbed preparation to the time of establishing a crop canopy. Even in a corn-wheat-meadow-meadow rotation with a good fertility program there are, during the time from seedbed preparation to establishing a crop canopy, periods of erosion hazard for corn and for wheat. But with the sod-based rotation, both the intensity and frequency of the hazard are appreciably less than with continuous grain cropping.

Although runoff is generally low and erosion of no consequence from established pasture sods, both are moderately high from small grain-lespedeza rotations. Grazing these areas increases significantly both runoff and erosion as compared to using them for hay and grain production.

Average annual runoff from the small plots during 1941–50 varied from 6.8 to 11.7 inches for different cropping and fertilization systems. The lowest was for well-fertilized pastures of timothy, sweetclover, and lespedeza and the highest for an unfertilized corn-oats rotation.

Pasture production studies in the late 1940's and early 1950's indicated that pasture fertility improvement is profitable. Trends in the late 1950's and early 1960's, with adequate soil fertilization,

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[1] The results reported here were conducted on Mexico silt loam soil.

showed that greater immediate profit may be expected from continuous corn than from pasture or rotation cropping systems on Mexico silt loam and similiar soils; however, the erosion hazard is higher.

Terracing.—Slope lengths too long for effective erosion control by contouring alone can be shortened by terracing. Movement of soil toward terrace channels can be counteracted by upslope plowing of the terrace intervals.

In a 7-year observational study of channel grades for terraces about 800 feet long, grades less than 0.3 percent were subject to sufficient ponding to damage crops growing in the channel and to hamper tillage and harvesting operations. Grades steeper than 0.5 percent subjected the channel to scour hazard for cultivated crops, although grades up to 0.7 percent were relatively free from scour when cropped to wheat or meadow.

Conversion of conventional to parallel terrraces nearly doubled the average contour row length, reduced the number of turns, and decreased the point-row areas by 70 percent. Average rate of travel of farm equipment was 16 percent faster on the land with the parallel terraces. The average saving in production time for corn and soybeans was about 24 percent. There was no apparent increase in channel scour over that observed with conventional terraces of equal grade.

Eleven years of terrace-capacity studies showed that the experimental terraces were designed with flow capacities above experienced runoff volumes. The terraces are the conventional type on land with about 3-percent average slope, 0.33-percent grade, 1,050-foot length, 2½-foot vertical interval, 23-square-foot average channel capacity, and about 2¼-acre drainage area. Runoff from the most severe storm of the period utilized about half the capacity of the channels. Such a storm may be expected somewhat less frequently than once in 10 years. For similar conditions, a channel cross section that increases to about 20 square feet at the outlet should safely accommodate the maximum runoff volume that may be expected once in 15 years. With terraces designed to accommodate multirow farm equipment, channel capacity generally will exceed that required to carry the runoff volume expected once in 15 years.

Soil Moisture.—The claypan restriction on internal drainage increases the available moisture storage capacity of the silt loam surface soil. The available water that the claypan itself may store is somewhat less than might be expected, because a very high proportion of the total stored amount cannot be extracted by plants. The amount of rainfall that enters the Mexico silt loam or similar claypan soils is dependent on soil surface conditions as well as on the profile.

Studies of the year-round volume moisture changes in the various profile layers showed that moisture extraction by bluegrass is largely confined to the upper 2 feet, whereas corn and alfalfa extract appreciable moisture to depths greater than 4 feet. Volume changes under claypan soils supporting deep-rooted plants are not restricted to the surface and claypan layers. Differential changes under and around buildings in these soils cause stresses and cracking of foundations and walls during changes from wet weather to extreme drought.

Irrigation.—Evapotranspiration estimates, rainfall records since 1890, and available moisture capacity data for Mexico silt loam were used to predict average drought frequencies in the McCredie, Mo., area. These data indicate that 4 years out of 10 will be drought years when the yields of grain, hay, and pasture crops may be materially increased by irrigation.

In a 10-year test of irrigation on corn, an average annual application of 5.3 inches of water increased yields by 34 bushels per acre. Based on an assumed cost of $4 per acre-inch for the water applied, the cost of the corn-yield increase would have been $0.62 per bushel. If handling, storage, and marketing costs are added and the average price to be expected for corn is less than $1 per bushel, the profit will be small.

Irrigation of soybeans showed a profitable increase in only 1 year out of 6. A single application of 4.7 inches in August 1953 increased yield by 14 bushels per acre at an estimated cost of $1.34 per bushel. It appears that irrigation water can be applied more profitably to other crops than to soybeans at this location.

Although irrigation of pasture plots increased beef production in 2 years out of 3, the value of the extra beef did not pay for the cost of irrigation. Annual application depths varied between 2½ and 12 inches. The estimated cost per pound of extra beef produced by irrigation varied from $0.25 to $0.74.

Irrigation of wheat grown in rotation with meadow may help to insure a stand of grass-legume seeding in the wheat. A significant yield increase of 3.2 bushels per acre was obtained 1 year during a 5-year study period.

Water requirements of crops, storage losses, and expected water yields from the drainage area must be considered in the design of a storage reservoir to be used as a water-supply source for irrigation. Measurements at McCredie, Mo., during the drought year of 1954 indicated that evapotranspiration from small corn plots over the 120-day production period averaged 0.185 inch per day, or about 22 inches for the season.

Mexico silt loam is capable of storing about 6 inches of available moisture in the upper 4 feet of the profile. Since storage recharge is complete at planting only about one-half of the time, probably no more than 4 inches of available water should be used in estimating reservoir storage requirements. Considering the application efficiency to be 75 to 80 percent and pond storage losses to be about 14 inches (estimated seepage and evaporation losses from the 16-acre reservoir at McCredie during the irrigation season), it was estimated that 532 acre-inches of storage would be required to furnish an irrigation supply of 400 acre-inches. This would be the annual requirement for 16 acres of corn and 16 acres of pasture during extreme drought. A 2-year supply for this acreage would require a storage volume of 1,190 acre-inches.

Water-yield measurements for the 154-acre mixed-cover watershed at McCredie indicated that the expected minimum runoff volumes for consecutive 2-year periods were three to four times greater than for single years. The watershed area required to furnish the 2-year supply would be 433 acres, whereas that needed for a 1-year supply would be 806 acres. Thus, for a 1-year supply on this soil, a reservoir storage volume of 1.39 acre-feet and a drainage area of 25 acres would be required per irrigated acre. For a 2-year supply, the required storage volume would be 3.10 acre-feet and the drainage area 14 acres.

Grass Waterways.—Bluegrass sod in waterways can withstand high velocities of flow without deterioration of the channel if a few conditions are met in channel construction. Sharp changes in alinement, horizontal or vertical, tend to result in scour damage under high flow velocities. However, increases in bed slope from 1 to 4 or from 4 to 8 percent did not cause damage to sod by flows up to 9 f.p.s. with a duration of 50 minutes. The rate of scour in inches per hour was directly related to the square root of the average velocity in feet per second and inversely to the grass density.

For 2-year-old sods, Kentucky bluegrass gave better protection against scour than did other grasses tested. But for 1-year-old sods, timothy and redtop were superior to bluegrass. Kentucky bluegrass, 1 year after seeding, did not provide adequate protection for velocities of 3 f.p.s. and greater. Bluegrass, 2 years after seeding, withstood up to 7 f.p.s. A grass mixture of timothy, redtop, and bluegrass is suggested for these soils.

The hydraulic data for bluegrass at maximum growth stage (headed out) were used to prepare charts for channel design. The factors considered in these charts are the expected maximum rates of discharge, average velocity of flow, and bed slope. These are used to determine the appropriate channel width and depth. Separate charts are presented for use in designing channels with trapezoidal or parabolic cross sections.

Subsoiling and Deep Fertilization.—Subsoiling alone had little effect on yields of corn, small grains, and soybeans on Mexico silt loam. Application of lime or lime and phosphate in the subsoil during the subsoiling produced small increases in yields of corn and alfalfa and enhanced the depth of rooting of sweetclover. However, the yield increases were not enough to recommend the practice for practical farm use.

Reclamation of Severely Eroded Land.—The returns from reclaimed areas on the Midwest Claypan Experiment Farm over a 5-year period justified the costs of filling in gullies and smoothing and fertilizing eroded and infertile areas in Mexico silt loam and associated soils.

INTRODUCTION

The claypan soils[2] of the Midwest prairie region are problem soils. A clay subsoil layer beginning at a depth of 7 to 18 inches restricts air and water movement and retards the development of plant roots. The upper horizons are usually low in natural fertility and, unless corrective treatments are made, the profile down to and including the claypan is usually acid. Neglect, misuse, and erosion have further depleted fertility and reduced the productivity of these soils. However, many of them respond very well to good management practices; and, with a fairly deep silt loam surface remaining, they can be brought to a level of production approaching that of the best soils.

The total area of claypan soils of the Midwest (fig. 1) has been estimated to be about 10 million acres (*52*).[3] The principal extensive areas are in Missouri, Illinois, and Kansas. Secondary, less extensive areas are in Nebraska, Oklahoma, and Iowa. The latter are fringe areas, where the soils are so nearly like claypan that much of the information on claypan management practices applies to them also.[4]

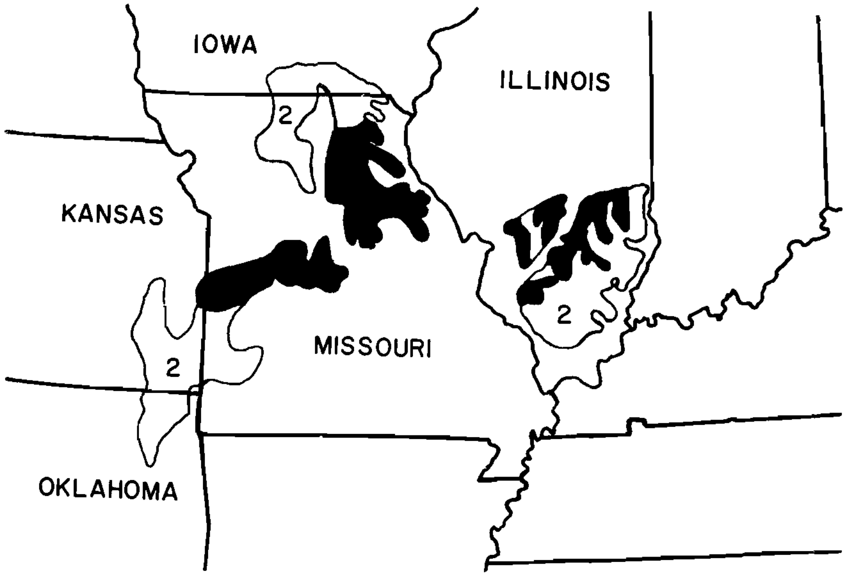

FIGURE 1.—Extent of claypan soils in Midwestern United States. Research results at Midwest Claypan Experiment Farm may be considered directly applicable for dark areas and generally applicable for larger outlined (2) areas.

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[2] The studies reported here were conducted on Mexico silt loam soil, which is considered typical of the sloping Midwest claypan soil.

[3] Italic numbers in parentheses refer to Literature Cited, p. 108.

[4] Personal communication from Roy W. Simonson, Director, Soil Classification and Correlation, Soil Conservation Service, U.S. Department of Agriculture.

The term "claypan" usually refers to those soils in which a clay subsoil layer has formed during soil development and maturity (*58*), although soils with clay subsoils that were deposited in place have sometimes also been called claypan (*72*). Most of the Midwest claypan soils were developed under grass vegetation, although some occur under forest cover (*8, 40*). The largest areas are in the more humid prairie region, but some claypan soils are found in drier chernozem areas (*7, 29, 70*).

Extensive areas of claypan are relatively flat prairie lands. Streams and natural drainageways dissect the prairie, forming gently rolling slopes, which are occasionally more than 5 percent. The sloping claypan soils are subject to erosion unless wisely managed. Soil surveys prior to 1936 showed a loss of about 7 inches, or about one-half the original topsoil, from the sloping claypan soils of Boone and Callaway Counties, Mo., in about 70 years.[3] During this period, increasing areas of the sloping claypan soils were plowed from pasture or meadow and planted to small grains and intertilled crops without fertilizer and usually without regard to slope. Production declined with continued removal of nutrients by the crops and through losses from runoff and erosion.

Description of Representative Claypan Profile

Mexico silt loam is representative of most of the gently rolling, more erosive soils of the claypan areas in the Midwest. A typical profile is shown in figure 2.

The surface layer (A_p, 0–7 inches) is very dark grayish-brown friable silt loam (*27*). A lighter gray horizon is often incorporated with this layer in cultivated soils. The next surface layer (A_3, 7–11 inches) is dark grayish-brown fine silt loam, with fine splotching of dark yellowish-brown stains. The structure is weakly developed, fine-to-medium granular.

The upper illuvial claypan layer (B_{21}, 11–16 inches) is dark grayish-brown silty clay, highly mottled with yellowish red. There are numerous small iron concretions. The structure is very fine, moderately developed, angular, and blocky, with thin clay skins on some aggregate faces. The next claypan layer (B_{22}, 16–25 inches) is dark grayish-brown silty clay, with fine reddish-brown mottling and numerous small concretions. It is plastic when wet and breaks indistinctly into fine angular fragments, with thin clay coatings on the faces. The lower illuvial claypan layer (B_3, 25–34 inches), which is the transition zone, is a massive brown silty clay, with large splotches of yellowish-brown and yellowish-red stains.

The parent material (C layer, 34–50 inches), or deep subsoil, is dark grayish-brown silt loam to coarse silty clay loam. There are splotches of brown and dark-red concretions. The structure is massive. The C layer is loessal in origin and often overlies a layer of gumbotil (*28*).

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[3] Personal communication from H. E. Grogger, State Soil Scientist, Soil Conservation Service, U.S. Department of Agriculture.

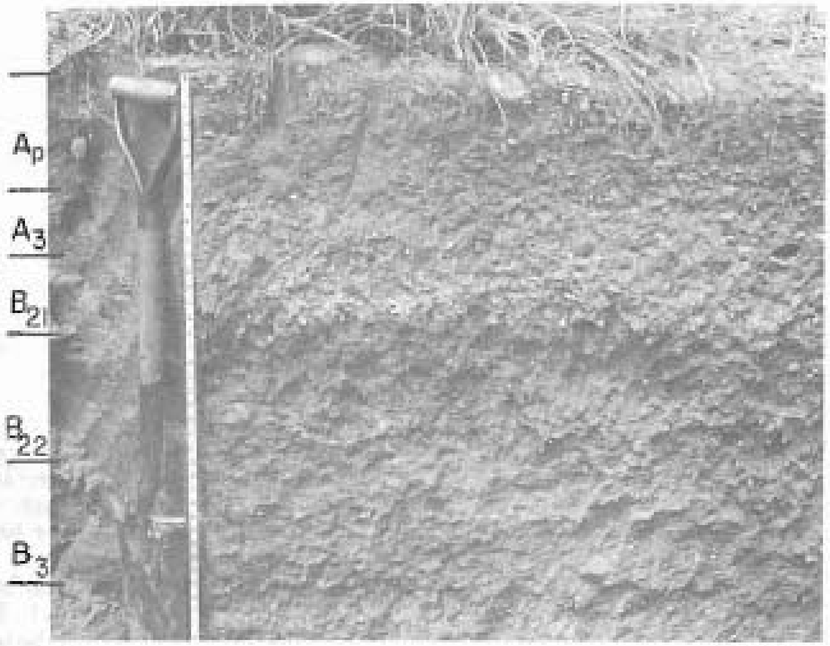

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FIGURE 2.—Typical Mexico silt loam profile.

The loessal parent materials of the Midwest claypan soils are generally considered to be of windblown or eolian origin (*14, 20, 21, 31, 32, 34, 39, 57, 58, 60, 61, 63*). The claypan soils of the north-central Missouri prairie have developed in Yarmouth loess overlying glacial till of the Kansas stage (*67*).

Physical and Chemical Characteristics of Claypan Soils

The claypan soils of the Midwest are naturally acid and low in some nutrient elements in the upper layers and in the claypan. The original loessal material was rich in lime, magnesium- and potassium-rich minerals, and phosphates. The percentages of potassium and plagioclase feldspar in the silt fraction of these soils are directly proportional to soil fertility and indirectly proportional to degree of silt weathering (*19*). Younger soils near loessal sources of deposition are naturally higher in fertility than the mature claypan soils. Soil maturity increases in loessal-derived soils with windward distance from the major stream source (*26*). Leaching not only removes the carbonates from the A and B horizons but reduces the calcium, potassium, and other nutrient cations from the primary mineral crystals of the soil surface layer.

The exchange complex of the secondary minerals of the Midwest prairie claypan soils is dominated by hydrogen unless lime is applied to correct soil acidity. The surface layers are low in total phosphorus. The deep subsoil loessal layer beneath the claypan is usually richer in phosphorus than either the claypan or the layers above it (*15, 16, 33*). With an increase in acidity, the phosphates remaining in the claypan layer are transformed to less soluble or fixed compounds of iron and aluminum or to strongly adsorbed phosphates. In the surface layers this tendency is counteracted somewhat by the accumulated organic matter (*1, 10*).

The soil surface layer or A horizon is markedly different physically and chemically from the claypan or zone of clay accumulation. The A horizon is high in silt content. This is inherent from the loessal parent material for most of the Midwest claypan soils (*67*). Weathering of some of the loess and movement of the very fine secondary clay particles formed by the process to the lower horizons leave the soil surface as coarse or a little coarser in texture than the parent loess. Some organic matter accumulation in the surface may give a degree of aggregation and structural stability not present in the parent loess. Because of its high silt content, the surface layer is usually high in total and available moisture storage capacity (*23*). Available moisture storage capacity of more than 0.25 inch of water per inch of depth has been estimated for a surface layer sample of Mexico silt loam.

Although leaching has reduced the fertility of the soil surface, nutrient deficiencies in this layer are not difficult to correct. Because of its silty nature and relatively low clay content, the exchange capacity of the surface is not extremely high. Moderate applications of lime and potash fertilizer will adjust the exchangeable calcium and potassium to desirable soil test levels (*17*).

The principal clay minerals in the claypan layer are of the montmorillonitic group, which is characterized by an expanding crystal lattice. When wet, these clays swell, closing cracks in the claypan layer and forming a plastic mass with a very slow rate of absorption. Upon drying, the mass will shrink, forming some large cracks and numerous small ones. The bulk density of the wet soil may not be very high; yet, because of fine particles, the permeability is low. With drying and shrinking, the bulk density increases. The density of a hard, dry fragment between cracks may be more than 1.6 grams per cubic centimeter, whereas the corresponding dry-weight density of a mass of the wet clay may be less than 1.2 grams per cubic centimeter.

Because of its fine porosity, very little oxygen can diffuse into a wet claypan. The pores in this layer will remain nearly full of water over a wide range of low suctions for claypan of Putnam, Mexico, and similar soils (*23*).

Although the total moisture-holding capacity of the claypan layer is high, the available storage capacity is somewhat lower than that for the silt loam surface, because a large part of the stored water is retained in the clay when the wilting point is reached (*23*).

Climate of Area

The climate of the claypan prairie area of central and northeastern Missouri is continental (*35*). There are frequent changes in the weather, both from day to day and from season to season. Missouri lies in the path of cold air masses moving out of Canada, dry air from the West, and warm moist currents from the Gulf of Mexico.

The average annual precipitation for 1891–1960 for weather stations in the vicinity of McCredie, Mo., was 37.95 inches (table 1). In the cool months, part of the precipitation occurs as snow. Most of the snow falls in December, January, and February, but some may fall as early as October or as late as April in the central prairie area of Missouri. The average annual snowfall north of the Missouri River is 18 to 22 inches. It is unusual for snow to remain on the ground for more than 1 or 2 weeks.

The average monthly rainfall is highest during the late spring and the summer. The storms during the warm season usually have greater intensity. Since they often occur during seedbed preparation or before growing crops provide adequate protective cover, they may cause considerable erosion damage.

Rainfall during the crop-production period varied widely. The 70-year average (1891–1960) for the July-August period was 6.98 inches. The typical claypan soil will store 6 to 7 inches of available moisture in the upper 4 feet of soil (*27*). With adequate moisture supply, the average evapotranspiration rate at McCredie is about 0.2 inch per day during the 3 summer months. Thus, if the soil storage capacity is filled at the beginning of the hot summer season and average rainfall is so distributed that runoff losses are small, there will be sufficient moisture to supply the needs of most crops. However, such a fortunate combination of circumstances will occur in only about one growing season out of two. At the Midwest Claypan Experiment Farm, moisture has been a limiting factor in crop production in about half the summer seasons.

The average annual temperature for 1941–60 was 54.7° F. (table 2). The average annual night temperature (minimum) was 23.0° lower than the average annual day temperature (maximum). The wide periodic variations in temperature throughout the year are obscured in the tabulated averages.

The average date of the last freezing temperature (28°–32° F.) in the spring is April 18 at Mexico, Mo., and of the first freezing temperature in the fall is October 18. The average frost-free interval is 183 days.

Midwest Claypan Experiment Farm

The Midwest Claypan Experiment Farm was established near McCredie, Mo., in 1937 by the Soil Conservation Service of the U.S. Department of Agriculture, in cooperation with the Missouri Agricultural Experiment Station, to study those problems common to the gently rolling area of Midwest claypan soils (fig. 3). The

TABLE 1.—*Average monthly and annual precipitation for 1941–60 and 1891–1960* [1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1941	2.76	0.15	0.76	6.69	1.97	4.24	7.22	2.45	6.64	17.74	2.46	1.09	54.17
1942	.46	2.47	1.76	2.62	4.57	10.30	2.11	2.39	4.26	1.95	3.91	4.77	41.57
1943	.64	.80	1.75	2.42	12.05	6.19	3.71	1.16	3.13	3.29	1.12	1.66	37.92
1944	.46	2.46	2.94	6.12	4.54	.46	1.85	6.54	4.19	1.77	1.43	1.07	33.83
1945	.87	1.82	5.66	5.43	5.05	7.53	.74	.87	13.13	.86	.98	.52	43.46
1946	2.20	1.85	2.60	3.01	5.99	1.35	1.80	4.84	1.24	5.88	5.30	1.05	37.11
1947	.83	.14	3.08	6.57	3.11	7.69	2.91	.35	2.75	3.17	1.21	1.70	33.51
1948	1.22	1.34	4.41	.95	3.53	6.86	6.24	4.34	2.00	3.65	3.22	1.22	38.98
1949	5.48	2.40	4.67	1.73	3.46	5.93	3.76	4.83	5.04	4.71	.96	3.04	46.01
1950	2.30	1.60	2.65	3.11	1.98	3.07	2.13	5.20	.55	1.04	1.33	.12	25.08
1951	1.50	4.03	3.75	1.99	2.85	6.52	2.35	4.22	5.65	3.59	1.66	1.75	39.86
1952	1.10	1.23	3.42	2.60	2.15	3.35	2.37	4.78	1.26	.21	4.23	1.43	28.13
1953	1.42	1.01	3.60	2.95	3.74	3.50	1.96	2.14	2.38	2.72	.60	.71	26.73
1954	.71	.72	1.99	3.58	3.62	2.45	.20	5.33	1.93	4.72	1.04	1.52	27.81
1955	2.01	3.06	1.26	3.05	3.12	4.95	2.89	2.66	3.89	4.52	.63	.16	32.20
1956	.38	1.17	.37	2.49	4.36	1.80	9.20	2.78	.65	1.22	1.60	2.84	28.86
1957	1.31	2.10	2.73	5.42	4.43	6.44	2.67	.44	1.26	2.80	1.96	2.81	34.37
1958	1.19	1.07	2.96	2.73	3.40	5.30	9.23	2.77	3.06	2.10	3.06	.38	37.25
1959	1.55	2.72	2.28	2.46	5.31	.03	3.37	2.14	4.56	5.92	.58	1.97	32.89
1960	1.20	1.41	1.64	4.41	3.01	3.51	3.65	1.30	.63	4.09	1.29	2.04	28.18
Average:													
1941–1960	1.48	1.68	2.71	3.52	4.11	4.57	3.52	3.08	3.41	3.80	1.93	1.59	35.40
1891–1960	1.96	1.77	2.88	3.70	4.60	4.66	3.52	3.46	4.00	3.11	2.35	1.94	37.95

[1] Data for 1891–1940 derived from Mexico and Fulton, Mo., records and for 1941–60 from McCredie records.

TABLE 2.—*Average monthly and annual temperature at McCredie, Mo., 1941–60*

Month	Maximum	Minimum	Average
	° *F.*	° *F.*	° *F.*
January	40.60	20.67	30.6
February	45.00	23.69	34.3
March	53.01	30.56	41.8
April	66.84	42.85	54.8
May	75.40	52.17	63.8
June	84.26	61.90	73.1
July	88.84	65.14	77.0
August	88.54	64.02	76.3
September	81.84	55.11	68.5
October	70.96	45.32	58.1
November	54.78	32.59	43.7
December	43.83	23.99	33.9
Average annual	66.16	43.17	54.7

experiment farm soil, classified as Mexico silt loam, is representative of the soils of the area. The farm is located on U.S. Highway 40, about 22 miles east of Columbia and 1 mile east of Kingdom City.

The tract contains approximately 300 acres, most of which is typical claypan soil. Except for small areas of exposed glacial material on the steeper slopes adjacent to the drainageways, the soils are developed on loessal deposits. The soil on the higher and flatter areas in this vicinity is classified as Putnam silt loam, whereas the loessal-derived soil on slopes is Mexico silt loam.

Shortly after the farm was acquired, all the areas designated as cropland were seeded to meadow. Most of this land was subsequently used in various experiments. The experimental plots, fields, and terraced fields established during 1939–52 are shown in figure 4. Major changes in the studies were made during the next 2 years.

The first experiment (series I), started in 1940, consisted of five 2-acre pastures with three subplots, each equipped for measuring runoff and erosion (figs. 4 and 5). The second experiment (series II), started in 1941, consisted of 39 plots, each 0.022 acre, for study of runoff and erosion from grain and meadow crops in various rotations. In 1955, a study on the effect of contouring on runoff and soil loss from continuous corn was started. Two 1-acre contour plots with a slope length of 420 feet were equipped to measure runoff and soil loss.

The first experimental field terraces were constructed in 1941 to obtain information on construction methods, channel design for interception of subsurface flow, terrace grade, and channel capacity. Modification of the conventional terraces to parallel ones on fields 2, 3, and 4 began in 1950.

Subsoiling and subsoil fertility treatments (series III) were started in 1942 on 27 plots. These were to test the response of corn, small grains, sweetclover, and alfalfa to subsoil shattering, with

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FIGURE 3.—Midwest Claypan Experiment Farm at McCredie, Mo., as it appeared when purchased in 1937.

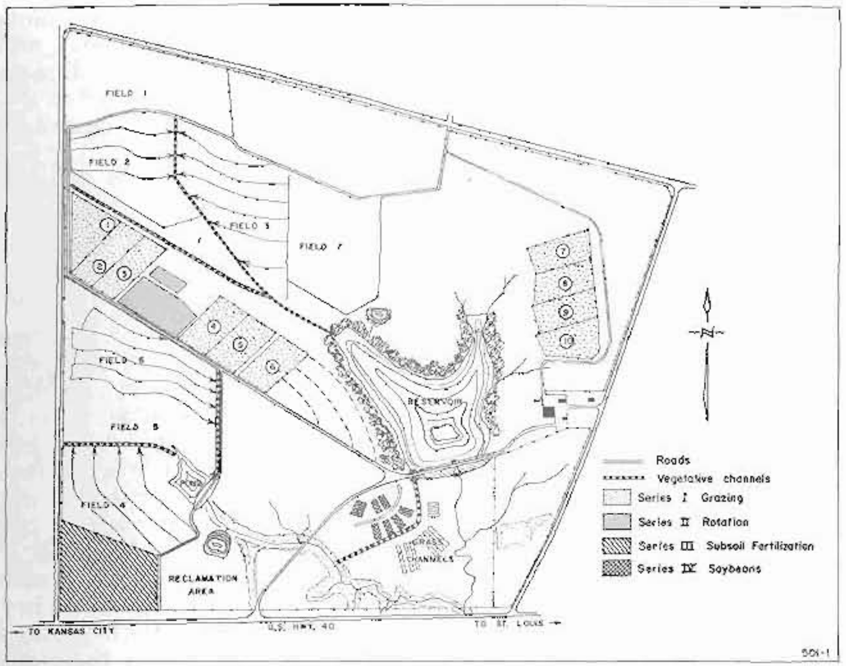

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FIGURE 4.—Midwest Claypan Experiment Farm, showing location of experimental plots and fields, 1939–52.

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FIGURE 5.—Pasture plot 4, showing small triplicate subplots from which soil and water losses were measured.

and without lime or lime and phosphate fertilizer. Series IV plots were started in 1942 to study the yield effect of row width and direction (contour versus up-and-down slope). Several studies on crop response to irrigation were started in 1948.

The results of these various field experiments are discussed in this bulletin.

RUNOFF AND EROSION

Equipment and Procedure

In the early studies, the effects of pasture crops and grain crops and their sequence in a rotation on runoff and erosion were emphasized. The pasture plots (series I) started in 1940 were on five 2-acre fields (*68*). Water- and soil-loss measurements were made on pasture plots 1 through 5 from small triplicate subplots within each pasture area (fig. 4). These small plots were 10½ by 90 feet and were laid out lengthwise with the slope, which averaged about 3 percent for each plot. These subplots were discontinued in the fall of 1950.

The 39 grain-crop plots (series II) started in 1941 were also 10½ by 90 feet and on a 3-percent average slope (fig. 6). They were laid out and farmed lengthwise with the slope. Both pasture and grain-crop plots were enclosed by steel dividers on the sides that were driven into the soil about 6 inches and extended about 4 inches above the surface. At the upper end of the plots was a small earthen dike. Borders were laid out 3½ feet on each side of each grain-crop plot and farmed the same as the plot itself.

The runoff- and soil-loss measuring equipment was essentially a standard installation (*45, 54, 68*). The system consisted of a sediment tank and a nine-slot divisor, ½ by 4 inches, with a silt-water storage tank having a maximum capacity of about 7 inches of runoff (fig. 7).

Representative triplicate samples of silted water and sediment were obtained from the tanks, and the volumes in the sediment and storage tanks were measured before cleaning. The sediment in the tanks could usually be stirred into suspension and sampled. For excessive soil loss, the silted water and the sediment in the sediment tank were measured for volume and sampled separately.

BN-[illegible]

FIGURE 6.—Grain-crop plots (series II) as they appeared on December 23, 1940, showing equipment for measuring runoff and soil loss.

BN-[illegible]

FIGURE 7.—Equipment for measuring runoff and soil losses, showing nine-slot divisor for separating one-ninth aliquot of overflow from sediment tank (foreground) for large runoff volume storms. Silt-water storage tank in background.

In 1943, three bluegrass pasture plots (series I) were established to study the effects of fertility treatments and legume seeding and of contour furrows on runoff and production. Runoff was measured from the entire 2-acre area with 2-foot H flumes and water-level recorders.

In 1955, two 1-acre contour plots with a slope length of 420 feet were equipped with flumes and samplers to measure runoff and soil loss.

Pasture Studies

Soil Treatments

Light applications of fertilizer were used during 1938–46 and higher levels during 1947–51 (table 3). These two levels of fertilization reflected the recommendations being made to Missouri farmers at the beginning of the two periods (*68*). The grass and legume pastures were established in 1938 with 200 pounds per acre of 0–20–10 fertilizer, and in 1943 and 1945 they received the same amount and kind. An unplowed bluegrass pasture was fertilized with 400 pounds of 0–20–10 in 1942 and with 200 pounds in 1945. Lime was applied to all plots receiving fertilizer in the 1938–46 tests.

TABLE 3.—*Cropping system and soil treatment on pastures (series I) during 1938–46* [1] *and 1947–51*

Years and plot	Cropping system	Soil treatment	
		Year	Amount per acre
1938–46			
1	Timothy, lespedeza	1938 1943 1945 1946	Lime, 3 tons; 0–20–10, 200 lbs. 0–20–10, 200 lbs. 0–20–10, 200 lbs. Lime, 2 tons.
2	Oats (hay), lespedeza	1938	Lime, 3 tons; 0–20–10, 100 lbs., with small grain seeding.
3	Wheat, lespedeza		
4	Barley, soybeans (hay).	1946	Lime, 2 tons; 0–20–10, 100 lbs., with small grain seeding.
5	Timothy, sweetclover, lespedeza.	1938 1943 1945 1946	Lime, 3 tons; 0–20–10, 200 lbs. 0–20–10, 200 lbs. 0–20–10, 200 lbs. Lime, 2 tons.
6	Bluestem [2]	1942 1945	Lime, 3 tons; 0–20–10, 400 lbs. Lime, 2 tons; 0–20–10, 200 lbs.
7	Bluegrass (renovated).	1942 1945	Lime, 3 tons; 0–20–10, 400 lbs. 0–20–10, 200 lbs.
8	Bluegrass (check)		None.
9	Bluegrass (contour furrow).		Do.
1947–51			
3	Wheat, Korean lespedeza.	1947–48 1949 and later	10–20–20, 100 lbs., on wheat. *Basic*: Lime, 2 tons, and rock phosphate, 466 lbs.; *maintenance*: 0–20–20, 200 lbs., and 33–0–0, 60 lbs., on wheat.
5	Kentucky bluegrass, Korean lespedeza.	1947 1949 and later	10–20–20, 200 lbs. *Basic*: 0–20–10, 830 lbs. (1949); *maintenance*: 0–20–20, 200 lbs. (1951).
6	Bromegrass (sweetclover seeded, 1947–49).	1947 1949 and later	10–20–20, 200 lbs. *Basic*: Lime, 2 tons, and 0–20–10, 760 lbs. (1949); *maintenance*: 0–20–20, 200 lbs. (1951), and 33–0–0, 100 lbs. (fall and spring, starting fall 1950).
7	Kentucky bluegrass (sweetclover seeded, 1947).	1947 1948 and later	10–20–20, 200 lbs. *Basic*: Lime, 2 tons, and 0–20–10, 800 lbs. (1949); *maintenance*: 0–20–20, 200 lbs. (1951), and 33–0–0, 100 lbs. (fall and spring, starting fall 1948).
8	Kentucky bluegrass		None.
4	Rye, soybeans (grain).	1948	Established 1948 (previously limed). *Basic*: Rock phosphate, 450 lbs., and 0–0–50, 200 lbs. (1948); *maintenance*: 10–20–20, 150 lbs., with rye, and 0–20–20, 150 lbs., with soybeans (1949 and 1950).
1	Alta fescue (Ladino clover seeded, spring 1951).	1949	Established spring 1949. *Basic*: Lime, 2 tons, rock phosphate, 2,000 lbs., 0–0–50, 315 lbs., and 8–8–8 starter, 325 lbs.; *maintenance*: 0–20–20, 200 lbs. (1951).
9	Bromegrass, Ladino clover.	1949	Established spring 1949. *Basic*: Surface 10 inches: Lime, 6 tons, rock phosphate, 2,000 lbs., 0–0–50, 357 lbs., and 0–20–20 starter, 115 lbs.; subsoil (10–15 inch horizon): Lime, 3 tons; *maintenance*: 0–20–20, 200 lbs. (every other year).

[1] Plots 1–6, 1938–46; plots 7–9, 1942–48; all crops grazed except as noted.

[2] Establishment of bluestem not satisfactory; no runoff and erosion or grazing measurements; reestablished in bromegrass and sweetclover in 1945.

Soil treatments applied in 1947–51 were made according to soil tests (*17*). Lime, phosphate, and potash were brought up to sufficiency levels on treated plots and nitrogen was applied on some plots (table 3). These applications of calcium, phosphorus, and potassium corrected the differences in levels of these nutrients that resulted during 1938–46. Plot 2, from which oats had been removed for hay when tested in 1946, required a special corrective treatment of 108 pounds of potassium per acre to bring the potash level up to that of adjacent plot 3, which had been used only for grazing. Removal of potassium in soybean hay from plot 4 also resulted in a lower level of potassium by 1946.

1951–52 was a period of transition. The drought years of 1952–54 brought an increased emphasis on irrigation, which resulted in several changes in the pasture treatments. Ladino clover was seeded in some of the pastures, but the stand did not survive the dry weather. Plots 1–3 were discontinued and six additional 2-acre plots were started during this period for an irrigation and nitrogen fertilization study on pastures.

Soil and Water Losses

Soil- and water-loss data for 1940–46, as summarized by Whitt (*68*), are shown in table 4. The two timothy pastures averaged less than one-half ton of soil loss per acre per year, and much of this loss came during the early years before good establishment. The plot with sweetclover retained an annual average of about 2 inches more water from rainfall than did the other timothy plot. This was probably due in part to soil structural improvement and in part to greater depth of drying of the subsoil by the clover roots, which resulted in increased intake from rainfall.

The two small grain-lespedeza pastures had about the same runoff losses, but the soil losses from the oats (for hay) and lespedeza were higher than those from the wheat-lespedeza plots. This difference was due largely to variations in weather and mois-

TABLE 4.—*Average annual runoff and soil loss from pasture and grain-crop plots, 1940–46 and 1945–48*

Years, series, and plot	Cropping system	Runoff	Soil loss
1940–46[1]			
Series I (pastures):		*Inches*	*Tons per acre*
1	Timothy, lespedeza	9.50	0.40
2	Oats (hay), lespedeza	10.53	2.59
3	Wheat, lespedeza	10.33	2.01
4	Barley, soybeans(hay)	8.70	3.93
5	Timothy, sweetclover, lespedeza.	7.41	.30
Series II (harvested for hay and grain):			
1, 3, 5	Oats (hay), lespedeza	9.19	1.78
2, 4, 6	Wheat, lespedeza	9.19	1.31
1945–48[2]			
Series I (pastures):			
7	Bluegrass (renovated)	9.06	
8	Bluegrass (check)	9.40	
9	Bluegrass (contour furrow)	8.02	

[1] Average annual precipitation of 40.34 inches. Measurements are averages of 3 plots, each 10½ by 90 feet.

[2] Annual precipitation of 38.27 inches. Runoff measured from 2-acre area.

ture conditions when the two grains were seeded. The oats were planted in the spring when the soil profile moisture content was relatively high and intake rates were low. Intense rains frequently occurred before a good soil cover was established by the crop. During the fall wheat seeding period the soil was drier and more absorptive and erosive storms occurred less frequently.

The combination of barley and soybeans was the most erosive pasture system studied in 1940–46. The barley was grazed and the soybeans were harvested for hay. This cropping system had two high loss periods. The most serious was in the spring when the barley was grazed and the beans were planted. The other was in the fall before the new barley seeding had established a good soil cover.

Soil loss under small grain and lespedeza harvested for hay and grain was measured in another set of plots (series II). Results are included in table 4 for comparison. Soil loss was approximately one-third less where hay and grain were harvested than where crops were grazed. This may be attributed to the better cover where the crops are left to mature, to lack of compaction and pulverization of the soil by trampling of animals, and perhaps to larger amounts of decayed crop residue remaining on the plots harvested for hay and grain.

Runoff from the three bluegrass pastures (table 4) during 1945–48 indicated that the renovation treatments that depended on legumes to provide nitrogen were relatively ineffective in reducing runoff. With contour furrows, 1.4 inches more rainfall were absorbed each year.

Runoff and soil loss were less in the drought years of 1952 and 1953 than in 1947–51 (table 5). The application of 4.41 inches of irrigation water to plot 8 in 1953 did not appear to increase runoff.

The average monthly and annual erosion index (EI) values (*73*) for four periods are shown in table 6. These values largely explain

TABLE 5.—*Average annual runoff and soil loss from pastures (series I), 1947–51 and 1952–53* [1]

Years and plot	Cropping system	Runoff	Soil loss
		Inches	*Tons per acre*
1947–51			
3	Wheat, Korean lespedeza	5.50	1.69
5	Kentucky bluegrass, Korean lespedeza.	[2]4.67	[2] .12
7	Kentucky bluegrass	[3]5.63	([4])
8	do.	[3,5]7.52	([4])
4	Rye, soybeans (grain)	[5]3.41	[2] .57
1952–53			
7	Kentucky bluegrass	2.16	([4])
8	Orchardgrass, Ladino and red clover.[6]	2.10	([4])
3	Wheat, Korean lespedeza	1.10	.14

[1] Average annual precipitation of 36.69 and 27.43 inches for 1947–51 and 1952–53, respectively.

[2] Average of 1947–50; not measured in 1951.

[3] Measured from full length of slope and not comparable with other runoff measurements.

[4] Not measured.

[5] Estimated for 1947 and 1951.

[6] Grass and weeds in 1952, seeded Aug. 20, 1952, and irrigated with 4.41 inches of water between June 10 and Sept. 1, 1953.

TABLE 6.—*Average monthly and annual erosion potentials for different research periods at McCredie, Mo.*

Month	Average accumulative EI values[1] for—			
	1941–46	1947–51	1952–53	1954–59
January	1	3	0	2
February	2	2	0	4
March	7	13	7	7
April	18	6	7	13
May	25	21	15	16
June	58	33	27	33
July	24	27	15	42
August	36	59	26	20
September	28	24	9	20
October	39	12	5	20
November	10	5	25	5
December	6	1	1	1
Average annual	254	206	137	183

[1] EI value is expression of erosion potential of rainfall during a time period. For any given storm, it is product of total rainfall energy (in foot-pounds × 10^{-4}) and maximum 30-minute intensity in inches per hour.

the lower runoff and erosion loss during the periods following 1941–46. Part of the reduction, however, may be from the improved crop growth and cover resulting from the higher fertility treatments. The rainfall-erosion potentials for April, May, June, September, and October of 1952–53 averaged only 45 percent of those for the two earlier periods. These months include most of the time required for seedbed preparation and establishment of various crops when land is most vulnerable to erosion.

Production Measurements

Production on the pasture areas was determined by grazing with 1- and 2-year-old Hereford cattle. The number of cattle grazing each pasture was adjusted as necessary to assure maximum utilization of herbage without overgrazing. The results for 1940–46 and 1947–51 are shown in table 7.

The variety of commodities harvested makes direct production comparisons difficult. Whitt (*69*) reduced the data to corn-equivalent production in bushels, as computed on the net energy basis from values given in a publication by Brown and Helm (*6*). In general, the increased fertilization of the second period (1947–51) resulted in a higher level of production in terms of corn equivalent and beef gains per animal unit day; although, for the same cropping systems, the carrying capacity of the pastures (animal unit days) was not greatly increased. The relatively high yield and carrying capacity for the Ladino clover pasture are of interest.

Whitt (*69*) made an economic analysis of the 1947–51 data at average price levels for the periods 1940–46 and 1947–51. In general, pasture fertility improvement appeared profitable at both price levels. However, fertility treatments on pasture showed greater profit at the higher price levels. This is true even if Whitt's net cash returns are adjusted to a common consumer price index level (table 8).

The data in table 9 show that production and carrying capacity of the pasture plots declined during the drought years (1952–53) as compared with 1947–51, unless growth was sustained by increased application of nitrogen.

Grain-Crop Studies

Soil Treatments

The first period of study of runoff and erosion under grain-crop rotations (series II) (1940–46) was conducted with light applications of fertilizers (table 10) recommended to farmers at that time. The 200 pounds per acre of 0–20–10 applied at the time of seeding was confined to the small grain crop. The corn-oats and one set of the corn-soybeans-wheat and lespedeza-lespedeza rotations received no lime or fertilizer. Rotations other than those given in table 10 for 1940–46 were corn-soybeans (hay)-wheat, lespedeza-lespedeza (unfertilized); corn-soybeans (hay)-wheat, lespedeza-lespedeza; soybeans (hay)-barley-meadow; corn-wheat-sweet-clover (hay); corn-wheat-meadow-meadow; and corn-wheat-meadow-meadow-meadow-meadow.

TABLE 7.—*Average annual production from pastures (series I), 1940–46 and 1947–51*

Years and plot	Cropping system	Product	Yield per acre[1]	Corn equivalent per acre	Beef gain per animal unit day	Pasture carrying capacity
1940–46				*Bushels*	*Pounds*	*Animal unit days*
1	Timothy, Korean lespedeza	Beef	228	36.5	1.85	123
2	Oats (hay), Korean lespedeza	do	117	18.7	1.43	82
		Hay	1.09	17.1		
3	Wheat, Korean lespedeza	Beef (wheat)	130	20.8	2.55	51
		Beef (lespedeza)	131	21.0	1.64	80
4	Barley, soybeans (hay)	Beef	105	16.8	2.19	48
		Hay	1.29	22.4		
5	Timothy, sweetclover, Korean lespedeza.	Beef	241	38.6	1.77	136
7	Kentucky bluegrass, sweet-clover.[2]	do	165	26.4	1.38	120
8	Kentucky bluegrass (check)[2]	do	115	18.4	1.24	93
1947–51						
3	Wheat, Korean lespedeza	Beef (wheat)	156	25.0	3.39	46
		Beef (lespedeza)	202	32.3	2.17	93
5	Kentucky bluegrass, Korean lespedeza.	Beef	308	49.3	2.28	135
6	Bromegrass	do	254	40.8	2.33	109
		Sweet clover seed	5	.1		
7	Kentucky bluegrass	Beef	262	41.9	1.83	143
8	Kentucky bluegrass (check)	do	173	27.7	1.99	87
4	Rye, soybeans (grain)[3]	do	139	22.2	5.15	27
		Beans	32.5	37.4		
1	Alta fescue[4]	Beef	321	51.4	2.15	149
9	Bromegrass, Ladino clover[4]	do	350	56.0	1.72	203
9	Bromegrass, Ladino clover[5]	do	493	78.9	1.90	259

[1] Yield of hay in tons, beef and seed in pounds, grain in bushels.
[2] Average for 1943–46, plot 8 did not receive fertility treatments.
[3] Average for 1948–50.
[4] Average for 1950–51.
[5] 1951 only.

Soil treatments in the second period (1947–51) were made according to soil tests (*17*). As indicated in table 10, the levels of treatment surpassed those of the earlier period. Lime, phosphate, and potash were brought up to a computed sufficiency level on plots receiving treatments, and the use of nitrogen fertilizer was begun on most of the grain plots. These applications of calcium, phosphorus, and potassium were designed to correct the differences in levels of these nutrients that had developed in the early years of study. Rotations other than those given in table 10 for 1947–51 were corn-oats, lespedeza; soybeans-oats, sweetclover; corn-corn-wheat-meadow; corn-soybeans (42-inch rows)-wheat-meadow; corn-wheat-clover; corn-wheat-meadow-meadow; and corn-wheat-meadow-meadow-meadow-meadow.

The experiment was revised in the fall of 1953 to test the effect of two fertility levels on runoff and soil loss from corn after corn and from corn in a rotation that included 2 years of meadow. The corn-oats rotation without fertilizer was continued. Also, the effect of seedbed preparation for corn after corn by subtillage so as to leave residues on the surface was compared with that of plowing residues under. In 1958, irrigated and adequately fertilized plots were added in order to study the effect of adequate soil moisture on runoff and erosion and on crop yields.

TABLE 8.—*Net cash returns from pastures with low and higher level soil treatments (series I) at 2 price levels*

Soil-treatment level and plot	Cropping system	Adjusted net returns per acre[1]	
		Low price level (1940–46)	Higher price level (1947–51)
LOW		*Dollars*	*Dollars*
1	Timothy, Korean lespedeza	26.67	47.11
2	Oats (hay), Korean lespedeza	21.42	30.37
3	Wheat, Korean lespedeza	24.75	48.41
4	Barley, soybeans (hay)	18.32	24.31
5	Timothy, sweetclover, Korean lespedeza.	24.88	45.90
7	Kentucky bluegrass, sweetclover	11.38	26.15
8	Kentucky bluegrass (no treatment).	15.03	24.42
HIGHER			
3	Wheat, Korean lespedeza	34.21	68.11
5	Kentucky bluegrass, Korean lespedeza.	32.95	61.54
6	Bromegrass	23.37	46.54
7	Kentucky bluegrass	18.83	44.21
8	Kentucky bluegrass (no treatment).		
4	Rye, soybeans (grain) (1948–50).	24.35	84.91
1	Alta fescue (1950–51)	31.17	61.95
9	Bromegrass, Ladino clover (1950–51).	35.95	68.49
9	Bromegrass, Ladino clover (1951).	56.76	102.85

[1] Net returns to land and management. Values adjusted to common average consumer price index level of 1947–51 (U.S. Dept. Agr. Agr. Statis. 1957, p. 967, table 803). Yields used are given in table 7.

The rotations, with fertilizer and seedbed preparation, are shown in table 11. All treatments except the corn-oats rotation without fertilizer were duplicated. For the no-fertilizer treatment, corn and oats were alternated on two plots so that both crops were grown each year. For the other rotations, each different crop and treatment occurred in cycle on two plots each year. The corn-wheat-meadow-meadow entailed eight plots, two for each crop. All plots were 0.0217 acre, except the 1-acre plot for the fourth continuous corn rotation (1954) in table 11.

The full-fertility treatment included lime, phosphate, and potash applications according to requirements shown by soil tests (*17*) in 1954. Lime has been applied since 1954 as needed to meet test requirements. Ammonium nitrate was applied at 200 pounds per acre before plowing or tilling for corn and again as a side dressing after the corn was growing. Wheat received ammonium nitrate at 200 pounds per acre before seedbed preparation. The first- and second-year meadows received ammonium nitrate in three applications of 100 pounds per acre about March 1 and after first and second cuttings.

TABLE 9.—*Average beef production and carrying capacity of pastures (series I) during drought period (1952–53) compared with more favorable period (1947–51)*

Plot	Cropping system	Beef production		Pasture carrying capacity	
		1947–51	1952–53	1947–51	1952–53
		Pounds per acre	*Pounds per acre*	*Annual unit days*	*Annual unit days*
3	Wheat, Korean lespedeza.[1]	358	254	139	128
5	Kentucky bluegrass, Korean lespedeza, Ladino clover.[2]	308	175	135	89
6	Bromegrass[3]	254	329	109	135
7	Kentucky bluegrass.[3]	262	270	143	137
1	Alta fescue, Ladino clover.[2]	321	222	149	142
9	Bromegrass, Ladino clover.[2]	350	308	203	132

[1] Nitrogen fertilization on wheat increased from 60 to 225 pounds of 33-0-0 in fall of 1952.

[2] Growth of Ladino clover reduced in 1952 and killed in 1953 by moisture deficiency.

[3] Nitrogen fertilization since 1950 (see table 3).

TABLE 10.—*Soil treatment for several grain rotations (series II), 1940–46* [1] *and 1947–51*

Years and plot	Grain rotation	Soil treatment: Year	Soil treatment: Amount per acre
1940–46			
1, 3, 5	Oats (hay)-lespedeza	1938	Lime, 3 tons; 0–20–10, 100 lbs., with small grain seeding.
2, 4, 6	Wheat-lespedeza	1946	Lime, 2 tons; 0–20–10, 100 lbs., with small grain seeding.
9, 14, 19, 24	Corn-corn-oats-wheat (sweetclover).	1939	Lime, 3 tons; 0–20–10, 200 lbs. with oat and 200 lbs. with wheat seeding; sweetclover under before first corn; stalks of first corn remain as residues.
29, 33, 37	Corn-wheat-meadow.[2]	1939	Lime, 3 tons; 0–20–10, 200 lbs., with wheat seeding.
25, 26	Corn-oats		None; cornstalks remain as residue.
1947–51			
7, 12, 17, 22	Corn-soybeans (7-inch rows)-wheat-meadow.	1947–48 1949 and later	Lime, 2 tons; 10–20–20, 250 lbs. on corn, 225 lbs. on beans, 200 lbs. on wheat, 150 lbs. on rye. *Basic:* Rock phosphate, 1,000 lbs., and 0–0–50, 100 lbs. 33–0–0 (plowed under), 311 lbs., and 3–12–12 (starter), 300 lbs., on corn; 0–20–20 (starter), 200 lbs., on beans; 10–20–20, 200 lbs., and 33–0–0, 50 lbs., on wheat (1949); 0–20–20, 200 lbs., and 33–0–0, 75 lbs., on wheat (1950–51); 0–20–20, 150 lbs., and 33–0–0, 100 lbs., on rye (1950–51).
29, 33, 37	Corn-wheat-meadow	1947–48 1949 and later	Lime, 2 tons; 10–20–20, 400 lbs. on corn and 200 lbs. on wheat. *Basic:* Rock phosphate, 1,000 lbs., and 0–0–50, 100 lbs. 33–0–0 (plowed under), 300 lbs. and 3–12–12 (starter), 300 lbs., on corn; 10–20–20, 200 lbs., and 33–0–0, 50 lbs., on wheat (1949); 0–20–20, 200 lbs., and 33–0–0, 150 lbs., on wheat (1950); 0–20–20, 200 lbs., and 33–0–0, 200 lbs., on wheat (1951).
11, 16, 21	Soybeans-small grain-meadow.	1947–48 1949 and later	Lime, 2 tons; 10–20–20, 400 lbs. on beans, 200 lbs. on barley (1947) and rye (1948). *Basic:* Rock phosphate, 1,000 lbs., and 0–0–50, 100 lbs. 0–20–20 (starter), 200 lbs., on beans; 10–20–20, 200 lbs., and 33–0–0, 50 lbs., on rye (1949); 0–20–20, 200 lbs., and 33–0–0, 75 lbs., on rye (1950) and wheat (1951).

TABLE 10.—*Soil treatment for several grain rotations (series II), 1940–46* [1] *and 1947–51*—Continued

Years and plot	Grain rotation	Soil treatment: Year	Soil treatment: Amount per acre
5, 6	Corn-oats (sweetclover[3]).	1947–48 1949 and later	Lime, 2 tons; 10–20–20, 200 lbs. on corn and 200 lbs. on oats. *Basic:* Rock phosphate, 1,000 lbs., and 0–0–50, 100 lbs. 33–0–0 (plowed under), 200 lbs., and 3–12–12 (starter), 300 lbs., on corn; 10–20–20, 200 lbs., on oats (1949); 0–20–20, 200 lbs., and 33–0–0, 150 lbs., on oats (1950); 0–20–20, 200 lbs., and 33–0–0, 200 lbs., on oats (1951).
25, 26	Corn-oats		None.

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[1] All crops for grain and hay except residues remaining as noted.

[2] Meadow consisted of mixture of timothy, redtop, red clover, alsike clover, and Korean lespedeza.

[3] Plowed under before corn.

TABLE 11.—*Treatments in study started in 1954 and modified by irrigation test in 1958*

Year started and grain rotation	Fertility treatment	Seedbed preparation
1954 (treatments)		
Corn-oats	None	Plow (for corn).
Continuous corn	Full	Subtill.
Do	do	Plow.
Do	Starter	Do.
Do	Full	Do.
Corn-wheat-meadow-meadow	do	Plow (for corn).
Do	Starter	Do.
1958 (irrigation)		
Continuous corn, irrigated	Full	Subtill. Plow.
Continuous corn, not irrigated	do	Subtill. Plow.

Starter-fertility treatments of 3–12–12 at 300 pounds per acre were applied at seeding of corn and 0–20–20 at 200 pounds per acre at seeding of wheat.

A field tiller was used to prepare the subtilled seedbed so as to leave the cornstalks on or near the surface. The conventional method of plowing and disking was followed to prepare the seedbed for corn on the other plots.

Soil and Water Losses (1941–53)

The effect of the preceding crops on runoff and soil loss under corn and soybeans during the growing season is shown in table 12 for 1941–46. All plots except those in the corn-oats sequence received lime at 3 tons per acre in 1941 and were fertilized with 0–20–10 at 200 pounds per acre for small grain. Soil loss under corn during its 5-month growing period was less than one-third as much on some fertilized plots as on others, depending on the type of crop grown on the plot in the previous year. This resulted from what has been called soil conditioning. It includes the effects of soil structure, organic matter, and the binding qualities of fibrous roots.

TABLE 12.—*Average runoff and soil loss during growing season (Apr. 27–Oct. 6) under corn and soybeans when preceded by other crops, 1941–46*

Current and preceding crop	Runoff	Soil loss
	Inches	*Tons per acre*
CORN		
Oats (no soil treatment)	7.2	10.2
Lespedeza hay	6.9	8.3
Corn (1-year stalks)	6.7	7.1
Sweetclover-timothy hay	5.1	4.6
Sweetclover (plowed under)	6.0	4.2
Grass-clover hay:		
4 years	5.6	4.2
2 years	4.7	2.4
1 year	5.9	3.0
SOYBEANS		
Corn	7.2	6.9
Grass-clover hay (1 year)	5.9	2.0

Grass crops preceding the corn were the most effective in providing resistance to soil erosion under corn. A period of 1 or 2 years of grass and legume meadow was more effective than a 4-year period of meadow. For the shorter meadow periods, the growth of grass was vigorous at the time of plowing for corn. By the fourth consecutive year of meadow, the stand of grass had deteriorated to almost nothing. Sweetclover plowed under, sweetclover-timothy hay, and lespedeza hay were considerably less effective in reducing soil loss than were 1 or 2 years of grass and clover meadow. Cornstalks gave more protection than oat stubble.

Those crop sequences that allowed the soil to remain bare for an extended period resulted in high soil loss (table 13). The losses during the fall, winter, and early spring following corn were greatest from corn stubble and least from soil protected by a fall growth of grass.

TABLE 13.—*Average fall, winter, and early-spring soil loss following corn (series II) from Oct. 7 to Mar. 19, 1941–46*

Preceding crop	Winter cover	Soil loss
		Tons per acre
Corn	Corn stubble	1.4
Do	Cornstalks	.7
Do	Corn stubble, wheat	1.2
Grass-clover hay	Fall growth of grass	.2

The effectiveness of a vigorous cover in reducing runoff and soil loss as compared with a sparse plant cover is shown in table 14. The unfertilized wheat developed slowly and suffered greater winterkilling than did fertilized wheat on comparable plots (*47*). The difference in cover that resulted from the application of 200 pounds of 0–20–10 fertilizer on plots with an initial application of 3 tons of lime per acre reduced runoff 11 percent and soil loss 23 percent during the 9-month period from seeding to harvest.

TABLE 14.—*Effect of fertilization on runoff, soil loss, and yield under wheat (series II) from Oct. 10 to June 28, 1941–46*[1]

Wheat treatment	Runoff	Soil loss	Yield
	Inches	*Tons per acre*	*Bushels per acre*
Fertilized	9.0	3.6	19.7
Unfertilized	10.1	4.7	10.3

[1] Losses from wheat in corn-soybeans-wheat and lespedeza-lespedeza rotation.

Average annual runoff and soil loss during the second soil-treatment period (1947–51) were somewhat lower than for 1941–46 (table 15). Whitt (*68*) attributed this to three principal reasons: (1) Rainfall distribution was better and intensity was lower during the second period; (2) crop residues such as cornstalks and soybean and grain straw were incorporated with the soil instead of being removed; and (3) application of sufficiency levels of mineral nutrients and additions of nitrogen helped to produce more vigorous plants and improved cover and soil conditioning.

The highest average soil loss from a fertilized grain-crop rotation during 1947–51 was only 1.01 tons per acre. The corn-oats rotation without soil treatment averaged 2.50 tons compared with 8.61 tons per acre in 1941–46. This attests to the favorable distribution of rainfall during the second period, with lower average erosion potentials for the storms (table 6). Runoff during the later and earlier periods was somewhat lower on the fertilized rotations than on the unfertilized corn-oats system.

Average annual runoff from the grain rotations in 1952–53 was generally lower than in either of the previous periods. The lower losses may be attributed largely to less severe rainstorms during this period (table 6). Other rotations not included in table 15 for 1952–53 were corn-wheat-meadow-meadow and corn-grass-grass-grass.

The effect of different management practices on runoff and soil loss during grain-crop growing seasons for 1947–53 is shown in table 16. Losses decreased for those grain rotations that were fertilized and that provided soil-conditioning effects from either meadow or crop residues returned to the soil. Losses were lowest from corn following meadow, though sweetclover turned under before corn also provided good protection by its soil-conditioning effects. Losses from soybeans are a little greater than those from corn under good management. Runoff from oats is somewhat higher than from wheat, probably because of the spring seeding date. Wheat developed an effective cover by the time of oat seeding.

TABLE 15.—*Average annual runoff and soil loss from grain rotations (series II), 1941–46, 1947–51, and 1952–53* [1]

Years and plot	Grain rotation[2]	Runoff	Soil loss
		Inches	*Tons per acre*
1941–46			
7, 12, 17, 22	Corn-soybeans-wheat, lespedeza-lespedeza.	11.92	5.35
29, 33, 37	Corn-wheat-meadow	[3] 8.24	[3]1.88
11, 16, 21	Soybeans-small grain-meadow	9.59	1.20
25, 26	Corn-oats (no soil treatment)	13.70	8.61
1947–51			
7, 12, 17, 22	Corn (rye)-soybeans-wheat-meadow.	5.20	1.01
29, 33, 37	Corn-wheat-meadow	4.78	.83
11, 16, 21	Soybeans-small grain-meadow	4.84	.65
5, 6	Corn-oats (sweetclover)	4.87	.84
25, 26	Corn-oats (no soil treatment)	9.79	2.50
1952–53			
5, 6	Corn-oats (sweetclover)	1.70	.21
25, 26	Corn-oats (no soil treatment)	4.30	1.16
11, 13, 16, 21	Soybeans-wheat-meadow-meadow	[4] .57	.71
7, 12, 15, 17, 22.	Corn-soybeans-wheat-meadow-meadow.	[4] 1.73	.36

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[1] Average annual precipitation was 41.34, 36.69, and 27.43 inches, respectively, for each period.

[2] All plots fertilized and limed according to soil tests after 1946, except corn-oats rotation.

[3] Measurements began in 1943; 1943–46 data adjusted to 1941–46 period using ratios of losses with similar rotations under measurement for 6-year period.

[4] Values estimated for meadow plots.

TABLE 16.—*Effect of different management practices on average runoff and soil loss during grain-crop growing seasons (series II), 1947–53*

Crop[1]	Grain rotation[2]	Runoff	Soil loss
		Inches	*Tons per acre*
Corn	Corn-oats (no soil treatment)	2.66	2.13
	Corn-oats, sweetclover	.87	.78
	Corn-wheat-meadow-meadow	.62	.50
Soybeans	Soybeans-rye or wheat-meadow	.97	.94
Oats	Corn-oats (no soil treatment)	7.07	1.87
	Corn-corn-oats-meadow	4.26	.53
	Corn-oats, sweetclover	3.20	.24
Wheat[3]	Corn-soybeans-wheat-meadow	3.94	.83
	Corn-wheat-meadow-meadow	3.26	.54
	Soybeans-rye or wheat-meadow	2.93	.44

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[1] Growing period and rainfall for corn and soybeans, Apr. 27–Oct. 9 and 19.44 inches; for oats and wheat, Oct. 10–July 7 and 23.85 inches.

[2] All plots fertilized and limed according to soil tests, except corn-oats rotation.

[3] Cornstalks and soybean straw left on plots.

Soil and Water Losses (1954–61)

Results for 1954–61 after the cropping systems and fertility treatments had been revised are shown in tables 17–19. Average annual precipitation during this period was 32.87 inches as compared with 37.95 inches for 1891–1960, but during the corn-growing season (Apr. 20–Oct. 2) it was 0.6 inch more than during the 70-year period. Runoff and erosion data for 1954–59 have been previously published (*66*).

A heavy cover of shredded cornstalks from adequately fertilized corn provided erosion protection nearly equal to that of meadow cover during the fall, winter, and early spring. The greatest erosion-reducing effect of adequately fertilized meadow in the rotation is when small grain or meadow is on the land. Soil conditioning due to adequate fertility and meadow in a rotation reduces

TABLE 17.—*Average runoff and soil loss for nonfertilized corn-oats rotation by crop periods (series II), 1954–61*

Cover	Crop period	Average precipitation	Runoff	Soil loss
		Inches	*Inches*	*Tons per acre*
Corn	Apr. 20–Oct. 2	18.47	2.54	2.86
Cornstalks	Oct. 3–Mar. 17	11.54	1.70	.36
Oats	Mar. 18–July 11	13.76	2.89	1.31
Oat stubble	July 12–Apr. 20	21.97	2.21	.19
Average annual		32.87	4.97	2.67

soil and water losses also during the corn-production period. However, soil conditioning may not provide adequate protection on cornland for high-intensity rains if they occur from seedbed preparation to the establishment of a crop cover.

The results of several storms with a total precipitation of 4.23 inches in 10 hours during June 29–30, 1957, are shown in figure 8. Soil and water losses from the corn in the meadow rotation during these 2 days were more than twice the annual 1954–61 average for the corn-growing season. Soil conditioning, whether residual from meadow or from shredded cornstalks plowed under, reduced losses to some extent during this storm period. Leaving the cornstalks on the surface by subtillage instead of plowing for seedbed preparation also reduced soil and water losses.

The period from seedbed preparation to the establishment of a crop cover of wheat is the other interval in the rotation cycle when soil losses may be high. This is usually during October. When several storms occurred during October 2–10, 1959, with a total of 5.75 inches of rain, wheatland with the starter-fertility treatment lost 1.08 tons per acre, or about 90 percent of the total loss for the year. The corresponding loss for the full-fertility treatment was 0.48 ton per acre, which was the annual loss for this treatment in 1959. More rapid growth and establishment of the newly seeded crop with full fertility account for the difference between treatments.

TABLE 18.—*Effect of soil-fertility treatments on average runoff and soil loss from corn (series II), 1954–61*

Years and cropping practice	Fertility treatment	Runoff	Soil loss
1954–61		*Inches*	*Tons per acre*
Corn-oats[1]	None	4.24	3.22
Continuous corn (plowed)	Starter	2.44	2.13
Do	Full	1.51	1.43
Continuous corn (subtill)	do	1.13	.99
Rotation (4 years)[2]	Starter	1.02	1.01
Rotation (4 years)	Full	.80	.85
1959–61			
Continuous corn (contour)[3]	do	4.69	6.34
Continuous corn (up-and-down slope)	do	5.70	8.94
1958–61			
Continuous corn (plowed, no irrigation)	do	1.52	.91
Continuous corn (plowed, irrigated)	do	1.95	.81
Continuous corn (subtill, no irrigation)	do	1.21	.69
Continuous corn (subtill, irrigated)	do	1.69	.86
1959–61			
Fallow		4.04	7.03

[1] Corn and stalk period Apr. 20–Mar. 17.
[2] Corn-wheat-meadow-meadow rotation; corn period Apr. 20–Oct. 2.
[3] One acre 420- by 103.7-foot plots, 420-foot slope length; all other 90- by 10½-foot plots, farmed up-and-down slope.

TABLE 19.—*Average runoff and soil loss for corn-wheat-meadow-meadow rotation with 2 fertility treatments by crop periods (series II), 1954–61*

Cover	Crop period	Average precipitation	Runoff with indicated fertility treatment		Soil loss with indicated fertility treatment	
			Starter	Full	Starter	Full
		Inches	*Inches*	*Inches*	*Tons per acre*	*Tons per acre*
Corn	Apr. 20–Oct. 1	17.16	1.02	0.80	1.01	0.35
Cornstalks and wheat	Oct. 2–Mar. 21	11.91	.64	.33	.20	.30
Wheat	Mar. 22–July 6	12.93	.33	.14	.02	.01
	July 7–Dec. 31	12.73	.41	.30	.01	([1])
Meadow (1st year)	Jan. 1–Dec. 31	21.08	1.00	.85	.02	.01
	Jan. 1–Dec. 31	29.82	.88	.54	.01	.01
Meadow (2d year)	Jan. 1–Apr. 12	4.94	.40	.32	.01	([1])
Average annual		32.87	1.17	0.82	0.32	0.24

[1] Trace.

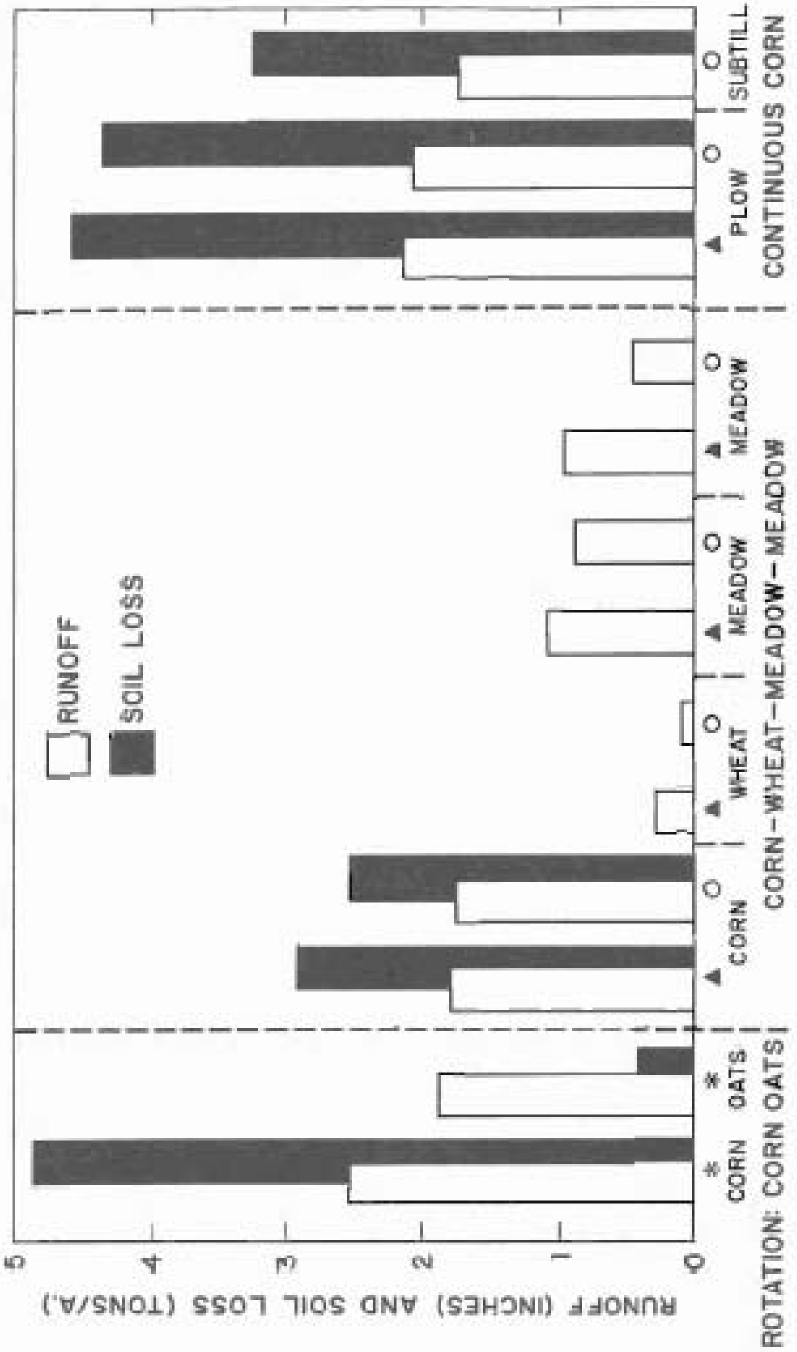

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FIGURE 8.—Runoff and soil loss from different crops and cropping systems during several severe storms, June 29–30, 1957.

The results from the corn-oats rotation show the effect of low fertility on runoff and soil loss (table 17). Soil loss from corn after corn during 1954–61 was more than double that from corn in the rotation with 2 years of meadow (table 18). Soil loss from continuous corn during the growing season was about double that from rotation corn; however, the full-fertility treatment reduced this ratio. When the seedbed was prepared by subtillage, soil loss from full-fertility corn after corn during 1954-61 was only slightly greater than that from rotation corn. Most of the loss occurred with corn or oats during the periods of seedbed preparation. Average soil loss from established meadow or wheat was very low (table 19). Soil loss per inch of runoff was greatest from corn during the corn-growing season. This ratio was also relatively high for oats in the nonfertilized corn-oats rotation (table 17).

The study to determine the effect of irrigation on runoff and erosion from corn after corn has not been in operation long enough (1958–61) to obtain conclusive data. No irrigation was needed in 1958 and 1961. Six irrigations (a total of 11.5 inches) were applied from July 26 to August 10 in 1959. Rainfall sufficient to cause runoff from any plots was not received until October of that year, when shredded cornstalks provided good cover. Soil loss for all treatments was low in 1959. Two irrigations in 1960 of about 2.35 inches each were applied on July 20 and August 1. No runoff occurred during the remainder of that year. The average runoff for 1958–61 from the irrigated plots was 1.77 inches and from the comparable nonirrigated corn-after-corn plots it was 1.37 inches (table 18). The soil loss for the irrigated plots was 0.83 ton per acre, or an increase of only 0.03 ton per acre for irrigation.

Although adequate fertilization affords a good protective cover of growing plants or cornstalks during most of the year when corn is grown, soil loss may be high during the interval of seedbed preparation, planting, and cultivation of the young crop. The soil conditioning given by well-fertilized meadow in the rotation before corn affords some protection. However, for an occasional storm of high intensity during the critical period, the soil loss from cornland may be high regardless of fertility and management practices. Thus, one advantage of growing corn in a rotation would be to reduce the average frequency of expected loss from such storms coming at this time of the year.

Adequate fertilization has stimulated crop growth and provided conditions of considerable value in reducing runoff and erosion from sloping claypan soils. Crop rotations that included grasses and legumes markedly improved productivity and resistance to erosion. With this improvement, the performance of these soils is approaching that of the better soils of Missouri (*47*). More rapid development of crops on these soils reduces the time when soil is directly exposed to the impact of falling raindrops. Improved systems, with increased crop residues returned to the soil, condition the soil so as to further increase resistance to erosion. Winterkilling of wheat has been greatly reduced by adequate fertility. The more rapid development of wheat is of utmost importance to both production and soil protection, especially during years when seeding is delayed by corn harvest or wet weather.

Effect of Improved Fertility on Yields (1940–53)

Grain and hay yields were adjusted to a uniform moisture basis and converted to corn equivalent values (*6, 68*) for comparison (table 20). The net returns, adjusted to the average consumer index for 1947–51 (*64*), are shown in table 21. The rotations with low soil treatments showed little advantage over the no-treatment corn-oats rotation, even at the higher price level (1947–51). The rotations receiving the higher level treatments during 1947–51 showed the higher profit for fertilized rotations including corn. The corn-oats rotation without treatment had dropped to a lower level of production than in the previous period as a result of continued depletion of soil nutrients.

TABLE 20.—*Average annual production from grain rotations (series II), 1940–46 and 1947–51*

Years and plot	Grain rotation	Crop	Yield per acre [1]	Corn equivalent per acre
1940–46 1, 3, 5	Oats (hay), Korean lespedeza.	Oats hay Lespedeza hay	1.12 .66	*Bushels* 17.5 12.8
Total				30.3
2, 4, 6	Wheat, Korean lespedeza.	Wheat Lespedeza hay	16.5 .71	19.0 13.8
Total				32.8
9, 14, 19, 24	Corn-corn-oats-wheat (sweetclover).	Corn do Oats Wheat	34.7 30.3 32.7 16.7	34.7 30.3 15.4 19.2
Average				24.9
29, 33, 37	Corn-wheat-meadow	Corn Wheat Hay [2]	32.6 15.0 1.26	32.6 17.3 21.8
Average				23.9
25, 26	Corn-oats	Corn Oats	28.4 21.9	28.4 10.3
Average				19.4
1947–51 7, 12, 17, 22	Corn (rye)-soybeans-wheat-meadow. [3]	Corn Soybeans Wheat Hay	90.5 27.0 28.8 2.54	*Bushels* 90.5 31.1 33.1 44.0
Average				49.7
29, 33, 37	Corn-wheat-meadow	Corn Wheat Hay	91.3 19.8 2.31	91.3 22.8 40.0
Average				51.4
11, 16, 21	Soybeans-small grain-meadow.	Soybeans Rye [4] Hay	25.2 30.2 2.09	29.0 27.5 36.2
Average				30.9
5, 6	Corn-oats (sweetclover).	Corn Oats	94.7 31.8	94.7 14.9
Average				54.8
25, 26	Corn-oats (*no soil treatment*).	Corn Oats	20.3 6.1	20.3 2.9
Average				11.6

[1] Yield of hay in tons, grain in bushels.
[2] Predominantly red clover and timothy.
[3] Rye winter cover turned under a green manure before soybeans.
[4] Yield is rye equivalent; in barley 1 year, wheat 1 year, and rye 3 years.

Comparisons of the net returns for pastures and for grain crops at these fertility and price levels (tables 8 and 21) suggest that pasture for grazing beef may be a more profitable land use than growing corn and small grain crops in rotations on sloping claypan soils. Whitt (*68*) concluded in 1952 that a movement toward a dominantly pasture type of farming on the sloping claypan soils of Missouri seemed warranted.

Table 22 compares the average crop yields for the drought period (1952–53) with the yields for 1947–51. Except for the corn-oats rotation without soil treatment, corn yields were below normal during 1952–53. Hay fields were also below normal, but small grain yields were normal or better. Precipitation was adequate during the fall, winter, and spring but below normal during the summer. Thus, in spite of the low annual precipitation for 1952–53, moisture conditions were favorable for small grain production during the cooler months, whereas summer droughts reduced production of corn and meadow.

Effect of Adequate Fertility on Corn Yields

The effect of the fertility treatments and cropping systems on corn yields for 1955–61 is shown in figure 9. The 1954 data were omitted from these averages because of crop failure due to drought. The average yields with full-fertility treatment were essentially

TABLE 21.—*Net cash returns from grain crops with low and higher soil treatments (series II) at 2 price levels*

Soil-treatment level and plot	Grain rotations	Adjusted net returns per acre[1]	
		Low price level (1940–46)	Higher price level (1947–51)
		Dollars	*Dollars*
LOW			
1, 3, 5	Oats (hay), Korean lespedeza	14.77	11.13
2, 4, 6	Wheat, Korean lespedeza	25.60	27.06
9, 14, 19, 24	Corn-corn-oats-wheat, (sweetclover).[2]	18.73	23.94
29, 33, 37	Corn-wheat-meadow	15.97	17.74
25, 26	Corn-oats (no soil treatment)	17.83	20.71
HIGHER			
7, 12, 17, 22	Corn (rye)[3]-soybeans-wheat-meadow.	39.57	45.57
29, 33, 37	Corn-wheat-meadow	36.28	43.19
11, 16, 21	Soybeans, small grain-meadow.	22.12	22.92
5, 6	Corn-oats (sweetclover)[2]	43.89	55.77
25, 26	Corn-oats (no soil treatment)	5.03	7.73

[1] Net returns to land and management. Values adjusted to common average consumer price index level of 1947–51 (U.S. Dept. Agr. Agr. Statis. 1957, p. 697, table 803). Yields used are given in table 20.

[2] Sweetclover turned under before first corn crop.

[3] Rye winter cover turned under before soybeans.

TABLE 22.—*Average crop yields during drought period (1952–53) compared with yields for more favorable period (1947–51) (series II)*

Crop and rotation		Yield per acre	
		1947–51	1952–53
Corn-oats (no soil treatment)	bushels	20.3	20.6
Corn-*oats* (no soil treatment)	do	6.1	7.2
Corn-oats, sweetclover	do	94.7	77.8
Corn-*oats*, sweetclover	do	31.8	44.7
Corn-wheat-meadow-meadow	do	91.3	80.5
Corn-*wheat*-meadow-meadow	do	19.8	30.6
Corn-wheat-*meadow*-meadow	tons	2.31	1.36
Corn-wheat-meadow-*meadow*[1]	do	2.35	1.73
Soybeans-wheat-meadow-meadow[2]	bushels	31.2	15.6
Soybeans-*wheat*-meadow-meadow	do	34.2	33.6
Soybeans-wheat-*meadow*-meadow	tons	2.22	1.10
Soybeans-wheat-meadow-*meadow*	do		2.12
Corn-soybeans-wheat-meadow-meadow	bushels	90.5	77.9
Corn-*soybeans*-wheat-meadow-meadow	do	27.0	12.5
Corn-soybeans-*wheat*-meadow-meadow	do	28.8	28.0
Corn-soybeans-wheat-*meadow*-meadow	tons	2.54	1.39
Corn-soybeans-wheat-meadow-*meadow*	do		2.31

[1] This meadow did not receive nitrogen, whereas 2d-year meadow of 2 rotations below received 2.33-pound applications during year.

[2] Rye in place of wheat, 1948–50.

the same for continuous corn (108 bushels) and corn grown in rotation with wheat and 2 years of meadow (109 bushels). But with starter fertilizer only, the yield for continuous corn was 47 bushels in contrast to 74 bushels for the rotation corn. Thus, full-fertility treatments apparently have a greater effect on continuous corn than on corn in a rotation with meadow. However, the big difference was between the 23-bushel yield of corn in the corn-oats rotation and the 109-bushel yield of corn in the corn-wheat-meadow-meadow rotation with the full-fertility treatment.

Not only have full-fertility treatments increased corn yields to a level nearly five times that without treatment, but also they have increased the efficiency of water use by corn. In the drought year of 1953, only 5,600 gallons of water were required to produce a bushel of corn with full treatment, whereas 21,000 gallons were required without benefit of fertilizer or a meadow-based rotation (*49*).

Not all the benefits of a good fertility program are easily measured. Increased yields and improved quality of row crops should allow the farmer to reduce the acreage needed to supply

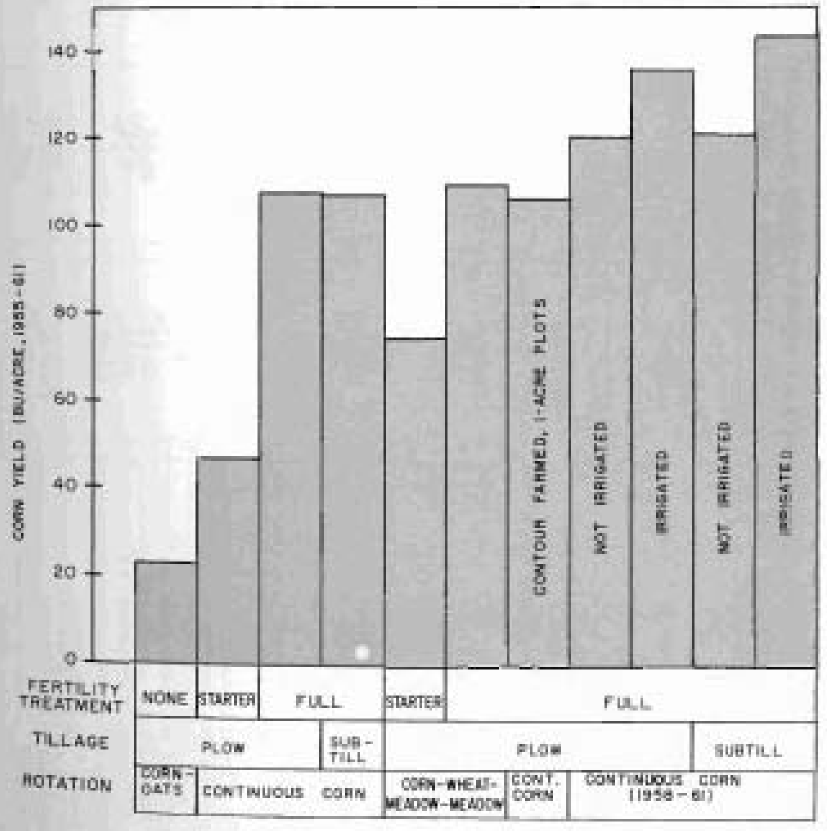

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FIGURE 9.—Corn yields for different fertility treatments and cropping systems.

TABLE 23.—*Comparison of estimated net returns from continuous corn with returns from rotation system for average- and full-fertility program on medium-size northeast Missouri farm*

Fertility program and item	Continuous corn	Rotation			
		Corn	Wheat	1st year meadow	2d-year meadow
AVERAGE FERTILITY					
Annual per acre returns:					
Yields[1]	*Bushels* 70	*Bushels* 70	*Bushels* 30	*Tons* 2	*Tons* 2
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Unit price[2]	1.00	1.00	1.60	14.00	14.00
Gross return	70.00	70.00	48.00	28.00	28.00
Annual per acre costs:					
Labor[2]	10.00	10.00	6.00	16.00	16.00
Tractor[3]	6.00	6.00	4.00	3.00	3.00
Machinery[3]	10.50	10.50	10.00	8.00	8.00
Seed[3]	1.50	1.50	3.50	3.00	
Fertilizer[3]	8.00	8.00	5.50	3.00	3.00
Lime and phosphate[3]	4.00	4.00	3.00	2.00	2.00
Total costs	40.00	40.00	32.00	35.00	32.00
Net annual per acre returns:[4]					
Each crop	30.00	30.00	16.00	−7.00	−4.00
Average for cropping system	30.00	8.75			
Difference[5]	21.25				
FULL FERTILITY					
Annual per acre returns:					
Yields[6]	*Bushels* 106	*Bushels* 109	*Bushels* 45	*Tons* 3.54	*Tons* 3.60
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Unit price[2]	1.00	1.00	1.60	14.00	14.00
Gross return	106.00	109.00	72.00	49.56	50.40
Annual per acre costs:					
Labor[2]	12.00	12.00	6.50	24.00	24.00
Tractor[3]	7.00	7.00	5.00	3.50	3.50
Machinery[3]	12.00	12.00	11.00	9.00	9.00
Seed[3]	1.50	1.50	3.50	3.00	
Fertilizer[3]	26.60	22.80	13.85	11.85	11.85
Lime and phosphate[3]	4.00	4.00	4.00	3.00	3.00
Total costs	63.10	59.30	43.85	54.35	51.35
Net annual per acre returns:[4]					
Each crop	42.90	49.70	28.15	−4.79	− .95
Average for cropping system	42.90	18.03			
Difference[5]	24.87				

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[1] Based on estimates for Average Fertility Program (Mo. Agr. Expt. Sta. Farm Business Planning Guide, B. F. 6103, Jan. 1961).

[2] Labor requirements needed on medium-sized Missouri farm and paid at $1 per hour.

[3] Based on costs shown in Mo. Agr. Expt. Sta. Farm Business Planning Guide, B. F. 6103, Jan. 1961.

[4] Net return to management and capital investment. Land costs for continuous corn and rotation systems are considered the same.

[5] Difference between average annual returns for continuous corn and rotation cropping.

[6] Based on plot treatments and yields for full-fertility program.

grain for his particular livestock program. Extra forage of improved quality from the remainder of the land should increase the returns from livestock and reduce the hazard of high erosion losses.

Because of the increasing interest in growing corn year after year on the same land, the results from the runoff plots for the 1955–62 period were used as a basis to compare the cost returns from continuous corn and the corn-wheat-meadow-meadow rotation for a medium size northeast Missouri farm.[6] The same comparison was made using estimated average yields and fertility levels.[7] These computations do not include the cost of the increased erosion hazard nor of control measures that may be required with the continuous corn. The prices of fertilizer and produce were based on those paid in central Missouri in the fall of 1961. The results are shown in table 23.

For the full-fertility program, estimates from runoff plots indicate an annual difference of $24.87 in returns per acre, favoring the continuous corn. The difference computed from estimated returns for average fertilization levels of a northeast Missouri farm was $21.25 per acre, favoring continuous corn. However, it must be remembered that these comparisons are based on production costs and prices in 1961. Shifts in production costs or prices of produce will change this relationship as would alternate use of the meadow, such as for grazing of beef animals. Full analysis of returns for alternate systems for individual farms is beyond the scope of this publication.

Contour Tillage Studies

Annual and Severe Storm Losses

A study of the effect of contouring on runoff and soil loss from continuous corn was started in 1955. Two 1-acre contour plots having a slope length of 420 feet were equipped to measure runoff and soil loss. Corn was grown each year with the same full-fertility treatment as that used on 90-foot runoff plots farmed up-and-down slope. Because of difference in slope length, the results are not directly comparable with those of the smaller plots. In 1959, one of the long plots was changed to up-and-down slope farming. The runoff and soil loss for the 420-foot contour plots compared with the 90-foot plots are shown in table 24.

According to Smith and Wischmeier (*55*), the combined contour-slope length factor for estimating soil loss from contour plots of 420-foot slope length and from small up-and-down slope plots would be approximately 1.25. Its application to the data of the full 6-year period would result in an estimate somewhat lower than the average measured amount. Three years' data for the long plots, since one of them has been farmed up-and-down slope, are not sufficient to test the reliability of the contour factor of about 0.50 (*55*).

TABLE 24.—*Effect of contouring compared with up-and-down slope farming on runoff and soil loss from adequately fertilized continuous corn (series II)*

Losses, years, and row direction	Slope length[1]	Runoff	Soil loss
ANNUAL	*Feet*	*Inches*	*Tons per acre*
1955–61:[2]			
Up-and-down slope	90	1.76	1.54
Contour	420	3.45	4.80
1959–61:[3]			
Up-and-down slope	420	5.70	8.94
Contour	420	4.69	6.34
CORN-PRODUCTION PERIOD			
1955–61:[2]			
Up-and-down slope	90	1.12	1.49
Contour	420	1.61	4.54
1959–61:[3]			
Up-and-down slope	420	3.91	8.56
Contour	420	1.73	6.21

[1] Short plots with 3-percent slope; long plots average 3-percent slope and lower half of plots about 4-percent slope.

[2] Long plots started on contour in 1955; hence, annual averages shown are for indicated 7-year period. Average corn-production period for 6 years was from Apr. 9 to Oct. 2.

[3] Only 3 years' data available for long plot with rows up-and-down slope; hence, averages shown are for indicated 3-year period. Average corn-production period for these plots for 3 years was from Apr. 27 to Oct. 3.

The relatively high average soil loss from the contour plots for 1955-61 resulted largely from 4.23 inches of rain occurring in 10 hours on June 29 and 30, 1957. Soil loss from the 420-foot contour plots during these storms was 10.45 tons per acre. Without these storms, the 7-year average annual loss would have been only 0.73 ton per acre. The ratio of soil loss from the long contour plots to that of the small plots (with the same crop and treatment but farmed up-and-down slope) has varied from 0.36 in 1959 to 2.34 in 1957. The ratio of the averages for the 7-year period was 1.81. Although growing corn on the contour may conserve water and save soil during most seasons, the hazard from high-intensity storms that sometimes occurs during the critical period for corn production may be increased by the practice. Some method of reducing slope-length hazard, such as terracing or strip-cropping, is needed to cultivate rolling land safely (*53*).

From observations made at McCredie, Mo., and on a limited number of contoured fields throughout Missouri, the effect of contouring tends to break down when critical slope lengths are exceeded (*52*). The critical length depends mostly on steepness and irregularity of slope. The approximate limits from observations are as follows:

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[6] The authors are indebted to Ronald Bird, Economic Research Service, U.S. Department of Agriculture, for assistance in making the computations.

[7] MISSOURI AGRICULTURAL EXPERIMENT STATION. FARM BUSINESS PLANNING GUIDE. Balanced Farming 6103, 41 pp. 1964.

Slope (percent)	*Length (feet)*
0–1	400
3–5	300
6–8	200
Over 8	Not to exceed 90.

The erosion hazard due to breakingover in contour rows may be reduced by constructing grass waterways at intervals where natural depressions occur on the slope.

Effect of Contouring on Yield

Smith (44) found that the effectiveness of contour farming on corn, soybeans, and oats on Missouri soils increased with increases in percent slope and soil permeability.

The average yield of contour-farmed corn in 40 tests during 1943–45 was 63.2 bushels per acre, or 7 bushels more than from the yield of comparable up-and-down slope fields. He concluded that one of the main factors in the increased corn yield with contouring was the greater stand. Erosion in the planter tracts on the up-and-down slope fields caused a loss of corn plants, especially on the steeper slopes.

The water-trapping effect of the contours on the more permeable soils would be expected to conserve moisture. On less permeable soils, such as Mexico silt loam, water accumulating in the furrows from some storms breaks over the furrow at low points and results in loss as runoff. Retention of water in the furrows of the flatter fields of Putnam soil during wet periods resulted in an average decrease of about 3 percent in corn yields during the test period.

Soybeans planted on the contour averaged 21.3 bushels per acre in 43 tests during 1942–45 (44). This was an increase of nearly 2 bushels per acre over the up-and-down slope yield. The yield increases were significant in 28 out of 43 tests. In two tests on flatter, less permeable soils, the yields were significantly depressed.

During 1955–61, the average corn yield from the contour-farmed plots 420 feet long at the Midwest Claypan Experiment Farm has not differed significantly from that of the 90-foot-long plots farmed up-and-down slope (table 25). In the 3 years since one of the long-slope plots has been farmed up-and-down hill, the average yield difference was only 0.4 bushel per acre.

In most years when no severe storms occur during the early part of the corn-growing season, some yield benefit may be expected through increased moisture retention. During periods of moderate rainfall, corn rows running across the slope trap runoff and increase moisture storage. In 1956, 16 more bushels of corn per acre were produced on the contour plot, primarily because of an inch of increased moisture absorption during the critical growth period for corn. In 1957, when the severe storms of June 29 and 30 caused breakingover of the contour rows and a higher soil and water loss, the yields were equal. But in the very wet summer of 1958, the excess moisture trapped in the contour rows was probably responsible for the 19-bushel-per-acre lower yield on the contour plot.

TABLE 25.—*Comparison of runoff and corn yields from short plots farmed up-and-down slope and from full-slope length contour plots (series II), 1955–61*

Season	Farmed up-and-down slope[1]		Contour farmed[2]	
	Runoff	Yield	Runoff	Yield
	Inches	*Bushels per acre*	*Inches*	*Bushels per acre*
1955	0.32	60	0.32	68
1956	1.52	123	.64	139
1957	2.14	81	2.24	80
1958	1.99	148	2.88	129
1959	.60	89	.19	88
1960	.08	123	.08	113
1961	1.26	107	4.90	106
Average	1.13	104	1.61	103

[1] Plots 90 by 10½ feet, average 3-percent slope.

[2] One-acre plots, 420 feet long, average 3-percent slope and lower half of plots about 4-percent slope.

TERRACING

Construction and Maintenance of Conventional Terraces

As terracing offered a means for reducing the lengths of the long slopes common on claypan soils, studies were started at the Midwest Claypan Experiment Farm in 1945 to develop terrace systems adapted specifically for these soils. Studies included plow method of construction, upslope plowing, channel grades, parallel-terrace construction, time study of farming operations, and runoff rate and amount.

Study of the plow method of terrace construction showed that an undesirable secondary channel developed below the ridge by the conventional method of plowing around a 15-foot-wide island five times with six replowings. This small secondary channel was eliminated by increasing the replowing on the upper side and reducing the replowing on the lower side. The return trips for the two extra replowings on the upper side were used to plow part of the interterrace area. Figure 10 shows the resulting cross section by the two methods of plowing. The channel capacities were ample to carry runoff from a 13-inch rain that occurred shortly after construction.

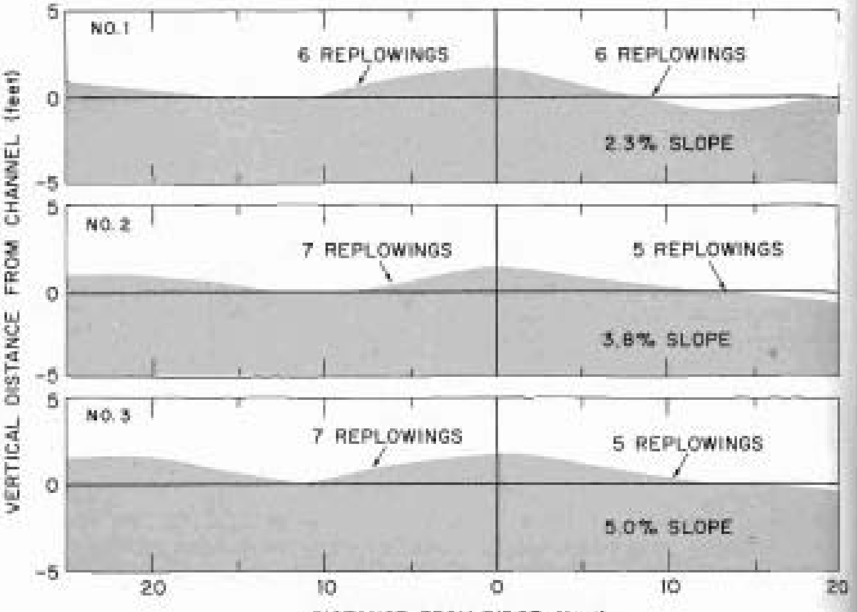


FIGURE 10.—Cross sections of three terraces constructed by equal (No. 1) and unequal (Nos. 2 and 3) replowing above and below ridge.

The two-way plow by which all furrow slices can be turned the same direction was selected for plowing the terraces at the Midwest Claypan Experiment Farm after successful use at the U.S. Soil Conservation Experiment Station, Bethany, Mo. By turning all furrows up slope, soil deposited in the channel was moved back up slope and the need for periodic terrace rebuilding to restore channel capacity was eliminated. One upslope plowing will essentially move one furrow slice from the bottom to the top of each terrace interval. For recommended terrace spacings, more soil will be transferred up slope by this process on the steeper slopes since the intervals are shorter. Erosion to the channels, however, is greater. The calculated upslope transfer of soil by one plowing for the terrace spacings used on different land slopes is shown in table 26.

Channel Grades

Terrace channel grades varying from 0.2 to 0.8 percent were studied on two Mexico silt loam fields at the Midwest Claypan Experiment Farm during 1946–52. The vertical interval varied from 2 to 3 feet depending on land slope. Terrace length varied from 700 to 1,000 feet. For a 780-foot channel in wheat during 1948, a grade of 0.2 percent impounded sufficient water to damage the crop growing in the channel. Some unthreshed wheat was left in the channel at harvesttime because the machinery would mire if pulled through the wet channel.

TABLE 26.—*Calculated upslope movement of soil by one upslope plowing for different land slopes and terrace spacings*

Land slope (percent)	Terrace spacing	Soil moved up slope[1]
	Feet	*Tons per acre*
1	130	10.7
4	85	16.3
7	70	19.9
10	60	23.2
15	54	26.0
20	54	26.2

[1] Assuming no tumbleback of soil with furrows 14 inches wide and 7 inches deep and with bulk density of soil before plowing 1.5 grams per cubic centimeter.

Grades of 0.3, 0.5, and 0.7 percent were more satisfactory. With wheat and a young meadow seeding as the crop, there were no silt deposits in the grass of the outlet channel in 1948, even with the 0.7-percent channel grade. Under corn and soybeans, no deposits were observed in the grass of the outlet for grades up to 0.5 percent, although a small amount of deposition was observed for the 0.7-percent grade. In 1950, no silting was observed for any of the four grades under observation. Even with the low runoff in 1952, there was some damage to meadow crops in the channels having the flatter grades; however, that was the first year since construction of these terraces that no difficulty in farming operations was experienced in the flatter channels because of wet conditions.

Harvesting of hay was hampered by water impounded in the 0.2-percent channels in 1951. No erosion in the steeper grades or silting in the outlets was observed, even for the 0.7-percent grade. Profile elevations were taken on one of the fields after two small grain and three meadow crops had been produced since construction of terraces. During this period, channel obstructions that developed from farm operations resulted in ponding areas covering 82 percent of the 0.2-percent and 8 percent of the 0.3-percent grade channels. No pondage developed in the 0.5- and 0.7-percent grade channels. The velocity of water in these steeper channels was sufficient to smooth out silt fans or prevent them from developing. Consequently, these channels drained well and dried in sufficient time to allow normal farming operations to proceed without difficulty. Silting and ponding of water in the flatter channels caused damage to crops and miring of farm machines.

Profile readings in the channels of the terraces in the other field confirmed these observations. The 0.2-percent grade showed evidence of ponding in 34 percent of the channel. For channel grades of 0.3 and 0.4 percent, pondage was 8 and 7 percent, respectively. None was observed for steeper grades. During the 5-year period since the construction of the terraces, this field was farmed to a rotation of corn-wheat-meadow-meadow-meadow. Scour occurred on the 0.7- and 0.8-percent grades only during the first year before corn planting.

These observations indicate that for Mexico silt loam and similar claypan soils, terrace channel grades should not be less than 0.3 percent. However, the channels were not subjected to the higher rates of runoff that occur once in 5 or more years, and scour observations under such conditions were not obtained. It is probable, therefore, that terrace channel grades should not exceed 0.4 percent, except for short terraces draining small areas or for upper ends of long terraces.

Parallel Terracing

Elimination of Point Rows

The first parallel terraces on Midwest claypan soils were constructed at the Midwest Claypan Experiment Farm in 1951. By 1953, three of the four terraced fields were reconstructed into parallel systems. This was motivated by dissatisfaction with the time required for farming operations and the inability to follow the sharp curves with modern crop-harvesting equipment.

In conversion of these terraces, the third one from the top of the slope was selected as the key terrace to which the two above and the one below on the slope were made parallel. The short-radius curves of the key terrace were eliminated by establishing a long-radius curve across the line of the original terrace. This required cutting the channel up to 12 inches deeper than normal for short distances. Little work above normal construction time was required for the upper two terraces. The fourth terrace on one field required a cut of about 22 inches deeper than normal for a short distance. A land leveler was used to smooth the field after reconstruction.

The total cost of conversion and bulldozer smoothing between terraces was about $16 per acre. The original cost of the terracing in 1947 was estimated at $14 per acre.

The reductions in point-row area by terrace improvement of the three fields are shown in table 27. The point-row areas of field 6 conventional terraces are included, since these were used in subsequent comparative time studies. Except for some areas remaining at upper edges of the fields, point rows were eliminated by the reconstruction. The area remaining as point rows or as full-length rows crossing terrace ridges was 7 percent of the total as compared with 30 percent before improvement of the three fields.

Somewhat larger areas of subsoil were exposed in shaping the ridges above the deep cuts to make them suitable for farming operations than in the conventional terrace channels. These areas required extra lime and fertilizer to bring them to soil-test fertility levels. Of the earlier treatments tried, lime, manure, and phosphate applications seemed to be the most satisfactory. Yields from the exposed clay areas, even with the treatments used, were no more than half those of the normal surface soil between terraces immediately after construction. In the second rotation, the yields were about 85 percent of those on the normal surface soil that received lower rates of treatment.

TABLE 27.—*Point-row area reduction from reconstructing conventional into parallel terraces on Mexico silt loam at Midwest Claypan Experiment Farm*

Field and terrace	Conventional terraces			Parallel terraces		
	Total area	Point-row area		Total area	Point-row area	
	Acres	*Acres*	*Percent*	*Acres*	*Acres*	*Percent*
Field 2:						
2	2.25	0.78	35	2.39	[1]0.31	13
3	3.12	1.41	45	2.26	[2].34	15
Field 3:						
2	1.90	.20	11	1.87	[1].15	8
3	1.88	.53	28	1.98	0	0
4	1.80	.46	26	1.98	0	0
5	1.56	.56	36	2.01	0	0
Field 4:						
1	1.57	.20	13	1.15	[1].38	30
2	1.89	.83	44	1.93	0	0
3	2.42	.40	17	1.84	0	0
4	2.13	.77	36	1.63	[2].24	15
Average	2.05	.61	30	1.90	.14	7
Field 6:						
2	2.38	.49	21	....	....	....
3	2.38	.50	21	....	....	....
4	2.12	.42	20	....	....	....
5	2.12	.39	18	....	....	....
Average	2.25	.45	20	....	....	....

[1] Irregular point-row area at upper edge of field.

[2] Uniform-width area extending part distance across field. Rows on these two areas have not been planted as point rows, but as full-length rows by crossing terrace ridge.

Saving in Production Time

Smith (*51*) developed the following equation relating production rate of farming operations to area, row length and width, time for and number of turns, and speed of travel on conventional and parallel terraces:

$$R = \frac{WNL}{(8.25NL/S) + 43{,}560t(N-1)} \qquad (1)$$

where R = production rate in acres per hour
W = row or cut width of implement in feet
L = average row length in feet
N = total number of rows or cut widths per terrace interval
S = speed in miles per hours
t = time per complete turn in hours

If the number of turns is taken as N instead of $N-1$, the equation reduces to

$$R = \frac{SWL}{8.25L + 43{,}560tS} \tag{2}$$

$$S = \frac{8.25RL}{WL - 43{,}560tR} \tag{3}$$

$$L = 43{,}560A/W \tag{4}$$

The area in acres (A) and the number of cut widths per terrace interval (N) can be obtained from a scale map of the area. By knowing the total time required for a specific operation over a complete terrace interval and the average time of turning measured with a stopwatch, solution of the equation for the average effective speed is possible. For areas on which production rates (R) are not known, they can be calculated by assuming a value of S for use in equation (2).

Data obtained during 1954 for corn on conventional terraces and on parallel terraces indicated a 28-percent reduction with the latter in operating time for planting, cultivating, and shredding stalks. Data on plowing are not reported because the terraces were plowed at different times and at different moisture contents. The drought made husking of corn unnecessary. During 1955, when all operations were included, the saving in time averaged 18 percent with the parallel terraces. The data are shown in table 28.

The conventional terraces were located in field 6 and the parallel terraces in fields 2, 3, and 4 (fig. 4 and table 28). For the conventional terraces, the average row length was 579 feet in 1954 and 555 feet in 1955. If the terraces had been parallel, the row length would have been 1,033 feet in 1954 and 1,048 feet in 1955. The area consisted of second and third terraces on slope in 1954 and second, third, fourth, and fifth terraces on slope in 1955. For the parallel terraces, the average row length was 641 feet in 1954 and 839 feet in 1955. In 1954, point rows were at the bottom and top of the field. In 1955, the area consisted of second, third, and fourth terraces on slope.

Values for the fields with parallel terraces were adjusted for differences in field width by use of equations (2) and (3). Row length and other data for these terraces on the field were as follows: Average area per interval, 2¼ acres; average row length, 555 feet, and, if parallel, 1048 feet; average row length, percent of parallel, 53 percent; point-row area, percent of total, 20 percent; and value of t, 0.008 hour for all fields and operations except husking, which averaged 0.0061 hour.

The average row length of 555 feet is 25 feet longer than obtained by equation (4). This difference represents the overlap resulting from planting of the point rows. The tendency to overlap in planting point rows is indicated by stand and harvesting data obtained during 1953 and 1954 on the conventional terrace field. Turning within the field to cultivate point rows generally has resulted in reduced stand and yield in these areas. The data obtained did not indicate that either stand or yield where point-row turning occurred differed significantly from those on adjacent areas where there was no turning. Apparently the overlap in planting resulted in a sufficiently greater original stand to compensate for stalks killed by turning. These data are shown in table 29.

TABLE 28.—*Production time and saving with parallel compared with conventional terraces for corn, 1954 and 1955*

Year and operation	Production time per acre with—			Saving in time with parallel terraces
	Conventional terraces, measured	Parallel terraces		
		Measured	Adjusted[1]	
1954	*Hours*	*Hours*	*Hours*	*Percent*
Planting, two 42-inch rows	0.56	0.51	0.48	14
Cultivating, rotary hoe, 2-row.	.34	.26	.24	29
Cultivating (1st), 2-row....	.81	.41	.38	53
Cultivating (2d), 2-row....	.42	....	....	....
Cultivating (3d), 2-row....	.51	.48	.45	12
Shredding stalks, 2-row....	.53	.45	.42	21
Total or average......	[2]2.75	2.11	1.97	28
1955				
Plowing, two 16-inch rows	1.15	.92	.88	23
Disking, 10-ft. tandem......	.25 .28	.24 .24	.24 .24	4 14
Planting, two 40-inch rows	.65	.54	.53	18
Cultivating (1st), 2-row....	.59	.51	.50	17
Cultivating (2d), 2-row....	.37	.35	.34	8
Cultivating (3d), 2-row....	.41	....	....	....
Husking, 1-row[3]	1.64	1.32	1.28.	22
Shredding stalks, 2-row....	.40	.38	.37	8
Total or average......	[2]5.33	4.50	4.38	18

[1] Data from field in third column adjusted to comparable row length (1,033 feet in 1954; 1,048 feet in 1955) for field in second column.

[2] Second (1954) and third (1955) cultivation times omitted from total.

[3] Down corn required husking one direction.

TABLE 29.—*Final stand and yield of corn on conventional terrace field with and without point-row turning*

Year and pairs of samples	Stalks per acre		Yield per acre[1]	
	Point-row turning	No turning	Point-row turning	No turning
	Number	*Number*		
1953, 2	10,200	8,600	54.5	47.4
1954, 6	10,200	10,800	[2] 1.06	[2] 1.03

[1] Bushels (1953); tons (1954).

[2] Dry matter in fodder; differences not significant.

The speed or rate of travel was not predetermined for the different operations. The operator's only instructions were to keep a record of starting and stopping time and to exclude any abnormal stoppage, such as that caused by mechanical failure of the implement or tractor. The same operator covered both conventional and parallel terrace areas in 1954. This was not possible during 1955. Also, in 1955, the tractor was equipped with a speedometer. The effective speed for each operation during both years was calculated by equation (3). All values are tabulated in table 30.

The tendency to reduce tractor speed on short rows had been observed for several years. Turning was usually at low speeds. If the distance of travel was short, the operator frequently did not open the throttle, as when he had a long row to plow or cultivate. This was evident during 1954 when the same operator worked on both areas, but with a tractor not equipped with a speedometer. The narrow ratio for 1955 data may have been because the operator attempted to maintain the rated tractor speed regardless of row length in an effort to speed operations.

TABLE 30.—*Average speed of operation per hour calculated from measured production rates and operating speed equation (3) for corn on conventional and parallel terraces and soybeans on parallel terraces, 1954 and 1955*

Operation	Corn, 1954		Corn, 1955		Soybeans, 1955, parallel terraces
	Conventional terraces	Parallel terraces	Conventional terraces	Parallel terraces	
	Miles	*Miles*	*Miles*	*Miles*	*Miles*
Plowing, two 16-inch rows.	....	....	3.39	4.06	2.54
Disking, 10-ft. tandem	....	....	3.45 2.98	3.45 3.45	3.01 3.82
Harrowing, 2-section	....	....	....	....	5.00
Planting, 2-row	2.50	2.70	2.23	2.57	2.53
Cultivating, rotary hoe, 2-row.	4.80	6.30	....	....	....
Cultivating (1st), 2-row.	1.65	3.53	2.49	2.75	4.15
Cultivating (2d), 2-row.	3.57	....	4.03	4.25	....
Cultivating (3d), 2-row.	2.83	2.91	4.75	....	....
Husking, 1-row	....	....	3.66	4.39	....
Shredding stalks, 2-row.	2.71	3.16	4.11	3.87	....
Average	2.90	3.72	3.29	3.60	....
Ratio of $\frac{S\text{ (conventional)}^{1}}{S\text{ (parallel)}}$	....	0.78	....	0.91	....

[1] Ratio for both years is 0.86.

Production-time records were obtained for a field of parallel terraces planted to soybeans during 1955. These data are shown in table 31.

The rate for conventional terraces was calculated, using equation (2) and assuming speeds for conventional terrace operation as 0.86 of those for the parallel terrace field. Theoretically this ratio should increase to unity as the operating speed decreases to the average speed during turning. The plotting of the ratios for individual operations against speed suggests this trend. There were not, however, sufficient data for establishing a true trend line, so a simple average was used. The length of row, also assumed, was 53 percent of the length with parallel terraces, the same as determined for the conventional terrace field in corn.

The rate for parallel terraces was measured, based on an average for five terraces with a total area of 9.7 acres and an average row length of 690 feet.

These data support the hypothesis that operating time can be reduced materially by improvement of terrace alinement. With data on cost of layout and construction, an estimate could be made of the number of years of operation required to pay for the additional original costs for the parallel terraces.

These studies indicated an average increase in row length and decrease in point-row area by terrace improvement. The row lengths were nearly doubled and the point-row areas decreased by 70 percent for fields with parallel terraces over those with conventional terraces. Average rate of travel of farming equipment on the parallel terraces was 16 percent faster than that on the conventional terraces. The saving in production time for corn and soybeans averaged about 24 percent. Since the parallel terrace overcomes many of the objectionable features of the conventional terrace, parallel terraces should increase in acceptance and use by farmers.

TABLE 31.—*Production time and saving with parallel compared with conventional terraces for production of soybeans, 1955*

Operation	Production time per acre with—		Saving in time with parallel terraces
	Conventional terraces (calculated)	Parallel terraces (measured)	
	Hours	*Hours*	*Percent*
Plowing, two 16-inch rows	1.79	1.23	31
Disking, 10-ft. tandem	.42 .35	.32 .27	24 23
Harrowing, 2-section (10 ft.)	.29	.22	24
Planting, two 40-inch rows	.72	.57	21
Cultivating, 2-row	.49	.37	24
Total or average	4.06	2.98	27

Terrace Runoff and Channel Capacity

Measurements of maximum runoff from terraces are essential to predict peak channel flow and design of terrace systems. Runoff recording equipment has been in operation at the outlets of the four terraces in field 6 since 1950. These are conventional terraces, with an average grade of 0.33 percent. The drainage areas of each of the upper two (Nos. 2 and 3) and each of the lower two (Nos. 4 and 5) terraces are 2.375 and 2.125 acres, respectively. The upper (No. 1) terrace on this slope is not equipped to measure runoff. These terraces are on a land slope of about 3 percent. The channel lengths vary from 984 to 1,075 feet and the vertical intervals are about 2½ feet. The channels are 4 to 5 feet wide, with about 10:1 front ridge slope and about 14:1 slope above the channel.

Annual maximum runoff rate for each terrace during 1951–64 is given in table 32. The highest rates during the period were recorded during the severe storms on June 29–30, 1957, and the lowest during the dry year of 1954.

TABLE 32.—*Annual maximum runoff from terraces in field 6, 1951–64*

Year	Cover	Date	Maximum runoff rate per hour for terrace—			
			2	3	4	5
			Inches	*Inches*	*Inches*	*Inches*
1951[1]	Cornstalks	Mar. 17	0.43	0.51	0.37	0.45
	Corn	June 23–24			.85	.99
1952	Cornstalks	Mar. 31			.26	.40
		Nov. 17	.43	.41		
1953	Wheat	May 22	.05	.05		
	Corn	May 22			.26	.48
1954	Wheat stubble	Oct. 14			.02	.03
	Cornstalks	Oct. 14	.03	.01		
1955	Seedbed for corn	Apr. 23	.41	.14		
	Wheat stubble	Jan. 4–6			.14	.15
1956	Soybeans	July 3–4	.76	.74	.79	1.14
1957	do	June 29–30	3.12	3.02	3.20	2.81
1958	Corn	June 14	.51	.33	[2] .35	.48
1959[3]	do	Oct. 10	.23	.26	.37	.37
1960[3]	Corn	June 30–July 1	.62			.60
	Cornstalks	Mar. 27		.43	.35	
1961	Corn	June 30–July 1	.96	.99	1.07	1.14
1962	Cornstalks	Mar. 20–21	.20	.15	.18	.17
1963	Corn	May 16	.08	.03	.05	.07
1964	do	May 26–28	.22	.20	.26	.24

[1] Terraces 3 and 4 subsoiled and lime applied at 4 tons per acre placed at 9- to 16-inch depth in 1948.

[2] Estimated; plug was out of float well.

[3] Minimum tillage (wheel-track planting) on terraces 3 and 4; conventional tillage on terraces 2 and 5.

The total dimensions of the four terrace channels and the dimensions used for the maximum runoff from the intense storms of June 29 and 30, 1957, are shown in table 33. Storms of this magnitude can be expected to occur somewhat less frequently than once in 10 years. These terraces were originally designed to have a maximum channel cross-section area of 16 square feet. Each of these terraces was in row crops every year during 1955–60 and on alternate years during 1950–54. Upslope plowing in each of the row-crop years has increased the terrace berm heights and channel capacities to an average of 22.5 square feet by 1957 (table 33). The flow from this storm did not utilize half the actual cross-section area of any of the channels. Had the channels been maintained at only the design capacity, the greatest flow measurement at any station would have utilized only about 61 percent of the available

TABLE 33.—*Channel and flow measurements of terraces carrying runoff from 4.23 inches of rain, June 29 and 30, 1957*

Terrace and station distance (feet)[1]	Channel measurements				Flow measurements[2]		
	Elevation	Top width	Depth	Area	Top width	Depth	Area
	Feet	*Feet*	*Feet*	*Square feet*	*Feet*	*Feet*	*Square feet*
Terrace 2:							
1,050	844.77					0.95	
1,000	845.15	32	1.33	24.4	20.5	.73	8.5
750	846.17	36	1.40	25.5	12.8	.48	3.3
500	847.10	35	1.20	24.0	15.3	.42	3.4
250	847.87	36	1.37	28.1	10.7	.17	1.8
Terrace 3:							
1,050	842.56					.93	
1,000	842.90	32	1.13	20.7	22.1	.69	8.7
750	843.75	30	1.26	22.2	14.0	.45	4.0
500	844.45	32	1.41	23.5	13.3	.50	3.5
250	845.45	35	1.25	25.7	10.9	.17	1.1
Terrace 4:							
1,050	840.05					.90	
1,000	840.39	32	1.00	23.8	23.6	.63	9.4
750	841.20	32	1.18	18.0	12.6	.42	2.8
500	842.20	34	1.19	20.6	12.4	.42	2.9
250	843.18	34	1.09	17.6	10.4	.17	1.8
Terrace 5:							
1,050	837.49					.83	
1,000	837.68	35	1.18	23.0	22.7	.75	9.7
750	838.77	31	1.15	20.4	15.2	.42	3.5
500	838.80	34	1.25	24.7	14.6	.37	2.9
250	840.60	33	1.10	19.5	7.0	.22	1.1

[1] From upper end of terrace. 1,050 station is flume entrance; elevation, that of flume discharge.

[2] Maximum discharge in cubic feet per second was 7.5, 7.2, 6.9, and 6 for terraces 2, 3, 4, and 5, respectively.

cross section. Since flow velocity increases with stream depth, the actual percent of design capacity utilized would be even less than this amount.

The storm of June 29–30, 1957, occurred about 3 weeks after soybeans were planted, and the soil had little vegetative cover. The data in table 33 indicate that a channel cross-section area of 18 to 20 square feet is adequate for the outlet end of terraces of the indicated length, grade spacing, and management practices for a 15-year runoff frequency under central Missouri rainfall. This would allow 5 to 6 inches of freeboard above the expected flow. Dimensions for shorter terraces could be somewhat smaller. With terraces designed to accommodate multirow farm equipment, the channel capacity generally will exceed that required to carry the runoff volume expected once in 15 years.

SOIL MOISTURE

Available Soil Moisture Storage

Moisture Storage Capacity

The quantity of water a soil will absorb from rainfall or irrigation and retain after draining for 1 or 2 days is usually considered the field capacity of that soil. Not all this "stored" moisture is available to plant roots. A considerable quantity of the total soil moisture may be held in fine pores and adsorbed on particle surfaces at energy levels so high as to make it unavailable to plants. The leaves of most crop plants show stress by wilting, or they are noticeably retarded in growth at energy levels equivalent to about 15 atmospheres of suction or negative pressure in the soil water.

The quantity of water that can be retained between the field capacity and the wilting point is called the "available moisture storage capacity." It may be expressed as a percentage ratio to the dry weight of the soil, or it may be given in more convenient volume units such as a percentage of the total soil volume or just as inches of water per unit depth of soil (inches per inch or inches per foot).

The field capacity for most soils is generally reached at a low energy level equivalent to about one-third atmosphere. The value found by experiment varies with soil texture and conditions in the soil profile. For some sandy soils, the field capacity may be approximately one-tenth atmosphere and for silt loams, between one-third and one-half atmosphere equivalent suction.

The field capacity condition is not an equilibrium state, but is that moisture condition reached in a soil after wetting and drainage have proceeded until moisture movement is very slow. In soils of coarse to medium texture, with no restrictive layers in the profile, most of the "excess" water will drain into the deep soil layers in 1 or 2 days. If evaporation from the surface is prevented and no plants are growing on the soil, further losses during a period of time needed to produce a crop will be very small. For dispersed clay soils, drainage is very slow after the soil is wet. There is no noticeable change between early rapid and later slow drainage rates. For such soils, the concept of "field capacity" is without practical meaning.

Effect of Claypan on Soil Moisture

The presence of a claypan layer in the soil will restrict water movement and affect moisture storage. This restriction in soils like Putnam or Mexico silt loam will effectively increase the available storage capacity, even at the expense of essential air capacity in very wet weather. However, for lack of more detailed information on water movement and storage in claypan soils, the approximate available storage capacity is taken as that held between the suction limits of one-third and 15 atmospheres. In wet weather on the flatter soils the suction would sometimes drop below the one-third atmosphere level in the surface. However, where irrigation may be used, it would be difficult to wet the soil below the one-third atmosphere level because of the low intake rate.

Although the claypan layer may tend to increase storage in the surface layer, the quantity of available water the claypan layer may deliver to growing plants is lower than its very high capacity to store water would indicate. A large part of the moisture retained is in the "unavailable" range at moisture contents below the wilting percentage. Although nearly all or about 45 percent of the pore space is filled with water, about half of it is probably not available to plants (*23*).

Moisture Storage and Use Efficiency

The relative proportion of the rain that enters the surface and is retained by the soil may be considered as the storage efficiency. This is dependent on the soil surface as well as profile conditions. Poor cover and soil surface conditions will reduce water intake and storage. Although the intake rate of a Mexico silt loam is high when the surface is very dry (*35*), it will decrease rapidly to very low values with a rainfall of high intensity unless the surface is protected or "conditioned" by water-stable aggregates. Grasses and legumes produce good conditioning against surface sealing, but not without adequate fertilization (*47*).

Smith and Wischmeier (*55*) reported that the average runoff from the plots at the Midwest Claypan Experiment Farm varied from 6.83 to 11.74 inches per year (1941–50) for different cropping and fertilization systems. (See also series I, plot 5, tables 4 and 5, and series II, plots 25 and 26, table 15.) The lowest was for the well-fertilized timothy, sweetclover, and lespedeza and the highest for the corn-oats rotation without fertilization. Adequate fertility of the soil improves the cover not only of small grains and row crops but of sod crops as well. In fact, fertilization of meadow in a crop rotation will benefit the succeeding row crop through residual conditioning and fertility of the soil (*53*). Those cropping systems with adequate fertilization that provide the best cover and soil conditioning will result in the most efficient use of rainfall.

Poor fertility in the subsoil, and particularly in the surface layer, will reduce the efficiency of moisture extraction from a claypan by deeper rooting plants (*12, 49, 75*). Smith (*51*) reported that, although more water was extracted by a corn crop from Mexico silt loam when the soil was adequately fertilized, the water use per bushel of corn produced was nearly four times as much on low-fertility as on high-fertility plots.

Soil Volume Changes With Wetting and Drying

Soils rich in clays of the expanding lattice type often exhibit spectacular volume changes with wetting and drying (*11, 30, 38, 65*). Such soils are those of the Midwest that have developed on loess, till, or fine alluvial parent materials.

Woodruff (*74*) found that large decreases in elevation of the surface of Shelby loam were caused by moisture losses during the severe drought of 1934. He concluded that measurements of soil surface elevation changes will not give reliable estimates of soil erosion losses on these soils.

Observations in pits excavated for soil moisture samples in Putnam and Mexico profiles during dry periods showed only a few vertical cracks in the surface. Some of the larger ones extended into the claypan. The body of the B_{22} horizon of the claypan, when extremely dry, was profusely cracked into numerous small, hard, prismatic fragments. Evidently much of the shrinkage and swelling in the claypan layer are absorbed by internal volume changes involving the opening and closing of the numerous small cracks. Crack formation in the silt loam layer beneath the claypan was never observed. An experiment was started in 1959 on the Midwest claypan soils at McCredie, Mo., to increase knowledge of soil moisture volume changes in clay-enriched soils in relation to the crop grown.

The first installations were made in March 1959 after the very wet summer of 1958. Two plots were laid out, one in a native bluegrass area and one in an alfalfa field with some native grasses. The study was expanded in 1960 to include a plot of growing corn after having been in alfalfa that received deep fertility treatments (*24*). This plot was added to see whether the subsoil lime and phosphate applications of 1954 had affected alfalfa root activity in the zone of application.

Screw-type soil anchors such as those used for guy-wire anchoring of fenceposts or power poles were turned into the various transition zones between the horizons in the upper 3 feet of the soil profile and to greater depths of 4, 5, and 6 feet. The shanks were fitted with 12-inch lengths of pipe sleeves to prevent frost heaving of the anchors. An elevation benchmark was installed at each site.

Three aluminum plates were pinned to the surface in each plot for surface elevation measurements. In the corn plots, seedbed preparation and cultivation were performed by hand, so as to leave the plates undisturbed.

The three anchors were set at random locations within each plot with the restriction that no adjacent anchors were turned to the same depth. Elevation readings for each of the anchors, in reference to the benchmark, were made at least once each month and when weather conditions indicated an appreciable change in soil moisture was probable. Each time elevations were determined, moisture readings were taken at depth intervals so as to give values representing the soil horizons or layers between anchor depths. A neutron moisture probe was used.

The elevation readings were processed to show deviations from those on a chosen reference date. The average deviations for the anchors at the different depths were used to calculate the average changes in thickness of the various soil layers with respect to the reference date. These changes were calculated as a percentage of the thickness of each layer and are reported as "percent volume changes." It is assumed that horizontal changes would be restricted to opening and closing of vertical cracks in the soil and that vertical elevation changes express variations in bulk volume.

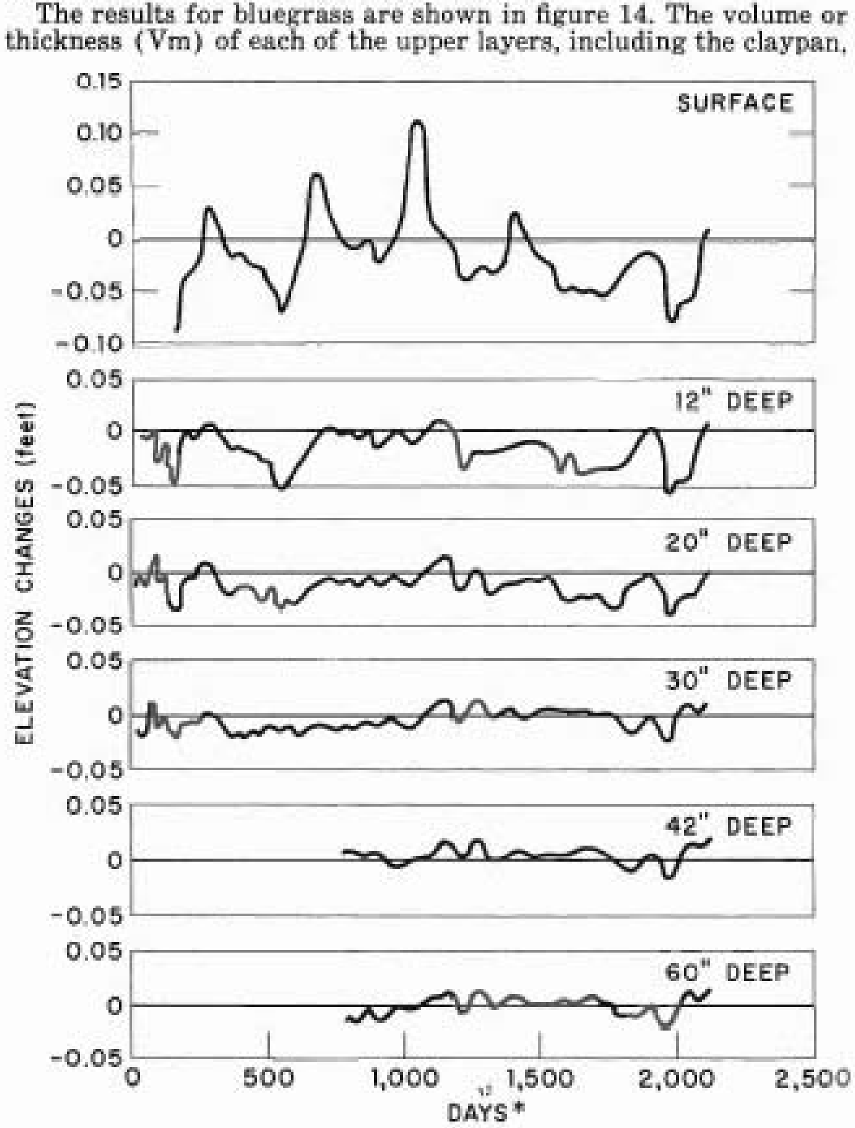
The soil volume changes were plotted as a function of moisture content for the different plots. The correlations were high, particularly for the claypan and B_3 horizons. However, it became evident after the winter of 1962 that shifts had occurred in this relationship for some layers. The shifts were noticeable for the upper horizons, particularly under corn, to a less extent under alfalfa, and least under bluegrass. At first, it was thought that there had been structural changes in the soil due to freezing and thawing (*9, 41, 62, 71*).

Since the shifts clearly occurred in the winter of 1962 and to layers below the frost zone in the soil, evidently there was frost heaving of the anchors, in spite of the precaution taken to prevent it. Apparently water from rain or melting snow froze in the space between the sleeve and shank of the anchor, and as the soil froze to the sleeves and swelled with ice accumulation, the anchors were lifted. With thawing of the soil, each heaved anchor did not return to its original elevation. The changes in elevation with respect to the reference date (Nov. 11, 1961) were corrected for the anchor heaving.

There was little general change in elevations of the soil layers under bluegrass (fig. 11). The anchors were at about the same level in 1965 as they were at the start of the experiment. The 12-inch layer elevations under corn (fig. 12) show a general decrease, but the deeper layers show a slight increasing trend, even after adjustment for "frost heaving" in 1962. The elevations under alfalfa show a general decrease since 1959 for all layers (fig. 13). There was a decrease of about 0.1 foot at the 28-inch depth and of 0.05 foot or more for the 45-, 60-, and 84-inch depths. The correction for frost heaving adds 0.01 to 0.03 foot to the values since the winter of 1962 for the 0-, 10-, and 18-inch layers. Since the changes under the deep-limed alfalfa were not significantly different from the untreated plot, the results are not shown graphically.

The changes in layer thickness were determined and plotted against time for the various soil layers under the different crops. In each case, the point of maximum expansion, excluding the winter months, was taken as the base line. Increases above this value for layers near the surface are assumed to be partly due to freezing of the soil. Decreases below this line are due to loss of moisture and shrinkage of the soil layers.

The results for bluegrass are shown in figure 14. The volume or thickness (Vm) of each of the upper layers, including the claypan,



* TIME SINCE APRIL 1959

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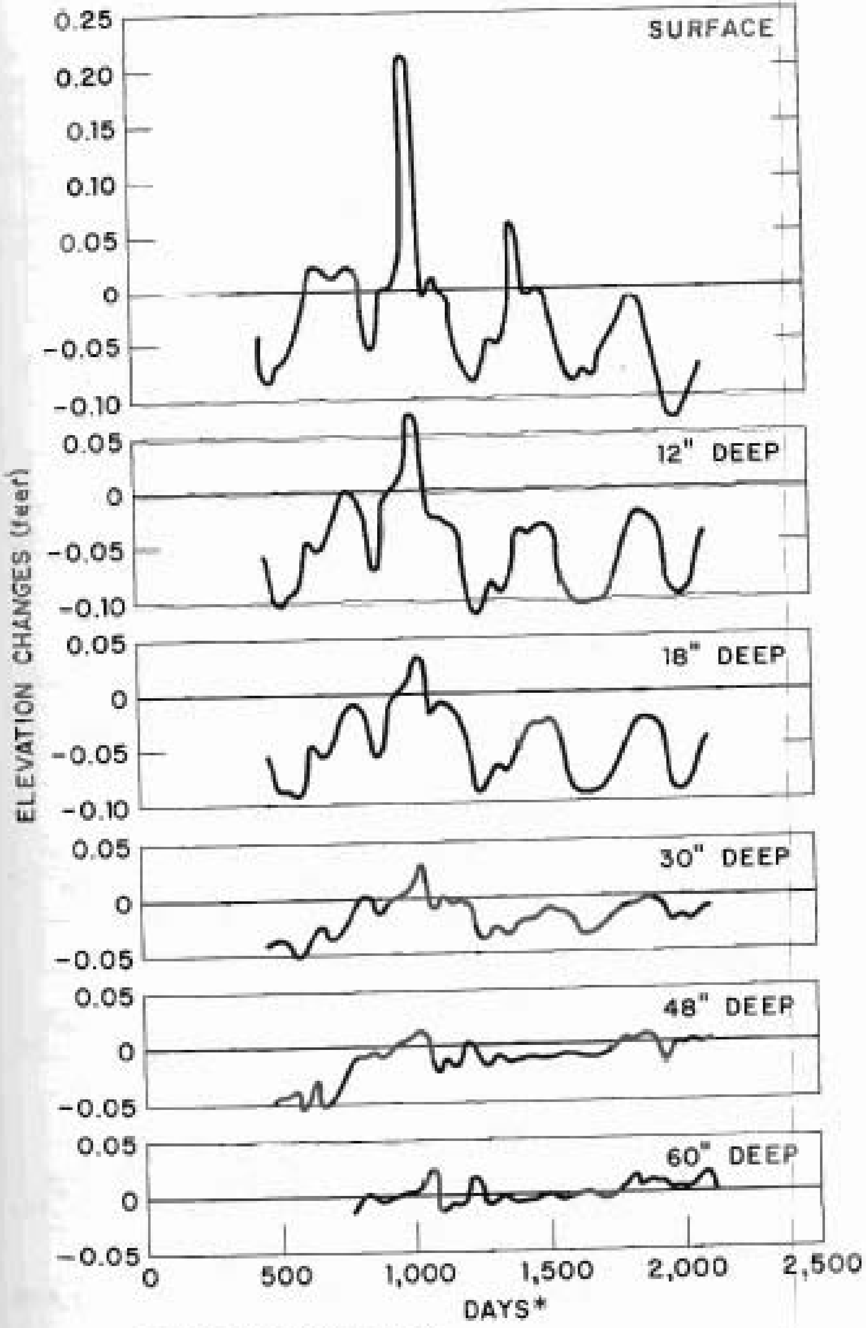
FIGURE 11.—Elevation changes of soil layers under bluegrass since April 1959.



* TIME SINCE APRIL 1959

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FIGURE 12.—Elevation changes of soil layers under corn since installation of anchors in 1960.

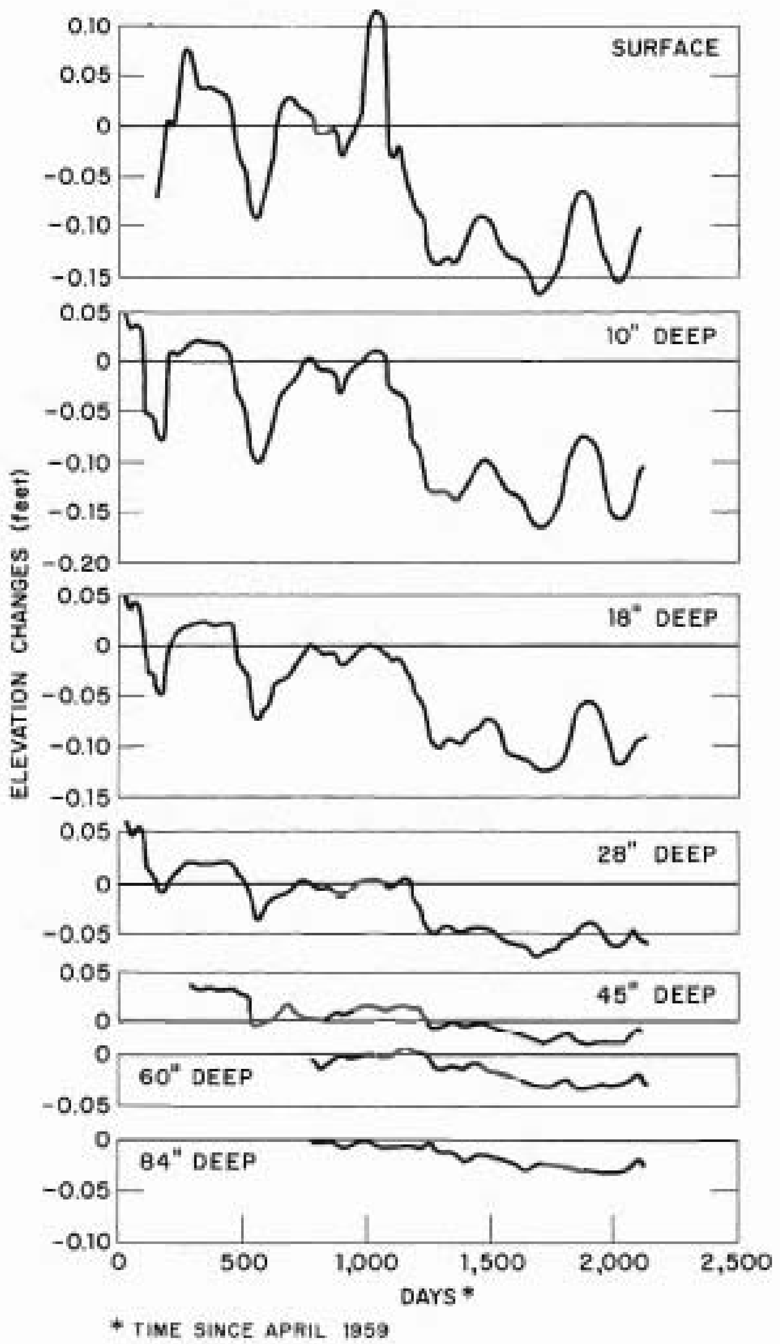

FIGURE 13.—Elevation changes of soil layers under alfalfa since April 1959.

decreased slightly, but there was little change in volume of the deeper layers. The changes in moisture content (Pv) are shown for comparison. Since both moisture content and layer thickness changes are expressed on the same volume scale, the relative magnitude of volume change with moisture content can be seen.

The results for the corn plots are shown in figure 15. Although there was periodic recharge of moisture and recovery from shrinkage in the surface and claypan layers, the 18- to 30-inch and the

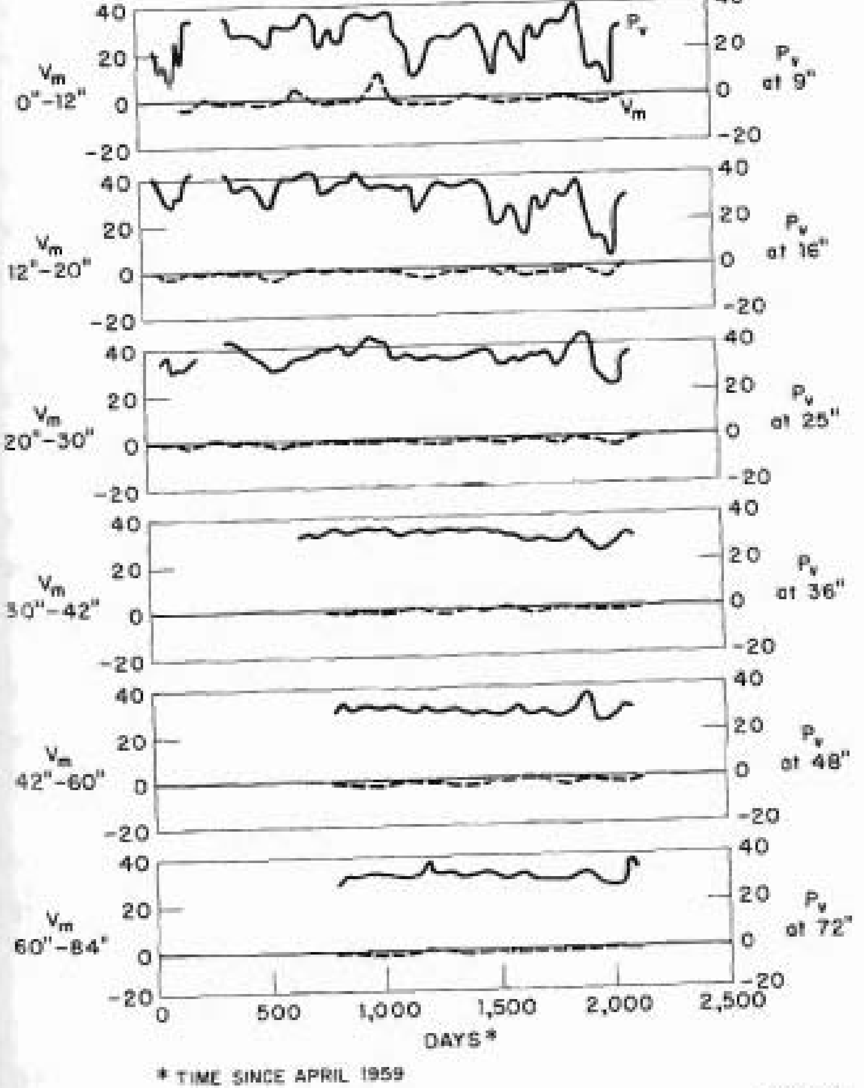

FIGURE 14.—Changes in layer thickness or volume (Vm) and soil moisture content (Pv) for different soil layers under bluegrass since April 1959.

30- to 48-inch layers showed a trend of decreasing thickness and moisture content. Volume and moisture changes below 5 feet under corn were small.

There was a general trend of decrease in soil volume and moisture content under alfalfa during the experiment (fig. 16). Soil shrinkage and removal of moisture continued with periods of

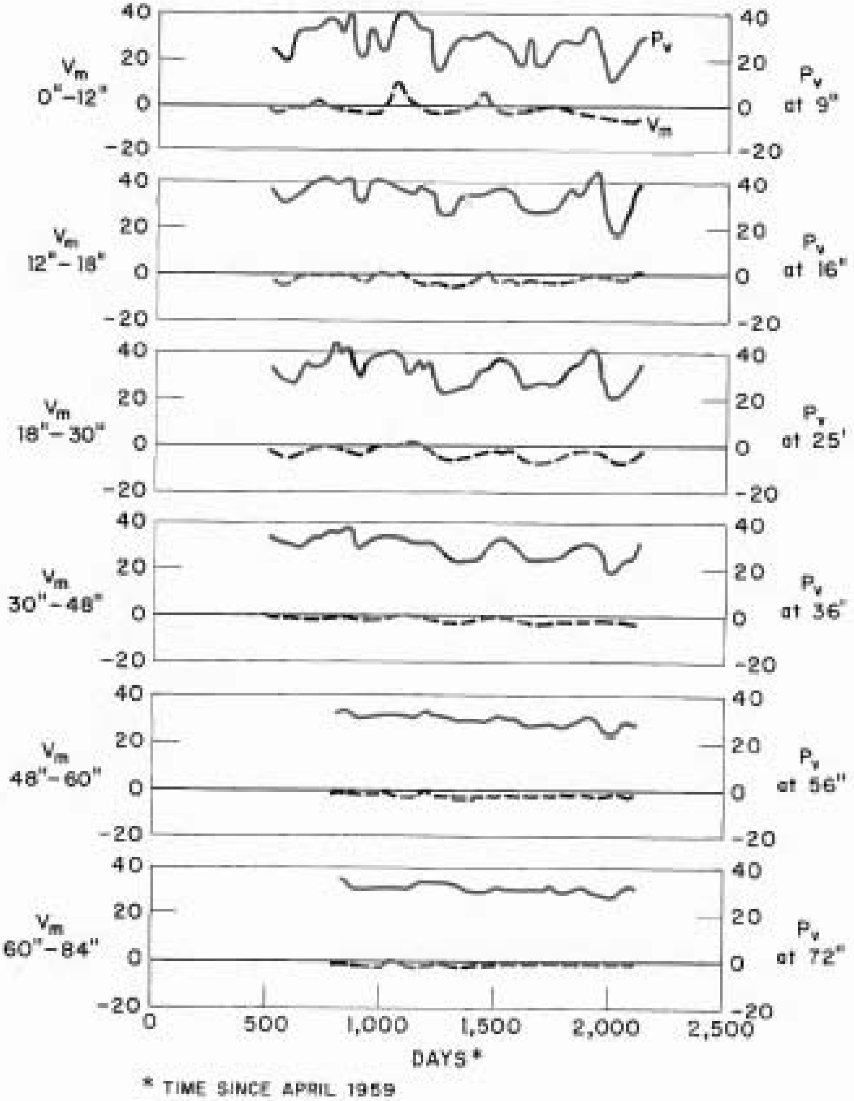

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FIGURE 15.—Changes in layer thickness or volume (Vm) and soil moisture content (Pv) for different soil layers under corn since installation of anchors in 1960.

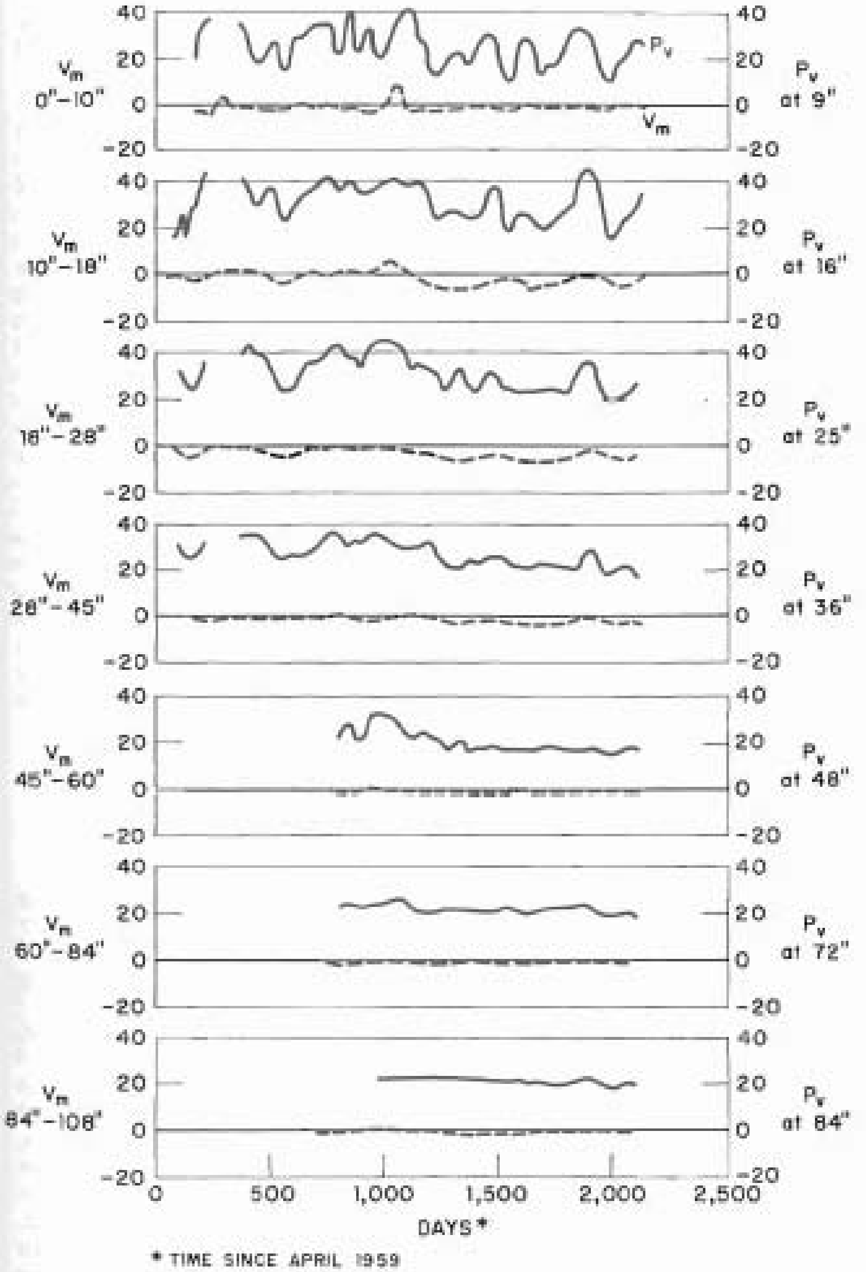

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FIGURE 16.—Changes in layer thickness or volume (Vm) and soil moisture content (Pv) for different soil layers under alfalfa since April 1959.

partial recovery during the experiment. Since volume moisture changes under the deep-treated alfalfa were little different from those for the alfalfa without treatment, the results are not shown graphically.

As may be expected from previous results (*25*), the effect of deep-placed lime and phosphate on alfalfa root activity was small. The treated alfalfa plot exhibited about the same patterns of shrinkage-moisture changes in the zone of lime-phosphate fertilization (10- to 18-inch layer) as the plot without treatment.

Differential changes in soil volume under and around buildings on Mexico silt loam and similar claypan soils cause uneven support and cracking of foundations and walls during changes from wet weather to extreme drought (*2, 13, 18, 62*).

The effect of deep-rooted plants on these soils should be considered in building design and landscaping. Since such plants are usually considered an esthetic requirement or are needed for shade around homes and many public buildings, precautions must be taken to counteract the effects of soil volume changes.

The McCredie, Mo., studies showed that bluegrass will use moisture in the upper 1 or 2 feet of soil and then wilt and lapse into dormancy until soil moisture, as well as temperature, becomes favorable for renewed growth. Deep-rooted alfalfa continues to extract water from the deeper soil layers during extended periods of drought. Deep-rooted trees and shrubs could be expected to function similarly. To protect foundations from differential settling or cracking, they should be set below the zone of shrinkage or based on piers that rest on firm soil or bedrock material.

IRRIGATION

Need for Irrigation

The claypan soils of the Midwest lie in climatic zones varying from humid to semiarid. Although the highest rainfall usually occurs in this region in the late spring and early summer, losses of moisture by evapotranspiration are correspondingly high during this time.

The summer rainfall in the eastern Midwest claypan region varies considerably from year to year. Although the average monthly rainfall is about the same for the spring and summer, the evapotranspiration losses are higher during June, July, and August. From U.S. Weather Bureau rainfall records for Columbia, Mo., and estimated average potential evapotranspiration,[8] the time distribution of the rainfall to potential evapotranspiration (R/E) values for the period of record (1890–1958) was calculated. The distribution of R/E values with percent of time lower than given values for the late spring and summer is shown in figure 17.

For the average season (50 percent of time level), the evapotranspiration loss was greater than the summer rainfall (R/E less than 1.0). This deficit may be compensated in part if the soil has a high capacity to store available water in the root zone and if slope, cover, and condition of the soil are such as to store most of the rainfall in the plant root zone. For the nearly flat Putnam silt loam in this area, runoff is generally low during dry seasons, and the storage capacity for the average crop plant root zone is about 4 inches.

Assuming that rainfall conditions remain about the same for any given season, the R/E intercepts for each of the percentage time values in intervals of 10 percent can be taken as representing 1 out of 10 years on an average from the driest to the wettest season one may expect. The minimum levels of moisture supply for the spring and summer on this soil to be expected for the 6 driest years in every 10 are shown by the solid lines in figure 18. The four wet seasons to be expected, when the soil storage will be kept full, are shown by the broken line. For this soil in central Missouri and for crop plants with roots permeating the upper 2 feet of soil, a need for irrigation may be expected at least 4 years out of 10 on an average. For about 1 year in 10, at least 12 inches of water would need to be applied by irrigation for optimum moisture conditions.

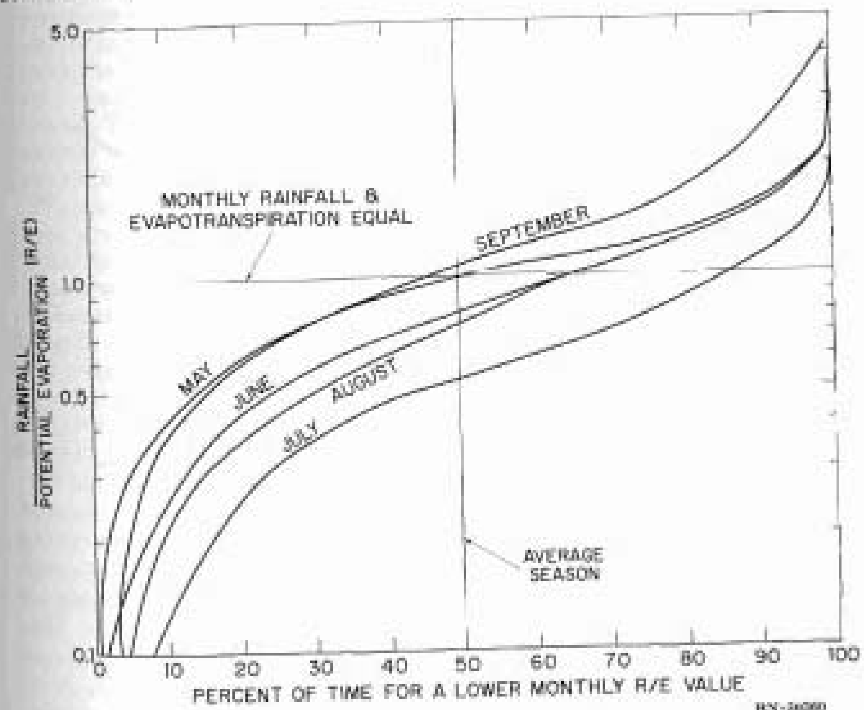

FIGURE 17.—Distribution of R/E values over 68-year period of record at Columbia, Mo.

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[8] The potential evapotranspiration is the maximum possible loss of water from soil and plants by evaporation under prevailing weather conditions if moisture is not limiting and plant cover is complete.

It should be emphasized that the curves in figure 18 represent average trends. There will always be a certain amount of reversal from the dry to wet conditions and vice versa in the same season. A very wet spring may be followed by a summer drought, or an early-season drought may be broken by heavy summer rainfall. The curves may be taken by irrigation engineers as representing only long-time average conditions one might expect for Putnam and Mexico silt loam in central Missouri. Decker,[3] however, estimates that irrigation may be used to advantage on some crops in the Columbia area 10 years out of 11 and that at least 12 inches of water will be needed for 13 percent of the years.

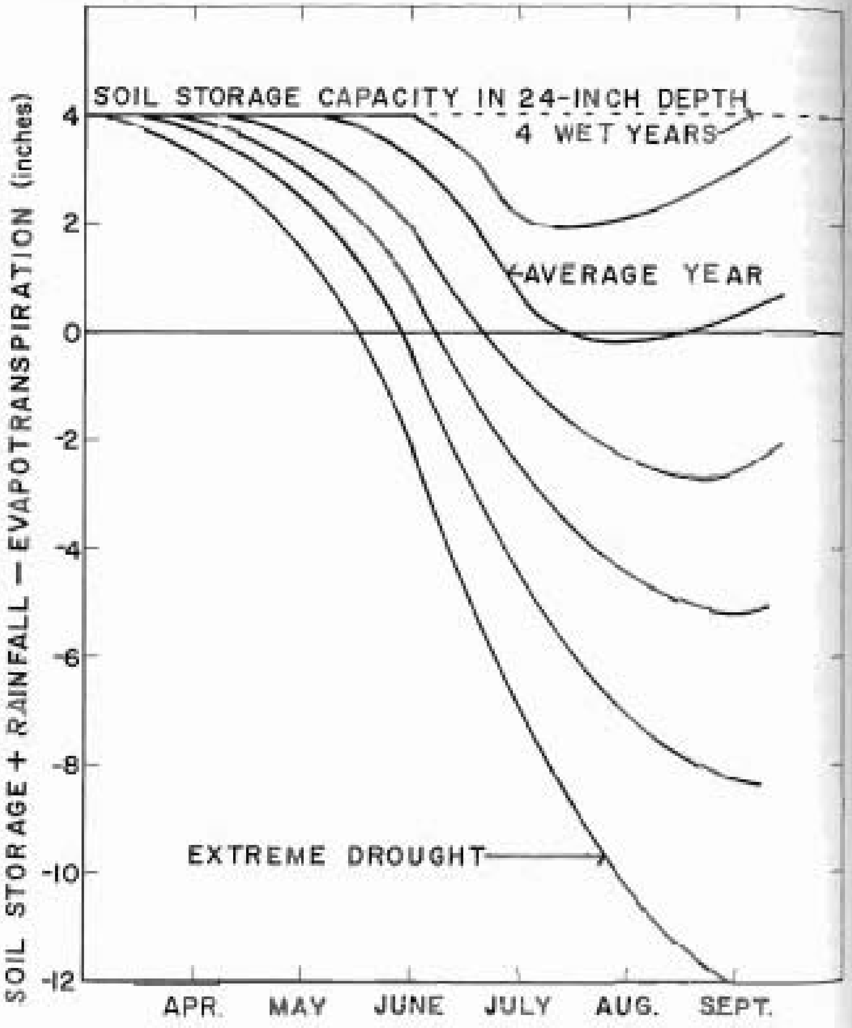

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FIGURE 18.—Crop growing seasonal distribution of available soil moisture to be expected over 10-year period at Columbia, Mo.

On sloping soils like Mexico silt loam, part of the rainfall from intense summer storms may be lost as runoff. Although losses are usually low from dry soil (*25*), the total summer runoff even in dry years may total 4 or 5 inches because of poor rainfall distribution. Also, in dry years the water loss by evapotranspiration from relatively small irrigated fields in otherwise dry areas will be higher than the potential estimates. This "oasis effect" would need to be compensated by the application of extra water to insure adequate soil moisture. In very dry years the soil storage reservoir may not be filled at the beginning of the growing season, although otherwise adequate summer rains may come after a dry fall and winter. Thus, the need for water on claypan soils of the subhumid region will probably be a little greater than would be predicted from figure 18.

The need for irrigation will also depend on the kind of crop and the period when moisture must be supplied. After grain crops have reached maturity, dry soil will favor ripening and harvesting the crop. For full production, pasture and hay crops will need to be supplied with moisture for the fall, as well as the spring and summer. Some crops can withstand a short drought with little loss in production. Corn suffers little production loss from limited drought during early growth if it has adequate moisture during the tasseling-to-early-dent stage (*22*). Soybeans are rather drought resistant. They appear to remain somewhat dormant during drought periods and may resume normal growth and fruiting if adequate moisture is supplied before the plants are seriously damaged (*69*).

There is evidence of indirect benefits to Midwest claypan soils from prolonged droughts. Production has appeared to be somewhat better in years of normal rainfall that follow dry years than in those that follow normal to wet seasons. This is probably a result of chemical changes that take place during thorough drying of the subsoil. Improved drainage and aeration through drying and shrinkage may produce profound physicochemical changes in the clay subsoil. Extreme drying of the subsoil of a claypan soil appears to produce effects that are of greater benefit to crop production than were the deep tillage methods tried thus far.

Whether irrigation will pay for crops grown on claypan soils depends on several factors. The market value of the crop to be grown and other production costs must be considered. The effective storage capacity of the soil for the crop should be known as well as the amount and distribution of summer rainfall. Variations in crop need for irrigation also should be determined. For some crops, it may be more economical to have an occasional crop failure or lower production than to invest in equipment that will be used to advantage for only 1 or 2 years out of 10. Also, if the supply of water is limited, the grower must determine the crops on which the short supply can be used most advantageously.

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[3] Personal communication from Wayne L. Decker, Professor of Climatology, Soils Department, University of Missouri.

Crop Response to Irrigation

Irrigation of Corn

Irrigation experiments with corn were begun in 1948 at the Midwest Claypan Experiment Farm. At first, water was applied to fertilized and unfertilized plots as the crop showed signs of moisture deficiency. In 1954, the experimental plan was revised to take into consideration the interactions between water, plant population, and nitrogen application. All plots were brought to the mineral fertility requirement shown by soil tests (*17*). Two inches of water were applied to the irrigated plots whenever available moisture dropped below 50 percent of available storage capacity at the 1-foot depth. This was continued through late silking of the corn. Nitrogen was applied at two levels, 125 and 245 pounds per acre. Population levels were approximately 7,000 and 14,000 plants per acre.

This experiment was terminated at the end of 1957. The results for the 10-year period are shown in table 34. An average increase of 34 bushels per acre was obtained with an average application of 5.3 inches of water. Yield increases in the years when water was applied varied from 11 to 78 bushels per acre. The 1954 growing season was very dry and the response of corn to irrigation was spectacular. Corn irrigated three times with a total of 8.4 inches of water produced 75 bushels per acre compared with only 2 bushels without irrigation. Yield was only slightly increased by the higher population and was nearly identical for the two levels of nitrogen under irrigation.

TABLE 34.—*Effect of irrigation on yield of corn grown on Mexico silt loam, McCredie, Mo., 1948–57*

Year	Rainfall (June-Aug.)	Runoff (June-Aug.)[1]	Irrigation		Yield per acre		
			Applications	Amount	No irrigation	Irrigation	Yield increase
	Inches	*Inches*	*Number*	*Inches*	*Bushels*	*Bushels*	*Bushels*
1948	17.44	4.23	1	3.4	95	137	42
1949	14.52	.83	2	2.0	95	106	11
1950	10.40	.19	2	4.9	76	97	21
1951	13.09	.94	None	None	106	[2] 101	-5
1952	10.50	.02	3	3.7	75	101	26
1953	7.60	.12	1	1.8	51	79	28
1954	7.98	.25	3	8.4	2	75	73
1955	10.50	.17	2	10.5	77	155	78
1956	13.78	1.50	2	10.4	121	145	24
1957	9.55	2.12	3	8.0	62	103	41
Average	[3] 11.54	1.04	1.9	5.3	76	110	34

[1] From similar plots not irrigated.
[2] Yield on plots that normally would have been irrigated.
[3] Long-period (66-year) average, 11.72.

Where farm ponds are constructed and used as a source of irrigation water, costs can be estimated at about $4 per acre-inch applied. At this rate the extra corn from irrigation would have cost an average of $0.62 per bushel for the 10-year period. If handling, storage, and marketing costs are added and the expected average price for corn is less than $1 per bushel, the profit will be small.

Although more corn per acre can be produced with ample irrigation, the cost per bushel is somewhat lower with moderate use of water (table 35). In 1956, on plots where the soil moisture was not allowed to drop lower than 2 inches below the available moisture storage capacity of the upper 4 feet of soil, corn yields were higher, but the cost-per-bushel increase was also higher than where the water was applied at a drier (4-inch deficit) level or where the soil was kept moist only during the tasseling-to-dent stage of corn maturity. For irrigation at the 2-inch deficit, 10.4 inches of water produced an extra 24 bushels at an estimated cost of $1.74 per bushel. Only 4 inches of water were required for irrigation at the 4-inch deficit to produce an extra 19 bushels at an estimated cost of $0.84 per bushel.

TABLE 35.—*Effect of conservative use of irrigation on yield of corn grown on Mexico silt loam, McCredie, Mo., 1956*

Treatment	Water applied	Yield per acre	Yield increase over no irrigation		Cost per bushel[1]
	Inches	*Bushels*	*Bushels per acre*	*Bushels per inch*	*Dollars*
No irrigation	None	121			
Irrigation at 2-inch deficit[2]	10.4	145	24	2.30	1.74
Irrigation at 4-inch deficit[2]	4.0	140	19	4.75	.84
Irrigation, tasseling-to-dent stage (2-inch deficit).	4.5	142	21	4.67	.86

[1] Assuming $4 per acre-inch as cost of water applied.
[2] Below available moisture capacity of upper 4 feet of soil.

Irrigation of Soybeans

Irrigation water was applied to soybeans in 6 out of 8 years (1949–56). Although significant yield responses were obtained, the increases were not sufficient to be profitable (table 36). Studies at Arkansas (*3*) indicate that soybeans enter a dormant stage during dry weather. Unless the dry period is prolonged, normal growth may be resumed when the moisture supply is replenished. There is also some evidence that timing of irrigation is important. The single application (4.7 inches) late in August 1953, when the pods were filling, gave a yield increase of 14 bushels per acre. That year the estimated cost per bushel was low enough to be economical. However, the results obtained during this 8-year period indicate that irrigation water can be applied more profitably to other crops than to soybeans.

TABLE 36.—*Effect of irrigation on yield of soybeans grown on Mexico silt loam, McCredie, Mo., 1949–56*

Year	Variety [1]	Water applied	Yield per acre	Yield increase over no irrigation		Cost per bushel [2]
		Inches	*Bushels*	*Bushels per acre*	*Bushels per inch*	*Dollars*
1949	Wabash	1.78	25.0	0	0	0
1950	do	3.04	36.0	0	0	0
1951	Lincoln	None				
1952	do	None				
1953	do	4.7	30.6	14.0	2.98	1.34
1954	Lincoln	9.6	19.7	7.7	.80	5.00
		14.2	27.4	15.4	1.08	3.70
	Clark	9.6	18.7	6.9	.72	5.56
		14.2	23.8	12.0	.85	4.71
1955	Hawkeye	3.7	33.9	6.7	1.81	2.21
	Clark	3.7	37.2	5.6	1.51	2.65
1956	Lincoln	2.0	27.6	1.7	.85	4.71
	Clark	2.0	33.6	2.6	1.30	3.08

[1] Wabash and Clark full-season and Lincoln and Hawkeye early-season varieties.

[2] Assuming $4 per acre-inch as cost of water applied.

Irrigation of Pasture

An irrigation experiment on pastures was started in 1955 on twelve 2-acre pasture plots (series I). All the plots received initial lime, phosphate, and potash applications to levels indicated by soil tests (*17*). They were uniformly seeded to orchardgrass, timothy, and Ladino clover. Nitrogen was applied to six of the plots, and irrigations were made whenever the available soil moisture was reduced below 50 percent in the upper 1 foot of soil. The six remaining plots received no nitrogen. Three of these plots were irrigated in the same manner as the irrigated plots receiving nitrogen. Nitrogen was applied at 89 pounds per acre in 1955 and 126 pounds in 1957. Water was applied to depths of 12, 9.1, and 2.5 inches in 1955, 1956, and 1957, respectively.

The meadow was harvested by grazing, and yields were based on beef production. Three plots receiving identical treatment were grazed in rotation; the number of animals was adjusted to utilize the feed produced without overgrazing the plots.

Clover was reseeded on the plots in 1956 and nitrogen applications were suspended that season to enhance clover survival against competing grasses. In 1957, the check plots (no nitrogen and no irrigation) were fertilized and irrigated in the same manner as the plots receiving water and nitrogen, but the former were harvested by green-chopping the forage and bunk-feeding it to animals in a feed lot. Delay in obtaining necessary feeding equipment resulted in green-chop feeding only for 71 days of the growing season.

The results for the 3 years are summarized in table 37. For 2 years out of 3, beef production was increased by irrigation. Carrying capacity was increased in 1956 by irrigation, although beef production was not. Both beef production and carrying capacity were increased by green-chop feeding the forage.

For the water application and nitrogen levels used, the cost of extra beef produced was too high to be profitable, whether the forage was harvested by green-chop feeding or by grazing. Estimates of the cost of extra beef produced are shown in table 38 for the 2 years when increases were obtained, together with the 3-year averages. Although green-chop feeding appears promising, the cost of extra beef is marginal and would ordinarily not be profitable.

Irrigation of Wheat

Wheat was grown in a rotation of corn-soybeans-wheat-meadow on irrigation study plots during 1948–53. Water was applied when-

TABLE 37.—*Effect of irrigation and nitrogen fertilization on beef production and pasture carrying capacity (series I), 1955–57*

Treatment	Beef production per acre			Pasture carrying capacity		
	1955	1956	1957	1955	1956	1957
	Pounds	*Pounds*	*Pounds*	*Animal unit days*	*Animal unit days*	*Animal unit days*
No water, no nitrogen	288	374	114	204	180	123
No water plus nitrogen	320	372	129	219	226	169
Water, no nitrogen	404	372		260	247	
Water plus nitrogen	416	374	185	290	254	220
Water plus nitrogen [1]			264			325

[1] Forage harvested and fed as green-chop to animals in feed lot.

TABLE 38.—*Estimated cost per pound of extra beef produced by irrigation and nitrogen fertilization (series I)*

Treatment	Cost per pound of extra beef		
	1955	1957	Average (1955–57) [1]
	Dollars	*Dollars*	*Dollars*
Nitrogen	0.33	1.01	0.57
Irrigation	.41		.74
Irrigation plus nitrogen	.46	.35	.60
Irrigation plus nitrogen [2]		.25	.25

[1] In 1956, no increase for irrigation and no nitrogen applied because of reseeding plots to Ladino clover.

[2] Forage harvested by green-chop feeding instead of grazing.

ever soil moisture was considered deficient. In the fall of 1950, when no rain fell between October 7 and November 7, wheat yield was increased from 22.8 to 26 bushels per acre by a 1.95-inch irrigation on October 26 (*69*). Grasses seeded with wheat were well established on the irrigated plot in the fall of 1950, but reseeding was necessary on the unirrigated plot. The grass continued to be superior on the irrigated plot, and yields the following year were 1.63 tons per acre where water was applied compared with 0.9 ton where the wheat and grass seeding had not been irrigated.

In 1952, with only 0.62 inch of rain between September 1 and November 17, 1.5 inches of water were applied to one wheat plot on October 22. Observation on November 28 showed a good stand of wheat 2 to 3 inches tall on the irrigated plot compared with a thin stand one-fourth to 1 inch tall on the unirrigated plot. However, by April 30, 1953, there was practically no difference in growth and density of wheat on the two plots, and the stand of young grass was excellent on both plots.

Yield without irrigation was 51.6 bushels per acre compared with 53.9 bushels with the single irrigation. This difference was not significant at the 5-percent level. Prior to that year, 51.6 bushels had been the highest yield ever recorded on these plots, with or without irrigation. Another set of plots with full-fertility treatment yielded 59.4 bushels per acre in 1960.

Irrigation Water Supply

Two general sources of water for irrigation are ground water and streams. With intermittent streams, the water must be stored in ponds or reservoirs to be available when most needed. In the claypan prairie areas of Missouri, the farm storage pond is usually the only feasible source of water supply.

According to Smith (*50*), the principal factors to be evaluated in the design of farm reservoirs for an irrigation water supply are (1) the irrigation water requirement, (2) evaporation and seepage losses from the reservoirs, and (3) drainage area size and probable water yield during drought cycles. With these factors evaluated, the design engineer can determine the storage volume required and whether a 1- or 2-year water supply is more practical.

Irrigation Water Requirement

Measurements at McCredie, Mo., during the drought of 1954 indicated that for relatively small irrigated plot areas, evapotranspiration for corn over the 120-day production period averaged 0.185 inch per day (*50*). This is in agreement with the average value reported by Decker[10] for plots within an irrigated cornfield.

Irrigation water requirement during a growing period will depend on available soil moisture storage capacity and the extent to

which it is replenished between crop seasons. Mexico silt loam will have an available moisture storage capacity of more than 6 inches in the upper 4 feet of soil (*27*). About one-half of the time one may expect this soil storage to be recharged during the fall and winter between growing seasons. Probably no more than 4 inches of available storage should be used for this soil in estimating reservoir storage requirement (*50*).

The storage volume requirement will also depend on irrigation application efficiency. Evaporation and runoff losses have been estimated to be about 15 to 20 percent for sprinkler irrigation and furrow irrigation. Smith (*50*) concluded that an efficiency of 75 to 80 percent is a satisfactory estimate for design purposes in the Midwest.

Farm Pond Evaporation and Seepage Losses

Evaporation and seepage from the 16-acre and 1-acre reservoirs were measured beginning in 1951. Smith (*50*) used U.S. Weather Bureau evaporation pan data, together with the measured monthly reservoir losses, to estimate the seepage losses. Monthly losses from the reservoirs between April and October were plotted against the pan losses. A linear relationship was assumed from which the slope of each curve would give the relative rate of loss of the reservoir compared with the pan measurements. The intercept value for reservoir loss at the extrapolated pan loss of zero would represent the seepage loss. This relationship was expressed by the equation

$$E_r = S + bE_p$$

in which E_r = monthly reservoir loss in inches
E_p = monthly Weather Bureau pan loss in inches
S = average monthly seepage loss in inches
b = ratio of reservoir to pan loss

Estimation of S and b by the method of least squares for data collected during 1941–54 indicated the rate of losses of the 16-acre and 1-acre reservoirs to be 73 and 78 percent of the pan loss, respectively, with seepage losses of 0.96 and 2.25 inches per month.

Improved estimates of evaporation and seepage losses were obtained by using the available data for 1951–60. Results for this longer period are shown in figures 19 and 20. They indicate that the average monthly evaporation from the 16-acre reservoir was 77 percent of the pan loss and that the average monthly seepage loss was 0.85 inch. For the 1-acre pond, the evaporation from the reservoir was 94 percent of the average pan loss and the seepage rate was 1.71 inches per month. These estimates of seepage losses are lower and the relative evaporation ratios higher than those reported by Smith for the 4-year period. It is possible that seepage losses are slowly decreasing. Sealing of ponds usually improves with time. Why the average pond-pan evaporation ratios are higher for the longer period of record is not clear. Accuracy of the estimates was probably improved by the increased number of observations.

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[10] DECKER, W. L. EVAPOTRANSPIRATION MEASUREMENTS WITH CORN IN MISSOURI DURING 1961. Mo. Univ. Final Rpt. Contract Cwb–9992, 38 pp. 1962.

The average evaporation plus seepage losses from the 16-acre pond during the 5 months (November–April) of each year that Weather Bureau pans are not in operation was 1.95 inches per month for the 10-year period of record. Assuming the ratio of 0.77 from the equation for the 16-acre pond, the estimated average evaporated rate would be 1.43 inches per month for each month from November to March. This is 23.4 percent of the average monthly pan loss of 6.12 inches for each of the other 7 months of the year.

Watershed Yield

The size of watershed needed to insure supplies of water during drought cycles will depend on estimates of probable water yields. Runoff records are available for the Mexico silt loam at McCredie for 19 water years (July 1 to June 30) beginning in 1941. These are for the 154-acre mixed-cover watershed supplying the 16-acre reservoir.

The runoff amounts were plotted on logarithmic probability paper in the manner previously described (*50*). Plotted points were taken from a table presented by Beard (*4*). A linear relationship on the log probability paper was assumed, and the data were fitted to a trend line by the method of least squares. The plotted points were projected to linear graph paper, with the origin placed at an arbitrary minimum runoff-percent of time value less than any plotted point. The projected linear ordinates of the points were used to calculate the slope and intercept of the line, which was then projected onto the original graph.

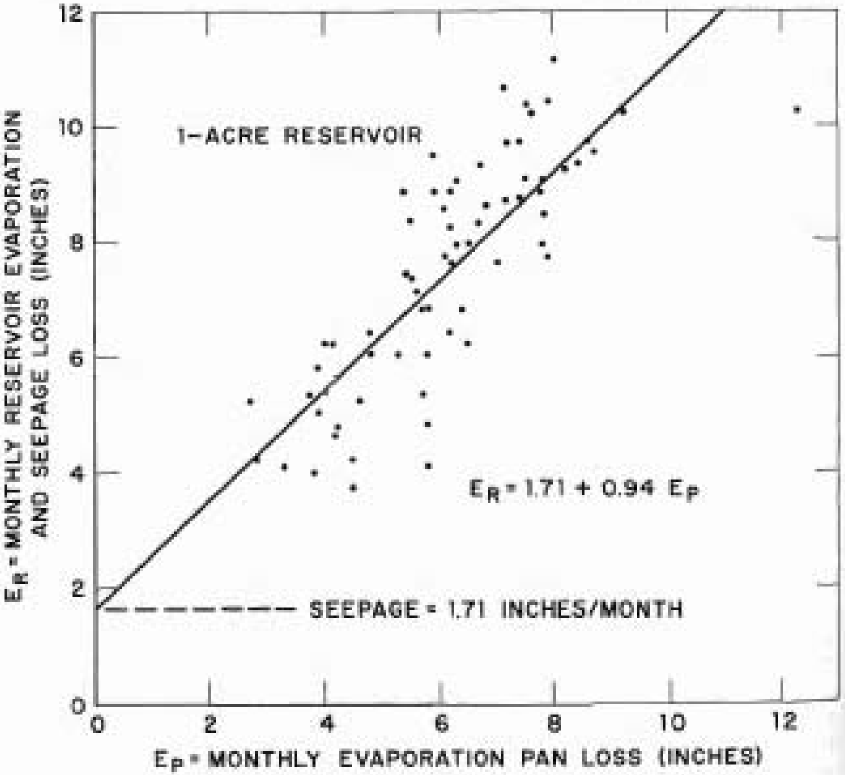

FIGURE 19.—Relationship between monthly evaporation pan loss and monthly reservoir evaporation and seepage loss from 1-acre reservoir at McCredie, Mo., 1941–60 (April-October values).

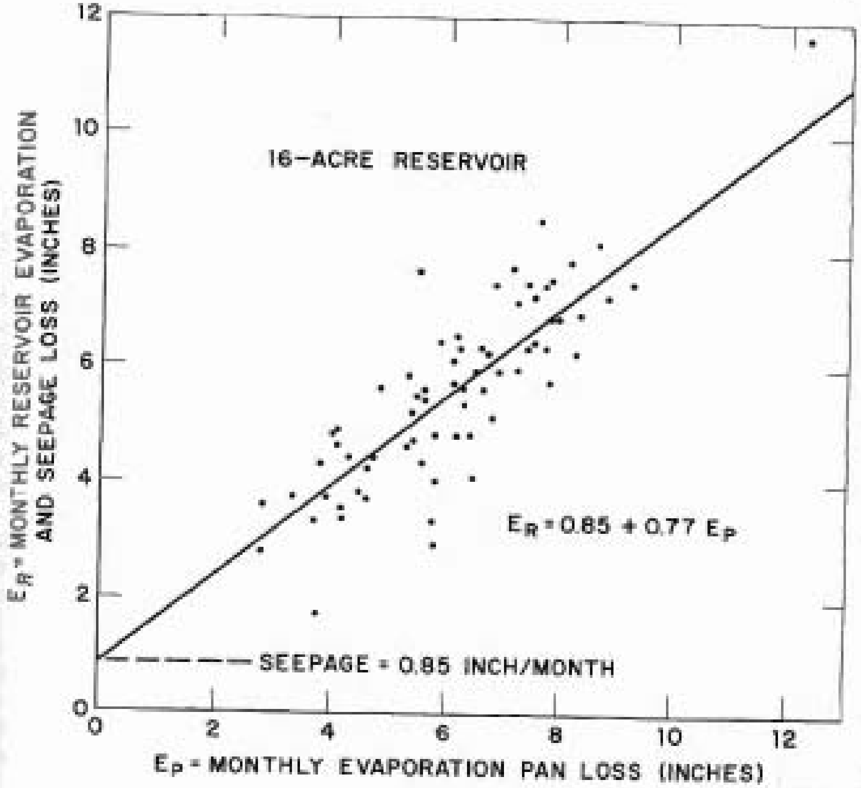

FIGURE 20.—Relationship between monthly evaporation pan loss and monthly reservoir evaporation and seepage loss from 16-acre reservoir at McCredie, Mo., 1941–60 (April-October values).

Plottings of runoff amounts for both single and 2 consecutive years show fairly satisfactory linear trends (fig. 21). The extremely low runoff of 0.21 inch for the water year ending June 30, 1954, increased the slope so that the line probably does not represent the true trend; however, the relationship has been improved over that obtained for the shorter period reported earlier (*50*). The trend line indicates that a runoff amount as low as that for the 1954 water year may be expected once in 996 years.

Size of Reservoir Required

Minimum 1- and 2-year amounts of runoff that may be expected during different time periods were read from the graph (fig. 21) and are shown in table 39. These values are lower than the earlier estimates made from the shorter period of record (1941–54). It is evident that the minimum runoff for 2 years is three to four times that for 1 year. Evaporation and seepage losses will be higher for a 2-year supply because of the larger average surface area during the first year. With a 1-year supply, the volume need be only large enough to hold the irrigation requirement during the irrigation season plus evaporation and seepage. But for a 2-year supply, the volume must be twice the single-year supply plus the increased loss during the first irrigation season because of the larger area plus the losses between seasons.

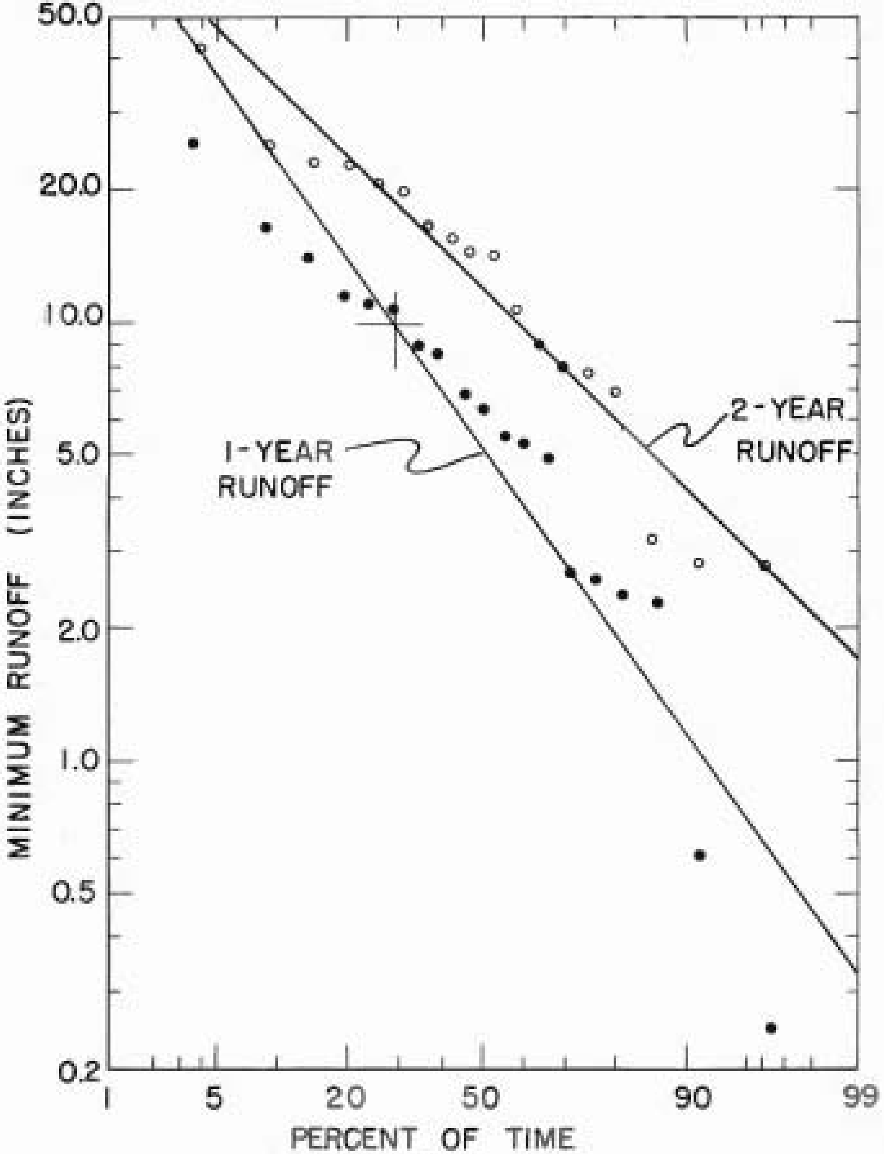

FIGURE 21.—Runoff for 1 and 2 consecutive years for 19 water years of record (1941–60).

If an irrigation requirement of 400 acre-inches is assumed for the period July through September, a total storage volume of 532 acre-inches of water will be required if it is to be stored in a reservoir with the storage-depth relationship of the 16-acre reservoir. Evaporation and seepage minus rainfall during the 3-month period were assumed to be 14.1 inches. This was the 3-month average net loss for the reservoir during 1953 and 1954. Without the direct measurement, it could have been estimated by the reservoir loss equation and Weather Bureau pan data.

For this reservoir, a water depth of 9.8 feet and a surface area of 10 acres would be required to hold the 532 acre-inches. But with only this amount of storage, the reservoir would be empty at the end of the irrigation season. For the supply to be replenished before the next season, runoff would have to equal the 532-acre-inch storage plus an additional 98 acre-inches for the net loss during the 9-month period (October to June). For 24 out of 25 years, this would require a claypan soil drainage area of 806 acres. But for 2 consecutive drought years like 1953–54, there would have been no water for irrigating during 1954.

The 16-acre reservoir would need to be filled to a storage volume of 1,190 acre-inches for a 2-year supply. The depth of water would be 14.3 feet and the surface area 15.45 acres. A claypan drainage area of about 433 acres would be required to supply 1,190 acre-inches of runoff during a 2-year period, with the minimum amount of runoff to be expected 96 percent of the time. A smaller drainage area is required for a 2-year supply reservoir than for a 1-year supply reservoir because 4.2 times as much runoff can be expected during 2 consecutive years than during a single year for a 25-year return period and a drainage area of claypan soil. This is shown in table 39.

A breakdown of the losses by periods for the 1- and 2-year supply reservoirs is shown in table 40. Depth-area and depth-volume curves for the 16-acre reservoir were used in making these determinations. The reservoir losses and monthly rainfall used in the analysis are shown in table 41.

The storage capacity of the 1-year supply reservoir was increased 33 percent to provide for evaporation and seepage losses, but an increase of 49 percent was required with the 2-year supply reservoir. The storage efficiencies of the reservoirs are 75 and 67 percent, respectively. Steeper reservoir side slopes would have decreased the net loss storage volume (table 40).

The annual irrigation requirement of 400 acre-inches assumed in the illustration is sufficient for 16 acres of corn and 16 acres

TABLE 39.—*Estimated minimum amounts of runoff to be expected during different time periods*[1] *from mixed-cover Mexico silt loam watershed*

Return period (years)	Runoff per time period	
	1 year	2 years
	Inches	*Inches*
10	1.15	4.10
25	.66	2.75
50	.47	2.15
100	.34	1.72

[1] Based on 19 water years of record (July 1 to June 30, 1941–60).

of pasture during severe drought such as occurred during 1953 and 1954 at McCredie. The 1-year storage volume is equivalent to 1.39 acre-feet per acre to be irrigated, and the 2-year storage volume is equivalent to 3.10 acre-feet per acre to be irrigated. For the 1 year supply, 25 acres of drainage area would be required per acre to be irrigated, but the 2-year supply reservoir would require only 14 acres. Both the storage volume and the drainage area per irrigated acre would be less with a reservoir with steeper side slopes (*50*).

GRASS WATERWAYS

Hydraulic studies on grass waterways were begun in 1942 at the Midwest Claypan Experiment Farm (*42*). The experiments were completed and reported by Smith in 1946 (*43*). The studies included the effect of varying channel slope and shape, flow velocity, and sod quality on scour and hydraulic retardance. The reservoir had a filled surface area of 16 acres and a capacity of 100 acre-feet below the spillway elevation, of which 60 acre-feet were available for tests. The headwork through which the water was supplied to the test area had a capacity of 60 c.f.s. This flow was equivalent to the calculated maximum 10-year frequency runoff from a 17-acre cultivated, terraced field (*76*).

Establishment of Grass in Test Channels

Pertinent data about the channels are given in table 42. The channels were excavated into the glacial subsoil to desired bed slopes, varying from 1 to 20 percent. A backfill of 6 inches of Mexico silt loam topsoil was then added after applying a soil treatment of well-rotted manure, lime, and superphosphate fertilizer. After the sod was in place, nitrate of soda was applied. The Kentucky bluegrass channels were sodded from Mexico silt loam in the late spring of 1941. Seeding of channels 7, 8, and 9 was completed on March 28. The sod was mowed as necessary.

TABLE 40.—*Annual irrigation requirement, evaporation and seepage losses, and total storage capacity, with corresponding reservoir depth and volume, for 1- and 2-year supply reservoirs with stage-volume relationship of 16-acre reservoir at McCredie, Mo.*

Supply reservoir period	Irrigation requirement		Evaporation and seepage net losses[1]				Total storage capacity	
			During irrigation season		Between seasons			
	Depth	Volume	Depth	Volume	Depth	Volume	Depth	Volume
	Feet	*Acre-inches*	*Feet*	*Acre-inches*	*Feet*	*Acre-inches*	*Feet*	*Acre-inches*
1 year	8.70	400	1.18	132			9.8	532
2 years:								
1st year	2.45	400	1.18	160			3.63	560
2d year	8.70	400	1.18	132	0.80	98	10.68	630
Total for 2-year period	11.15	800	2.36	292	.80	98	14.31	1,190

[1] Minus rainfall; based on 1953–54 records. Irrigation season assumed to be July 1 to Sept. 30.

TABLE 41.—*Monthly evaporation and seepage from 16-acre reservoir at McCredie, Mo., and monthly rainfall for drought years of 1953 and 1954*

Month	1953		1954	
	Evaporation and seepage	Rainfall	Evaporation and seepage	Rainfall
	Inches	*Inches*	*Inches*	*Inches*
January	1.19	1.42	0.92	0.71
February	2.09	1.01	1.64	.72
March	2.60	3.60	2.81	1.99
April	3.70	2.95	4.33	3.58
May	5.55	3.74	5.02	3.62
June	7.34	3.50	6.23	2.45
July	7.17	1.96	9.61	.20
August	7.06	2.14	5.94	5.33
September	6.91	2.38	6.09	1.93
October	3.46	2.72	3.72	4.72
November	3.02	.60	2.00	1.04
December	2.75	.71	1.13	1.52
Total	52.84	[1]26.73	49.44	[1]27.81

[1] Normal annual rainfall 39.01 inches.

TABLE 42.—*Data for grass channels established in spring of 1941*

Channel No.	Vegetation	Channel bed slope	Side slopes	Bottom width
		Percent		*Feet*
1	Bluegrass	12	2 on 1	2
2	do	16		
3	do	20		
4a	do	1	4 on 1	6
4b	do	4		
4c	do	8		
5a	do	1	6 on 1	0
5b	do	4		
5c	do	8		
6a	do	1	2 on 1	2
6b	do	4		
6c	do	8		
7a	Timothy, redtop	4	4 on 1	6
7b	Canada bluegrass			
7c	Kentucky bluegrass			
7d	Bromegrass			
8a	Timothy, redtop	4	4 on 1	6
8b	Canada bluegrass			
8c	Kentucky bluegrass			
8d	Bromegrass			
9a	Timothy, redtop	4	4 on 1	6
9b	Canada bluegrass			
9c	Kentucky bluegrass			
9d	Bromegrass			

Excellent stands of grasses were obtained from seeding. The drought of July and August reduced the stand, but not seriously. Best survival was for the timothy-redtop and bromegrass sections and poorest for Canada bluegrass, which appeared to be inferior to Kentucky bluegrass at this location.

The sodded channels were not completed until June. They were irrigated throughout July and August. Extremely wet weather during October damaged the sod in the bottom of channel 4, and this section was resodded in the spring of 1942.

Procedure

The first tests were conducted in May 1942. Another set was completed during the first half of October 1942. At that time, the new fall growth of sod was 4 to 6 inches high, and the annual grasses had been partially killed by a frost during the last week of September.

Vegetation readings were made before the tests by using the point quadrate apparatus with 10 needles set at an angle of 45° (fig. 22). The results of these readings are summarized in table 43. The bluegrass sod had an average density of 2.44 strikes per needle, which may be considered about average quality. A sod of excellent density would have a factor between 4 and 5 for a maximum height of 5 inches. The vegetation other than bluegrass was an annual grass locally known as foxtail. An exceptionally large amount of foxtail was present because of the abnormally high rainfall during June, which was detrimental to the bluegrass but favorable to the annual grass.

Flow was measured with a 4-foot Parshall flume without throat and diverging section. This flume was bolted to an entrance section extending through the berm of the supply channel. The entrance section included a sluice gate. The flow passed directly from the flume discharge into a connecting flume and to the test channel.

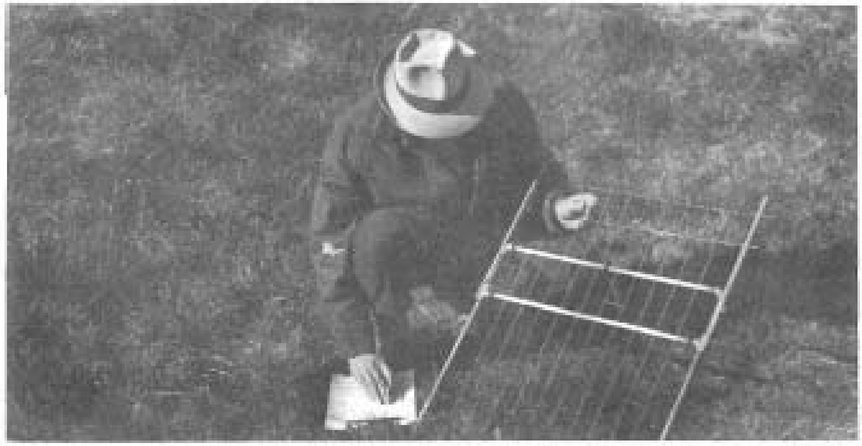

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FIGURE 22.—Inclined point quadrate used to determine grass density.

The connecting flume was set on a slope, and it was computed to give the normal flow velocity at the entrance to the test channel for the maximum rate of flow.

Ground surface elevation and water surface elevation for determining the area and velocity of flow were measured with point gages supported on wooden beams across the test channel at three locations spaced 10 feet apart. Piano wire stretched across the channel above the beams was the reference line for the readings. Elevation of the wire was determined by use of an engineer's level for calculation of the water surface slope. Ground surface readings before and after each test formed the basis for computing the scour occurring during each test. These readings, as well as the water surface readings, were taken every one-half foot across the channel. Figure 23 shows the beams and walkways, with observers taking water surface readings during a test.

The tests were performed in steps of increasing rate of flow, with a steady rate for each step. The duration of flow for each test was 50 minutes. Six tests were made on each channel at flows approximating 5, 10, 20, 30, 45, and 60 c.f.s. Three sets of water surface readings were taken at each of the three stations on a given channel after flow through the flume became uniform. The observers rotated positions so that each of the three men made water surface readings at each station during the test.

TABLE 43.—*Vegetation data for bluegrass sod channels, as determined by point quadrate apparatus*

Channel No.	Channel slope	Strikes per 240 needles at indicated feet above ground surface			Total strikes	Strikes per needle (density)	Bluegrass [1]
		0.4	0.4–0.2	0.2–0			
	Percent	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
6A	1	27	324	389	740	3.09	65
6B	4	12	230	344	586	2.44	78
6C	8	2	132	302	436	1.82	64
1	12	13	206	331	550	2.29	71
2	16	16	235	374	625	2.61	78
3	20	4	232	340	576	2.40	87

[1] Amount of total; other vegetation is annual grass.

Results

The tests showed that bluegrass sod could withstand very high velocities of flow without deterioration of the channel if a few conditions were met in construction of the channels. About 10 acre-feet of water passed through each channel in 1½ days. The average velocity of flow varied from 2 to 15 f.p.s. On the 20-percent slope channel, the steepest slope, the average velocity varied from 7 to 15 f.p.s. Figure 24 shows the grass of the upper section of the 20-percent slope channel before and after the six tests. The data from six slope channels in Kentucky bluegrass sod are summarized in table 44.

Excavation for the 20-percent slope channel was 6 feet into the subsoil at the lower end. An undrained seep caused a saturated soil condition in the lower 5 feet of the channel and killed the bluegrass sod. Although other grasses were growing on this area, they eroded during the first test, allowing the channel to cut back to a point midway of the second reach, where a mole had tunneled across the channel the night before the test. Thus, two points of weakness, which should be avoided for maximum hydraulic traffic on bluegrass sod, were present when the tests started.

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FIGURE 23.—Observers taking surface readings during flow of 60 c.f.s. over bluegrass sod on successive 50-foot sections of 1-, 4-, and 8-percent channel slopes.

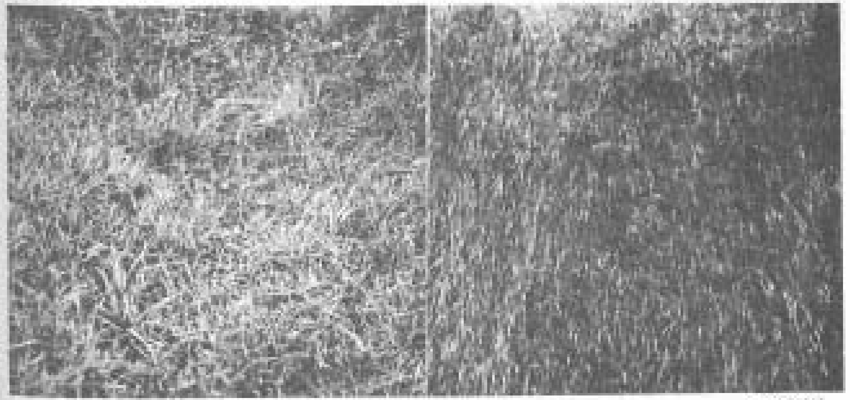

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FIGURE 24.—Bluegrass sod in channel with 20-percent slope before (left) and after (right) six tests in which flow velocity varied from 7 to 15 f.p.s.

The bluegrass sod of the 20-percent slope channel was of average density and about 6 inches long at the time of the test.

An appreciable change of alinement, either horizontal or vertical, that required the sod to resist the change of direction of the water velocity resulted in damage. The extent of damage increased with the degree of abrupt changes in alinement and the magnitude of velocity. However, increases in bed slope from 1 to 4 and from 4 to 8 percent did not cause any damage to sod by flows up to 9 f.p.s. with a duration of 50 minutes.

TABLE 44.—*Data for test flows on bluegrass sod channels,*[1] *Oct. 7–16, 1942*

Channel and test No.	Water temperature	Cross-section area of water	Hydraulic radius	Average velocity	Energy gradient	Manning's n
	°*F.*	*Square feet*	*Feet*	*F.p.s.*	*Feet per foot*	
6A:						
1	61	2.833	0.517	2.17	0.0147	0.0518
2	61	3.707	.624	2.86	.0141	.0450
3	61	5.517	.782	3.69	.0130	.0379
4	60	6.706	.872	4.05	.0124	.0358
5	60	8.886	1.007	4.79	.0111	.0309
6	60	10.964	1.126	5.44	.0092	.0263
6B:						
1	61	1.725	.392	3.58	.0385	.0437
2	61	2.254	.460	4.68	.0372	.0365
3	61	3.374	.596	6.00	.0357	.0331
4	60	4.113	.663	6.58	.0357	.0325
5	60	5.566	.806	7.64	.0318	.0301
6	60	6.955	.914	8.57	.0320	.0293
6C:						
1	61	1.202	.298	5.14	.0762	.0354
2	61	1.598	.361	6.60	.0739	.0311
3	61	2.409	.462	8.41	.0783	.0296
4	60	2.852	.503	9.48	.0750	.0272
5	60	3.952	.611	10.75	.0733	.0270
6	60	4.946	.682	12.04	.0666	.0247
1:						
1	62	1.012	.280	5.68	.119	.0387
2	62	1.468	.364	7.65	.117	.0338
3	61	2.033	.437	9.44	.112	.0305
4	61	2.513	.489	11.35	.111	.0271
5	63	3.489	.580	12.54	.110	.0273
6	63	4.277	.663	13.55	.104	.0269
2:						
1	60	.926	.274	6.19	.159	.0403
2	60	1.329	.324	8.16	.159	.0343
3	60	1.841	.401	10.39	.158	.0309
4	63	2.364	.461	11.86	.157	.0296
5	60	3.257	.540	13.24	.146	.0285
6	60	4.154	.622	14.27	.134	.0278
3:						
1	59	.841	.241	6.91	.213	.0382
2	59	1.197	.305	8.92	.204	.0341
3	59	1.725	.359	11.30	.180	.0282
4	59	2.353	.445	12.71	.181	.0290
5	60	3.263	.524	13.90	.163	.0280
6	59	3.944	.596	14.70	.182	.0305

[1] 2-foot bottom widths and 2 on 1 side slopes.

Scour

Very little scour occurred in any of the bluegrass sod channels during the six tests. The first evidence of scour was noted where there were discontinuities in the sod cover. The flowing water first removed the dead organic matter, leaving a fibrous mat of dead roots. As the velocity increased, these dead roots were removed, followed by a layer of surface soil. This left some live roots visible at the upstream side of the sod clumps. In general, the holes did not exceed 1 inch in depth, and no complete sod clumps were washed out.

The density of grass in six channels is given in table 43. The average velocity of flow in feet per second and rate of scour in surface inches per hour throughout the wetted perimeter for each of the six channels are listed in table 45. The scour values at first appear somewhat erratic. Some of the variation was undoubtedly due to experimental error. Reading of the ground surface was difficult, particularly after the soil was saturated with water. The rate of scour tended to increase more rapidly during the first or lower velocity tests than during the higher velocities. This may be attributed to the early loss of easily moved loose soil and vegetal particles near the soil surface.

TABLE 45.—*Flow velocity and scour of bluegrass sod channels,*[1] *based on 6 tests*

Channel No. and bed slope	Test No. [2]					
	1	2	3	4	5	6
6A, 1 percent:						
Velocity	2.2	2.9	3.7	4.1	4.8	5.4
Scour	.005	.021	0	0	.001	.002
6B, 4 percent:						
Velocity	3.6	4.7	6.0	6.6	7.6	8.6
Scour	.015	.018	.037	.045	.018	.026
6C, 8 percent:						
Velocity	5.1	6.6	8.4	9.5	10.8	12.0
Scour	.056	.011	.043	.066	.037	.074
1, 12 percent:						
Velocity	5.7	7.7	9.4	11.4	12.5	13.6
Scour	0	.044	.120	.024	.053	.042
2, 16 percent:						
Velocity	6.2	8.2	10.4	11.9	13.2	14.3
Scour	.021	.019	0	.003	.046	.029
3, 20 percent:						
Velocity	6.9	8.9	11.3	12.7	13.9	14.7
Scour	.010	.062	.094	0	.076	.072

[1] 2-foot bottom widths and 2 on 1 side slopes.

[2] Velocity in feet per second; scour in surface inches of soil removed per hour of flow.

The relationship between scour as the dependent variable and average velocity of flow and density of grass as two independent variables was tested by statistical methods. The coefficient of multiple correlation, assuming linear relationships, was first tried. The value of the coefficient was 0.56, which may be considered highly significant. Other determinations were made in an effort to obtain a more satisfactory estimating equation and a higher degree of correlation. Not all possibilities were tried, but of those tested the following empirical relationship appeared the most satisfactory:

$$Sc = 0.044 + 0.018V^{1/2} - 0.025G$$

in which Sc = rate of scour in surface inches per hour
V = average velocity of flow in feet per second
G = density of grass in average number of strikes per quadrate needle

The coefficient of multiple correlation determined for this estimating equation was 0.58, which may be considered highly significant.

Grass Age

Three grasses and a grass mixture at 1, 2, and 3 years of age in channels 7, 8, and 9 (table 42) were tested in May. The timothy and redtop mixture offered about the same retardance and protection from scour regardless of age. For 1-year-old sods they were superior to bluegrass. Only a limited amount of scour occurred at a velocity as high as 8 f.p.s. Kentucky bluegrass at 1 year old did not provide adequate protection for velocities of 3 f.p.s. and greater. After the second year, it reached its maximum retardance and protection from scour. It withstood up to 7 f.p.s. For 2-year-old sods, Kentucky bluegrass gave better protection against scour than did other grasses tested. A grass mixture of timothy, redtop, and bluegrass is suggested for these soils. Weed grasses invalidated the test data on the Canada bluegrass and bromegrass channels.

Limiting Velocities for Bluegrass

Selection of the maximum average velocity of flow in channel design involves consideration of numerous factors. Good-quality bluegrass sod withstood very high flow velocities without damage under nearly ideal channel conditions. The top growth had to be thick and long enough to provide an insulating mat during flow. For grass 2 to 4 inches tall, a denser stand was required to prevent scour than for grass 6 to 12 inches tall. The scour was not always in proportion to the velocity. It occurred as soon as water forced an opening in the mat, even though the velocity was relatively low. Loose soil and organic matter were removed first. After this, the scour was generally small until flow velocities became extremely high.

Channel irregularities, such as humps or depressions, were responsible for initiating scour. Crayfish or gopher holes had similar effects. A sudden decrease in channel bed slope increased scour at and just beyond the point of decrease.

Weather hazards, such as extremely high temperature and long periods of either drought or excessive rainfall, may appreciably reduce the density of bluegrass. This is especially true on claypan soils in the southern Corn Belt. Farther north and on soils of higher fertility than claypan, the weather factor is less important.

The tests do not indicate a definite limiting velocity below 15 f.p.s. for high-quality bluegrass. Uncertainty of maintenance, the possibility of poor channel alinement, damage from rodents, cattle, and farm implements, and the hazards of weather make necessary the recommendation of much lower velocities than the maximum attained in the tests. Also, damage caused by low-velocity runoff over a prolonged period may set the stage for severe damage from a high intensity storm coming before the sod reestablishes itself.

The accuracy with which rate of runoff for a given frequency may be determined is a factor in selecting the maximum design velocity. It would seem logical to use a different maximum velocity for a 10-year than for a 50-year frequency runoff.

Bluegrass with a density below two strikes per quadrate needle provided little protection against scour. Densities above two strikes per needle afforded good protection for relatively high velocities. The bluegrass densities that should give adequate protection against scour for velocities ranging from 1 to 8 f.p.s. are as follows:

Maximum design velocity (feet per second)	*Maximum grass density (strikes per quadrate needle)*
1	1.0
2	1.5
3	2.0
4	3.0
5	4.0
6	5.5
8	8.0

A maximum design velocity of 4 f.p.s. appears satisfactory for the Midwest claypan, 5 f.p.s. for Shelby, and 6 f.p.s. for Marshall soils that have 6 inches or more of topsoil and have a high fertility level. Very good bluegrass sod outlet channels that could withstand considerably higher velocities can generally be developed on such soils. However, experience has shown that the quality of sod may deteriorate during periods of extremely high temperature and drought or on flat slopes during prolonged periods of excessive rainfall.

The effect of temperature on the quality of sod was shown by variation in grass counts on each side of the test channels. Nine of the channels pointed southeast. The northeast banks with their southwest exposure to the hot afternoon sun had an average grass density of 3.7 strikes per needle compared with 5 on the opposite banks with the northeast exposure. This relationship was consistent on all nine of the channel sections. The most dense grass was on V-shaped channels. It averaged six strikes per needle. The side slopes were 6 horizontal to 1 vertical.

On trapezoidal channels, grass counts on the bottom averaged two strikes per needle compared with nearly four on the sides. The count on the bottom of the 4-percent channel slope was 33 percent greater than on the 1-percent channel slope. These differences on the trapezoidal channels appear to be the result of poor drainage during prolonged periods of excessive rainfall.

Where the weather hazards are less and the soil fertility and internal drainage more favorable for the growth of bluegrass than on the Midwest claypan, design velocities of 5 or 6 f.p.s. appear safe for a 25-year frequency runoff.

Hydraulic Factors

Calculation of Manning's n from the test data showed that n was not a constant. It was a maximum for low flow when the grass stood erect and a minimum when the grass was incorporated into the flow and the hydraulic radius increased. The value of n was affected by velocity, slope, hydraulic radius, grass density, and stage of growth. In figure 25, headed bluegrass is shown erect and in two stages of submergence.

Expotential equations were determined by the method of least squares for n and V using data from table 44. The resulting equations are as follows:

$$n = \frac{0.0106\,G^{0.43}}{R^{0.48}\,S^{0.15}}$$

$$V = \frac{149\,R^{1.15}\,S^{0.66}}{G^{0.46}}$$

in which n = retardance factor in the Manning formula
V = average velocity in feet per second
R = hydraulic radius in feet
S = energy gradient, also bed slope and water surface slope for uniform flow of constant depth in feet per foot
G = density of grass in average number of strikes per quadrate needle

The index of multiple curvilinear correlation for the n equation was 0.89 and for the V equation 0.99.

The tests for the data shown in table 44 were conducted in the late fall when bluegrass had attained a lush but pliable fall growth. Other tests of bluegrass channels, including channels 4, A, B, and C and 5, A, B, and C (table 42), were performed earlier in the year when bluegrass was headed. In the final analysis, all the bluegrass data were plotted in the n-VR relationship as developed

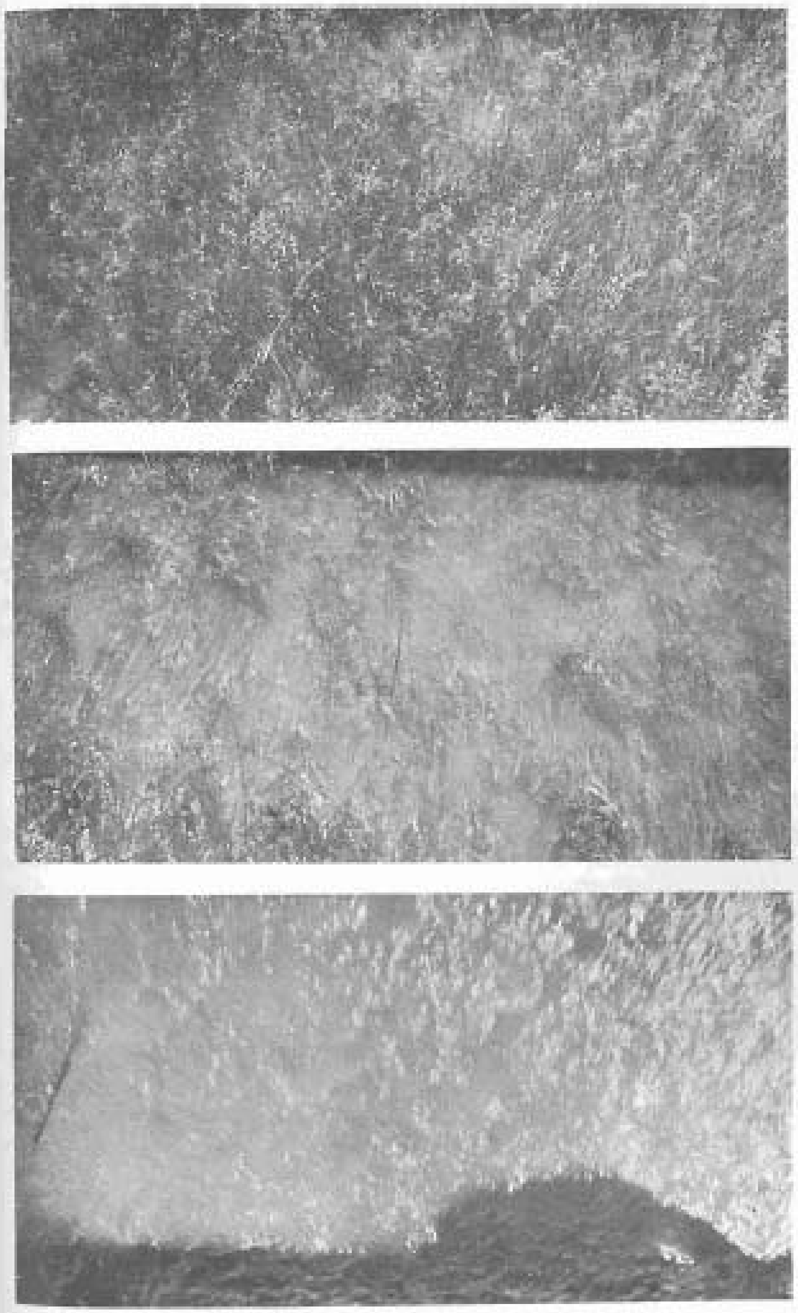

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FIGURE 25.—Bluegrass in channel with 4-percent bed slope at varying flow velocities: Top, V = 0.32 f.p.s. and VR = 0.74; center, V = 0.69 f.p.s. and VR = 0.23; bottom, V = 1.28 f.p.s. and VR = 0.45.

by Palmer (*37*) and Ree and Palmer (*38*). By this approach, channel slope and shape factors as variables are eliminated.

The data for tests at low velocity on headed bluegrass showed that bending of the grass began when the product of the velocity and hydraulic radius equaled 0.1, regardless of the magnitude of the slope factor. For the fall growth stage, the critical product was about 0.06.

Two distinct curves were indicated for the two growth stages of bluegrass. They are shown in figure 26. Bluegrass does not retard the flow of water as much in the fall as it does in the late spring when the stiff seed stems are present. There is little difference in retardance for the two growth stages at low flow depths. At intermediate flow depths, the seedstalks remain partially erect, but as *VR* values increase, the seed stems bend into the flow completely and retardance values for the two growth stages gradually come together.

Channel Design

The first step in channel design is to determine the discharge from the drainage area. This may be computed by one of several methods, or may be taken from previously prepared tables. With the discharge (Q) known and the desired maximum average velocity of flow (V) selected, the channel cross-section area (A) may be determined by the equation

$$Q = AV$$

For the trapezoidal channels with 4 on 1 side slopes, the area is

$$A = WD + 4D^2$$

in which W is the bottom width and D the center depth. W and D must be selected to satisfy the value of A in the equation $A = Q/V$, and must also satisfy the value of R read from the curves of figure 26. Then

$$R = \frac{A}{P} = \frac{WD + 4D^2}{W + 8.25D}$$

where P is the wetted perimeter of the channel.

This task is laborious because a direct solution is not possible. To simplify the procedure, the nomogram (fig. 27) for a trapezoidal channel was prepared using the n-VR curve of figure 26 for headed bluegrass. This equation in terms of VR may be written

$$V = \frac{1.268\ (VR)^{0.4}\ S^{0.3}}{n^{0.6}}$$

and

$$R = \frac{0.788\, n^{0.6}\ (VR)^{0.6}}{S^{0.3}}$$

where S is the channel bed slope (steady flow assumed).

The nomogram (fig. 28) for a parabolic channel was similarly prepared.

The nomogram in figure 28 is for a parabolic channel. It is used in the same way as the chart for the trapezoidal channel in figure 27. Such charts can be utilized in preparing tables of physical measurements for building channels (*46*), such as table 46. This table was prepared for the claypan prairie soils of Missouri, using 4 f.p.s. as the average maximum velocity of flow. The drainage area and discharge data used in the table were from a rate-of-runoff curve prepared by the U.S. Soil Conservation Service.

The first step in the use of the chart is to select the desired maximum average velocity of flow. (See fig. 27, broken lines superimposed on chart.) The velocity scale on the left applies to the vertical scale of the lower right-hand discharge curves as well as to the upper left-hand slope curves. From the selected velocity point, proceed diagonally and then horizontally from the vertical velocity scale to the appropriate discharge curve, and then move vertically to the channel width-depth curves. Likewise, from the same velocity point on the horizontal velocity scale, proceed vertically to the appropriate slope curve, and then move horizontally until this line and the vertical line from the discharge curve intersect. The closest curve to this intersection among the channel width curves originating at the left is determined. Proceed from there horizontally to an intersection with a width curve of the same value among the curves originating at the right. The channel depth is obtained by the intersection of a vertical line from this point with the channel depth scale. For example, if the selected velocity is 5 f.p.s., the slope is 4 percent, and the required discharge is 100 c.f.s. Then, the channel width would be 36 feet and the channel depth about 0.6 foot.

For the smaller acreages and particularly the flatter slopes, the expected quantity of flow was not sufficient to support a 4-f.p.s. average velocity. For these conditions, which are to the left of the heavy line in table 46, a maximum channel width of 6 feet was selected and the depth was determined for the maximum average velocity that the quantity of flow would support. In practice, use of a constant-width channel is often desirable. In most cases, the maximum width selected will be at the point of maximum slope. This width may then be continued up the slope where the drainage area generally decreases sufficiently to balance the decrease in capacity due to the decrease in slope.

Timothy, Redtop, and Other Grasses of Corn Belt

Mixtures of timothy and redtop, when tested in late May, yielded n-VR curves practically identical to those for headed bluegrass, as shown in figure 26. Thus, the design charts of figures 27 and 28 may be used for these grasses at this stage of growth. Retardance will probably be a little greater at the maximum growth stages of these grasses in late June and early July, when they are headed, than it is for headed bluegrass. Retardance for Alta fescue should be similar to that for the timothy-redtop mixture.

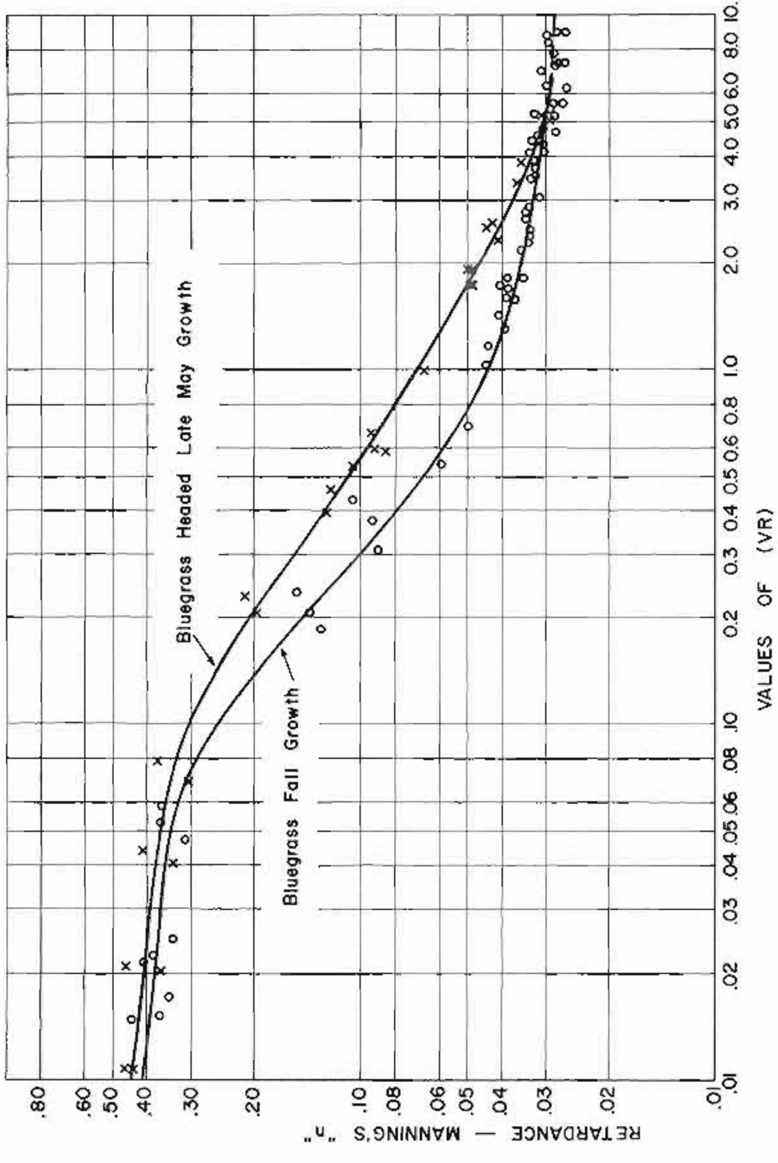

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FIGURE 26.—Relationship between *n* and *VR* for Kentucky bluegrass in trapezoidal channels with slopes from 1 to 20 percent, May 1943 and 1944 and October and November 1942, 1943, and 1944.

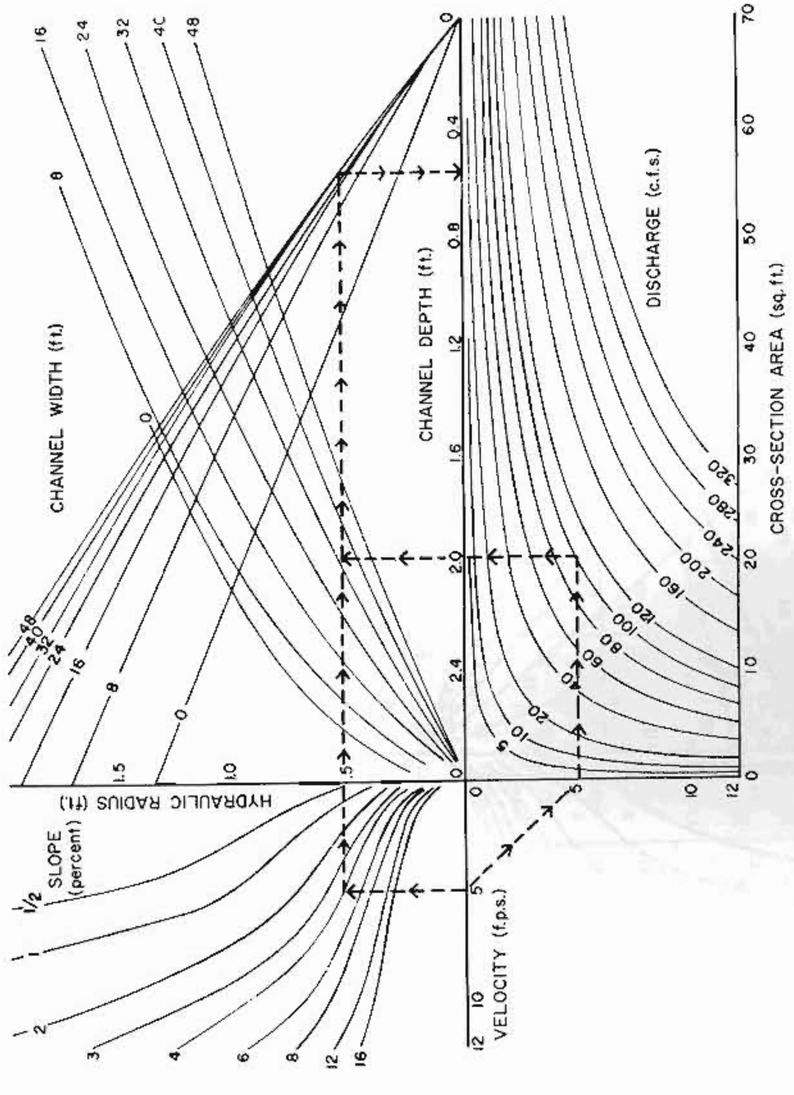

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FIGURE 27.—Design chart for headed Kentucky bluegrass trapezoidal channel with 4 on 1 side slopes, McCredie, Mo. (See p. 91 on how to use chart.)

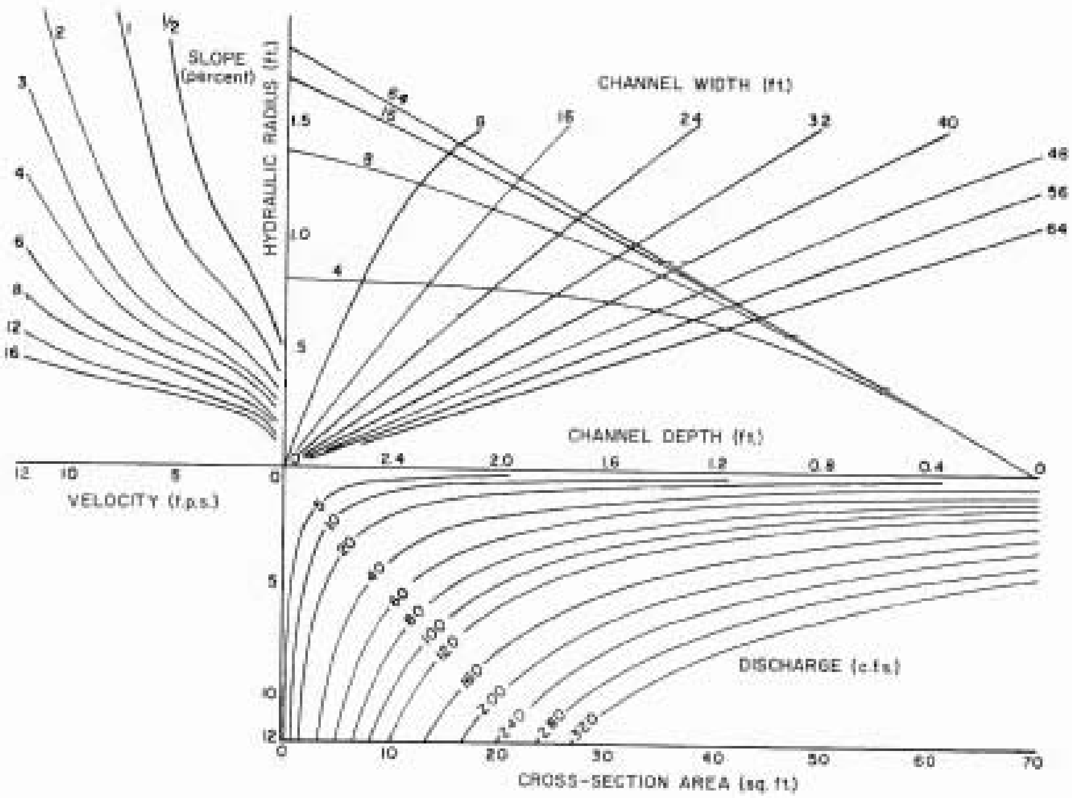

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FIGURE 28.—Design chart for headed Kentucky bluegrass parabolic channel with 4 on 1 side slopes, McCredie, Mo. (See p. 91 on how to use chart.)

TABLE 46.—*Physical measurements for building bluegrass channels on claypan prairie soils of Missouri*[1]

Channel bed slope (percent)	Drainage area (acres)	2	4	6	8	10	12	14	16	18	20	24	28	32	36	40	45	50
	Discharge (c.f.s.)	7.5	13.5	19	24	30	35	40	44	49	54	63	72	80	89	97	108	118
	Channel cross-section area (sq. ft.)[2]		3.4	4.8	6	7.5	8.8	10	11	12.3	13.5	15.8	18	20	22.3	24.3	27	29.5
	CHANNEL[2]																	
1	Width	6	6	6	6	6	6	6	6	6	6	6	10	12	16	18	21	23
	Depth	.77	.88	.96	1.03	1.10	1.14	1.18	1.23	1.27	1.30	1.37	1.24	1.18	1.13	1.10	1.08	1.06
	Velocity	1.1	1.6	2.0	2.3	2.7	2.9	3.1	3.3	3.5	3.7							
2	Width	6	6	6	6	6	6	8	9	12	14	17	21	24	26	30	34	38
	Depth	.65	.70	.79	.84	.89	.93	.90	.87	.83	.81	.78	.76	.75	.74	.74	.73	.72
	Velocity	1.4	2.2	2.7	3.1	3.6	3.9											
3	Width	6	6	6	6	7	10	12	14	17	19	23	27	31	35	38	44	
	Depth	.54	.63	.68	.73	.73	.69	.67	.65	.64	.63	.61	.61	.60	.60	.60	.59	
	Velocity	1.7	2.6	3.2	3.7													
4	Width	6	6	6	7	10	13	15	17	20	22	27	32	36	40	44		
	Depth	.50	.57	.62	.64	.61	.59	.57	.57	.55	.55	.54	.53	.53	.53	.53		
	Velocity	1.9	2.9	3.6														
5	Width	6	6	6	9	12	15	18	20	23	26	31	36	40	45			
	Depth	.47	.54	.50	.55	.52	.51	.50	.49	.49	.48	.48	.48	.48	.47			
	Velocity	2.1	3.1															
6	Width	6	6	7	10	14	17	20	23	25	28	35	39	44				
	Depth	.44	.51	.52	.49	.47	.47	.46	.45	.45	.45	.44	.44	.44				
	Velocity	2.3	3.3															
8	Width	6	6	9	13	17	20	23	26	30	33	39	45					
	Depth	.39	.45	.44	.42	.41	.40	.40	.40	.39	.39	.39	.39					
	Velocity	2.6	3.8															
10	Width	6	7	11	14	19	23	26	29	33	37	44						
	Depth	.37	.41	.39	.38	.37	.36	.36	.36	.36	.36	.35						
	Velocity	2.8																
12	Width	6	8	12	16	21	25	29	32	36	40							
	Depth	.35	.37	.36	.35	.34	.34	.33	.33	.33	.33							
	Velocity	3.0																
16	Width	6	9	14	19	24	28	32	36	42								
	Depth	.32	.32	.31	.30	.30	.30	.30	.30	.29								
	Velocity	3.3																

[1] Velocities to right of heavy line are 4 f.p.s. for indicated cross-section area. Channel cross-sectional areas do not apply to channel dimensions shown to left of heavy line.

[2] Channel width and depth in feet and velocity in feet per second.

SUBSOILING AND DEEP FERTILIZATION

Effect of Subsoil Shattering, Liming, and Fertilizing

Treatments

The effect on crop yields of subsoil shattering, both with and without lime and fertilizer mixed into the subsoil by the process, was tested with corn, oats, and winter barley on three replicates starting in the fall of 1942 (series III plots) (*56, 75*).

The shattering treatment consisted of double plowing when the subsoil was very dry (*48, 56, 75*). The first plowing was to a depth of 10 inches with a 16-inch wheel plow. The second plowing was to an additional depth of 8 inches (total of 18 inches) by a walking plow operating in the furrow left by the first plow. Subsoil treatment consisted of 2 tons of lime and 200 pounds of 8–20–10 fertilizer per acre scattered in the furrow after the first plowing. This was mixed with the loosened subsoil to some extent by slippage of the furrow wheel of the tractor while plowing the next furrow. All plots received a surface plow-layer treatment of lime at 3 tons per acre.

Additional treatments were applied in the fall of 1947. Four tons of lime and one ton of rock phosphate were mixed by the same method into the subsoil of the plots to which lime and fertilizer had previously been applied. In addition to this, lime was again applied to the surface soil of all plots at 3 tons per acre.

Effect of Treatments on Lime Requirement

Soil samples were taken in 1947 before applying the new treatments. Lime-requirement determinations indicated that only 75 percent of the original 2 tons of lime had been effective in neutralizing soil acidity during the 6-year period (table 47). The lime requirement of the upper 18 inches of these plots was still about 9 tons per acre. Thus, the 7 tons of lime applied per acre in the fall of 1947 fell short of meeting this total requirement for the surface 18 inches indicated by the test procedures.

TABLE 47.—*Average lime requirements of soils in series III plots in 1947*

Soil layer (inches)	Subsoil untreated	Subsoil treated
	Pounds per acre	*Pounds per acre*
0–6	4,600	4,200
6–12	7,500	5,500
12–18	8,800	8,200
Total	20,900	17,900

Effect on Grain-Crop Yields

Average corn yields for 1943–47 were increased significantly (*59*) by the deep shattering and fertilization of the subsoil (table 48). Although the increase for shattering alone was significant at the 6-percent probability level, this was not enough to recommend the practice for practical farm use.

The average oat-yield increases due to the treatments were not significant. Shattering alone significantly decreased the average yield of winter barley. The decrease may have been due to mixing some infertile subsoil with the plow layer. The effect was partly overcome by mixing lime and fertilizer in the shattered subsoil.

The average yields of corn, soybeans, and wheat for the 6-year period after re-treatment in 1947 were depressed by subsoil shattering without deep fertilization. The yields are shown in table 48. The decrease was significant for wheat. Mixing lime and rock phosphate into the subsoil significantly increased yields over those with subsoil shattering alone. However, the increase just overcame the detrimental effects of the shattering treatment alone. During this second period of study high soil treatments were applied to the plow depth of all plots. This appeared to offset any advantage of the deep treatments obtained during the first period of study when inadequate treatments were applied to the surface layer.

Residual Effects

The deep-treated plots of series III (fall, 1947) were seeded to alfalfa in 1955 after the second treatment period to test the residual effects of the treatment on hay yields. The surface soil of all plots received 0–20–20 fertilizer at 270 pounds per acre on April 1, 1955, before seeding of the alfalfa. The average yields per cutting, shown in table 49, are for two cuttings in 1955 and four cuttings each in 1956 and 1957. The subsoil treatments with lime and phosphate had shown little benefit on corn, soybeans, and wheat in the previous 6 years; however, small but significant increases in yield of deep-rooted legumes were obtained for from 7 to 10 years after the deep treatment. This is in agreement with the effect found on growth of sweetclover (*48, 56, 75*).

Treatment of Terraced Areas

Two field-terrace intervals in field 6 (T3 and T4) were deep treated by shattering subsoil and mixing lime at 4 tons per acre in the 9- to 16-inch depth in August 1949. Two terrace intervals (T2 and T5) served as untreated checks. A 2-year rotation of corn-small grain and sweetclover was grown through 1953, with each crop occurring on a check and a treated area each year. Corn was grown on all the terrace areas in 1954 and 1955. Of the small grains, wheat was grown in 1950 and 1953 and oats in 1951 and 1952; soybeans were planted in 1956 and 1957.

Average yields of corn, small grains, and soybeans were slightly higher with the deep treatment (table 50). For soybeans, the

TABLE 48.—*Effect of subsoil shattering and deep fertilization on average yields of various crops (series III) for 5 years (1943–47) after treatment and 6 years (1948–53) after re-treatment*[1]

Treatment and years	Corn Yield	Corn Probability level	Oats Yield	Oats Probability level	Winter barley Yield	Winter barley Probability level
	Bushels per acre	*Percent*	*Bushels per acre*	*Percent*	*Bushels per acre*	*Percent*
1943–47						
No treatment	26.9		29.6		23.1	
Increase for shattering	+3.4	6	+1.2	50	−4.1	*4*
Increase for shattering plus deep fertilization.	+5.8	*2*	+1.8	35	−1.1	45
Increase for deep fertilization over shattering.	+2.4	15	+.6	75	+3.0	9
	Corn		Soybeans		Wheat	
1948–53						
No treatment	100.7		30.4		30.5	
Increase for shattering	−7.0	8	−.4	65	−3.5	*2*
Increase for shattering plus deep fertilization.	+1.8	60	+1.7	8	+.7	60
Increase for deep fertilization over shattering.	+8.8	*3*	+2.1	*4*	+4.2	*1*

[1] Probability level: Values between 5 and 1 (italicized) significant (*59*).

TABLE 49.—*Residual effects of subsoil shattering and deep fertilization on alfalfa yields (series III) during 1955–57*

Treatment	Yields per cutting	Increase for treatment per cutting
	Tons per acre	*Tons per acre*
Untreated	1.16	
Shattering only	1.14	−0.02
Shattering plus deep fertilization.	1.25	[1]+ .09

[1] Significant at 5-percent probability level.

TABLE 50.—*Effect of subsoil treatment of terraced field 6 (T3 and T4) on crop yields*

Crop	Average yield[1]	Average increase for deep treatment	Probability level[2]
	Bushels per acre	*Bushels per acre*	*Percent*
Corn	69.1	+3.4	55
Small grains	30.0	+1.0	25
Soybeans	23.2	+2.4	*4*

[1] From untreated terrace intervals (T2 and T5).
[2] Values between 5 and 1 (italicized) significant.

increase was significant at the 4-percent probability level. Corn yields were actually a little higher in the check areas than on the treated terraces in 1953 and 1955. Only with soybeans did the subsoil lime seem to be effective as late as 1957. Assuming that a treatment cost $30 per acre and soybeans were $2 per bushel, it would take more than 6 years to pay for the treatment by growing soybeans. That the effect would persist to a measurable degree for such a long period is doubtful.

Average annual runoff from the deep-treated terrace intervals was 0.26 inch less than that from the untreated areas (table 51), but this difference was not statistically significant (probability level = 20 percent). The decreases were consistently large in favor of the deep treatment only when sweetclover was growing on the field. Clover production was somewhat more abundant and clover root penetration deeper on the treated areas. Evidently deeper rooting dried the soil to a greater depth, and more rainfall was retained by the treated than by the untreated areas. However, the differences between treatments were less than those between replicates (*24*).

Treatment of Pastures

A bluegrass pasture received a full-fertility surface treatment. It was fertilized annually with 0–20–10 at 200 pounds per acre; annual lime applications were needed (*18*), and 100 pounds per acre of 33–0–0 were applied each spring and fall. A 2-acre pasture

TABLE 51.—*Effect of subsoil treatment on runoff from terraced field 6*

Crop or cover	Period	Rainfall	Peak runoff		Total runoff	
			Check	Treated	Check	Treated
		Inches	*Inches per hour*	*Inches per hour*	*Inches*	*Inches*
	1951					
Corn	May 1–Oct. 11	23.17	0.99	0.85	2.98	2.59
Cornstalks	Oct. 12–Apr. 17	16.29	.43	.51	7.91	8.78
Oats, sweetclover	Apr. 18–July 21	11.15	.05	.05	.42	.24
Sweetclover	July 22–Apr. 30	29.55	.45	.37	7.43	5.88
	1952					
Corn	Apr. 30–Oct. 7	14.16	.27	.31	.21	.21
Cornstalks	Oct. 8–Apr. 8	12.18	.43	.41	4.33	3.35
Oats, sweetclover	Apr. 9–July 1	7.44	.13	.12	.95	.65
Sweetclover	July 2–Apr. 29	22.48	.33	.31	5.83	5.41
	1953					
Corn	Apr. 23–Oct. 6	17.23	.48	.26	.96	.74
Cornstalks, wheat	Oct. 7–Mar. 18	7.13	.03	.05	.48	.42
Wheat, sweetclover	Mar. 19–July 3	11.91	.05	.04	.52	.42
Sweetclover	July 4–Apr. 22	17.85	.18	.14	1.80	1.57
	1954					
Corn	Apr. 21–Sept. 30	14.93	.01	.01	.12	.10
Wheat	Oct. 1–June 28	19.77	.03	.01	.07	.03
Wheat stubble	June 29–Apr. 20	19.76	.03	.02	.17	.21
	[1]*1955*					
Cornstalks (1954 crop)	Jan. 1–Apr. 20	7.80	......	......	1.15	1.80
Corn (after corn)	Apr. 21–Oct. 2	18.76	......	......	.45	1.75
Cornstalks	Oct. 3–Dec. 31	5.24	......	......	.20	.55
Wheat stubble (1954 crop)	Jan. 1–May 4	9.17	......	......	4.46	3.30
Corn (after wheat)	May 2–Oct. 2	17.39	......	......	.51	.30
Cornstalks	Oct. 2–Dec. 31	5.24	......	......	.38	.37
Annual average	[2]1951–55	30.86	......	......	4.13	3.87

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[1] All terraces planted to corn in 1955.

[2] Annual average obtained by dividing sum of rainfall and runoff by 10. Data for each year represent 2 terrace years.

(series I, plot 9) was deep treated by subsoil shattering and mixing lime at 3 tons per acre in the 9- to 16-inch layer in September 1948. The area was left rough plowed until April 20, 1949, when it was seeded to bromegrass and Ladino clover. This seeding developed sufficiently for grazing to begin July 7. Average annual runoff for 1950–53 from the deep-treated pasture was 15 percent less than from the surface-treated pasture (table 52). However, the average peak rates were higher from the deep-treated pasture. Neither difference was significant.

Beef production and carrying capacity of the surface-treated bluegrass and the deep-treated bromegrass-Ladino clover pastures are shown in table 53. Although the deep-treated pasture was more productive in the third and fourth years (1951–52) after treatment and seeding, the average for the 5-year period was not sig-

TABLE 52.—*Comparison of runoff from surface-treated (series I, plot 7) and deep-treated pastures (series I, plot 9)*

Period	Rainfall	Peak runoff		Total runoff	
		Surface treated	Deep treated	Surface treated	Deep treated
	Inches	*Inches per hour*	*Inches per hour*	*Inches*	*Inches*
1948 (Sept. 16–Dec. 31)	9.52	0.08	0.02	0.96	0.20
1949:					
Jan. 1–July 6	24.94	.62	1.18	7.99	8.43
July 7–Dec. 31	21.81	.82	.62	2.30	2.37
1950	27.04	.11	.12	2.20	2.58
1951	41.54	.36	.37	3.18	2.72
1952	28.98	.29	.23	3.24	2.38
1953	27.47	.20	.47	1.07	.50
Annual average (1950–53).	31.26	0.35	0.43	2.42	2.05

TABLE 53.—*Comparison of beef production and pasture carrying capacity of surface-treated and deep-treated pastures*

Year	Beef production per acre		Pasture carrying capacity	
	Surface treated	Deep treated	Surface treated	Deep treated
	Pounds	*Pounds*	*Animal unit days*	*Animal unit days*
1949	320	110	157	127
1950	203	207	120	147
1951	238	493	143	259
1952	210	316	89	154
1953	331	301	185	109
Annual average.	260	285	138	159

nificantly greater than for the adequately surface-treated bluegrass pasture. Establishing the sward after treatment caused a production lag. Also, production declined in the fifth year because the Ladino clover stand in the deep-treated plot deteriorated during the summer drought of 1953. This is added evidence that lime and fertilizer will be more effective and economical if applied in the soil surface or plow layer. This is in agreement with other results for soils similar to Mexico silt loam (*12*).

Effect of Deep Placement of Lime and Phosphate on Yields

Deep-Placement Method

Different methods of mixing or placing lime and triple superphosphate in the subsoil were tested in the fall of 1954. The experimental design was a split-plot factorial, replicated four times for corn and alfalfa crops. The surface soil of all plots had lime, phosphate, and potash added according to soil tests (*17*). Four lime treatments and a no-treatment check were tested. The amount of lime needed to raise the 7- to 14-inch layer to 80-percent base saturation (8 tons per acre) was applied to the subsoil for each treatment.

The four treatments were (1) lime applied to the plowsole, (2) lime mixed with subsoil by double plowing 12 inches deep, (3) lime placed in 20-inch-deep subsoil clefts 21 inches apart, and (4) lime placed in subsoil clefts 30 inches deep and 42 inches apart. In treatment (2), lime at 2 tons per acre was disked into the surface. The soil was plowed 12 inches deep and an additional 6 tons of lime per acre were mixed into the exposed subsoil. The subsoil was turned into place with the surface soil on top again by a second 12-inch plowing. One-half of each plot received triple superphosphate 0–45–0 at 400 pounds per acre mixed into the soil in the same manner as the lime.

Corn yields were measured for 4 years before the experiment was terminated in the fall of 1958. Buffalo alfalfa was seeded on April 4, 1955. Two cuttings were harvested that year and three or four cuttings annually during 1956–58.

After termination of the experiment, a 3-foot trench was cut across at least one replicate of each treatment. The exposed subsoil was examined for rooting depth, distribution of residual lime in the subsoil clefts, and soil acidity in and outside the clefts.

Effect of Deep Treatment on Corn Yields

The effect on corn yields of different methods of mixing lime and triple superphosphate in the subsoil is shown in table 54. In general, subsoil liming gave small but significant average increases for the 4 years. Mixing lime into the subsoil by plowing 12 inches deep was less effective than deep placement. Mixing of some infertile subsoil with the surface layer during plowing may account for this difference.

TABLE 54.—*Effect of deep treatments on corn and alfalfa production, 1955–58*

Crop and subsoil treatments	Average annual yield	Average annual increase	Probability level[1]
	Bushels per acre	*Bushels per acre*	*Percent*
CORN			
Untreated subsoil	95.78		
Effect of lime alone:			
All lime treatments	99.04	3.26	<0.01
Plowsole	96.52	.74	.28
Plowed 12 inches deep	97.48	1.70	.02
Subsoil cleft, 7–20 inches, 21-inch spacing.	98.70	2.93	< .01
Subsoil cleft, 7–30 inches, 42-inch spacing.	103.45	7.67	< .01
Effect of phosphate alone, plowsole.	99.18	3.40	< .01
Effect of phosphate plus lime:			
Plowsole	96.95	1.17	.10
Increase over lime alone		.43	.68
Plowed 12 inches deep	98.10	2.32	< .01
Increase over lime alone		.62	.37
Subsoil cleft, 7–20 inches, 21-inch spacing.	96.68	.90	.19
Increase over lime alone		−2.02	< .01
Subsoil cleft, 7–30 inches, 42-inch spacing.	101.50	5.72	< .01
Increase over lime alone		−1.95	.01
	Tons per acre	*Tons per acre*	*Percent*
ALFALFA			
Untreated subsoil	1.100		
Effect of lime alone:			
All lime treatments	1.100	0	> .99
Plowsole	1.084	− .016	.64
Plowed 12 inches deep	1.111	.011	.75
Subsoil cleft, 7–20 inches, 21-inch spacing.	1.093	− .007	.84
Subsoil cleft, 7–30 inches, 42-inch spacing.	1.084	− .016	.64
Effect of phosphate alone, plowsole.	1.137	.037	.30
Effect of phosphate plus lime:			
Plowsole	1.159	.059	.09
Increase over lime alone		.075	.04
Plowed 12 inches deep	1.089	− .011	.75
Increase over lime alone		− .022	.52
Subsoil cleft, 7–20 inches, 21-inch spacing.	1.179	.079	.03
Increase over lime alone		.086	.02
Subsoil cleft, 7–30 inches, 42-inch spacing.	1.126	.026	.45
Increase over lime alone		.032	.35

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[1] Probability level: 0.01 or less, highly significant; 0.01–0.05, significant; greater than 0.05, not significant.

Small additional yield increases from phosphate applied with lime to the plowsole or mixed with lime in the subsoil were inconsistent and were not significant. When phosphate was added with lime in the subsoil clefts, the increases were significantly less than with lime alone in the clefts. It appears that when lime and phosphate are mixed in this soil by plowing, they supplement each other in their effect on corn. However, when they are placed together in a subsoil cleft with limited mixing, the effectiveness of either or both on corn yields is decreased.

Effect of Deep Treatment on Alfalfa Yields

The effect of various lime and phosphate subsoil treatments on alfalfa yields is shown in table 54. In general, lime was not very effective, regardless of how it was mixed or placed in the subsoil. Only where phosphate was placed with lime on the plowsole or in the 7- to 20-inch clefts were significant average yield increases obtained.

The differences in the responses of corn and alfalfa to the same treatments are of interest. Mixing phosphate with lime in the soil or in a subsoil cleft appears to give opposite responses for corn and alfalfa. Reasons for the differences must be due to chemical reactions between lime, phosphate, and the soil and to differences in corn and alfalfa roots. Examination of the soil in the trenches cut across the plots gave no evidence of alfalfa root concentration on plowsole or in clefts, whereas some corn root concentration occurred in the subsoil clefts where unreacted lime remained.

Examination of the subsoil in alfalfa plots may explain differences in response to these treatments and to the earlier plowsole tillage method of subsoil liming (tables 49 and 54).

Considerable unreacted lime was found in the bottom of each subsoil cleft. The lime had no effect on the soil pH at a distance of more than 2 inches and little effect at 1 inch from the unreacted lime deposit. Bulk density measurements in undisturbed and disturbed subsoil zones averaged 1.347 and 1.289 grams per cubic centimeter, respectively. The differences did not appear related to either depth or diameter of alfalfa roots.

When lime was mixed more thoroughly by the plowsole-treatment method or by deep plowing so as to react with the subsoil mass, alfalfa seemed to benefit more than it did from the placement of lime in zones where it failed to react. For phosphate to be more effective in many soils, it probably should be placed in closely spaced zones of concentration in the root zone. The formation of insoluble iron and aluminum phosphates or of phosphate-clay complexes of low plant availability will reduce the effectiveness of phosphate applications.

Applying lime to the plowsole and mixing it with the subsoil by plowsole tillage appears to be more effective than deep placement in subsoil clefts. Although the plowsole tillage method resulted in only small increases in corn and soybeans (table 48), there were small but significant residual effects for alfalfa 8 to 10 years after the last treatment (table 49).

Even though statistically significant corn-yield increases were obtained for the deep placement of lime and phosphate, the increases were too small to be of practical value. If fertility of the root zone of this soil and similar claypan soils is to be improved, it appears that less expensive and more practical methods than subsoil placement should be used. When good fertility and management practices are used on the surface plow layer, it is doubtful that expensive subsurface treatments will give economic yield increases for corn and alfalfa.

RECLAMATION OF SEVERELY ERODED LAND

Treatment

Reclamation of a severely eroded 5.45-acre field on the Midwest Claypan Experiment Farm was begun in 1945 (fig. 29). Mechani-

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FIGURE 29.—Reclaiming severely eroded field on Midwest Claypan Experiment Farm. Filling in gully in August 1945 (top); same area with crop of rye 3 years later (bottom).

cal treatment consisted of smoothing gullies and building a terrace system with a grass outlet. Approximately 3 tons of lime and 10 tons of manure were applied per acre. The field was divided into two fenced areas, with a 2-year rotation of rye-sweetclover, lespedeza, and redtop.

Area 1 was in rye and first-year sweetclover in 1946 and second-year sweetclover in 1947. Area 2 was in rye and first-year sweetclover in 1947 and in second-year sweetclover in 1948. This system was continued, and the cost and income from beef were recorded until 1950.

Results

Production on the areas during 1946–50 is shown in table 55. Cost of reclamation and cash returns per acre from beef produced during this period, with adjustments from published estimates (*5*), are as follows:

Receipts		[1]$264.26
Costs:		
Mechanical treatments[2]	$21.47	
Lime and manure	31.16	
Farming	59.88	
Other:[3]		
Death loss	13.10	
Veterinary and drugs	10.00	
Taxes and insurance	12.75	
Salt and minerals	5.00	
Depreciation on fences	3.90	
Interest on land	45.00	
Interest on animal investment	18.90	
Interest on cash outlay	8.35	
Miscellaneous	12.00	
Total		241.51
Return		22.75
Average net annual return		4.55

[1] Based on price of beef during test period.

[2] Smoothing gullies and constructing terraces and outlets.

[3] Computations based on published estimates for Missouri farms (*5*).

Net annual return per acre in the 5-year period averaged $4.55. For this production and these costs, the break-even price for beef would be about $0.20 per pound. At 1963 prices for beef, the profit from reclaiming severely eroded areas like this would be small, even for the average of 243 pounds of beef per acre per year obtained in the test (table 55). However, reclamation of such areas on a farm enhances the overall value of property and reduces the hazard of ruinous gully encroachment into valuable field areas.

Another severely gullied pasture area of 5.23 acres was treated in 1946. The gullies were filled in with a bulldozer, and a water diversion terrace was constructed above the area to remove runoff from the watershed area above. The field was seeded to rye, redtop, and sweetclover after treatment with 3 tons of lime and 400 pounds of 10–20–20 per acre. The grazing from the rye and sweetclover during the first 2 years paid most of the renovation and farming costs. Since soil tests indicated the need for additional treatment, the area was progressively rerenovated in strips below the diversion. The additional treatments consisted of 3 tons of lime and 500 pounds of 10–20–20 per acre. Seedings of the strips to alta fescue, alfalfa, and Ladino clover were highly successful.

TABLE 55.—*Annual beef production and pasture carrying capacity for reclamation areas 1 and 2 with 2-year rotation of rye and sweetclover, McCredie, Mo., 1946–50*

Crops of rotation system	Beef production	Pasture carrying capacity
	Pounds per acre	*Animal unit days*
1st year of rotation:		
Rye	155	47
1st-year sweetclover	107	57
2d year of rotation:		
2d-year sweetclover	195	105
Fall-growth rye	29	13
System average	243	111

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