TEXAS AGRICULTURAL EXPERIMENT STATION

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WATER AND SOIL CONSERVATION EXPERIMENTS AT SPUR, TEXAS

Division of Agronomy and the Soil Conservation Service,
United States Department of Agriculture Cooperating

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
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This bulletin reports 14 years of work at Substation No. 7, located near Spur, Dickens County, Texas, in a study of factors influencing run-off and erosion and the effects of conservation on plant growth. The results are directly applicable to about 14 million acres in which Miles and Abilene soils predominate, and are indirectly applicable to all regions where soil moisture at some time during the year may be inadequate for maximum plant growth or where there is danger of the soil becoming impoverished through erosion. The average annual rainfall at Spur for the 29-year period, 1911-1939, is 20.78 inches, 80 per cent of which comes during the growing season. Violent fluctuations have occurred ranging from 11.09 inches in 1924 to 38.08 inches in 1926.

Factors other than total rainfall and intensity of rainfall play an important part in determining the extent of water and soil losses. These losses decrease with an increase in the amount of vegetative cover or litter on the land, and they increase with increase in slope of land but the losses are not proportional to the increase in slope.

A comparison of terraces with 3-inch slope per 100 feet along the terrace with level terraces having ends open shows that the level terraces are much more efficient in conserving water and cause an appreciable increase in crop yields. Level terraces with ends closed so as to hold all the water that falls have given an average increase in crop returns for 12 years of $6.21 per acre per year over the old conventional practice of running the rows with the slope. By diverting the run-off water from a 1,200-acre watershed onto a 120-acre syrup pan terrace system the water for use by crops on the system has been increased approximately 16 per cent and crop yields have shown a marked increase.

A close relationship exists between the available water in the soil at planting time and the yield of lint cotton. Seasonal rainfall, although a highly significant factor in determining crop yields, apparently is of less importance than moisture stored in the soil prior to planting time.

Solid contour listing of native grass pastures has resulted in a deeper penetration of soil moisture and a greater amount of available moisture and has given a three-fold increase in forage production.

Seventy per cent of the rainfall during 1937, 1938 and 1939 was evaporated from fallowed plats of Abilene clay loam soil. Tillage and cropping practices that may increase the rate and amount of penetration of water are being studied with a view to increasing the amount of available water by decreasing evaporational opportunities.

In brief, the chief aim of water conservation studies at the Spur Station is to develop a flexible system of water management on agricultural and range land that will reduce risk due to adverse climatic conditions and tend to stabilize production through periods of low rainfall. The endeavor to store water when and where it falls and to supplement this with flood water from waste land and thus to build up a reserve supply is one that pays large dividends for the time and effort expended.

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WATER AND SOIL CONSERVATION EXPERIMENTS AT SPUR, TEXAS

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Texas Agricultural Experiment Station in Cooperation With the Soil Conservation Service, United States Department of Agriculture

"Much water goeth by the mill that the miller knoweth not of."—John Heywood, 1546.

In much of the writing and speaking of soil conservation stress is laid on the responsibility to future generations, and it is by no means amiss. The owners of the land are in a very real sense only trustees and any depletion of the intrinsic value of the property is passed to future generations, but not enough has been said of the immediate profit of conservation of fertility and moisture, and it is on this phase that emphasis is placed in this bulletin. It is realized that water and soil losses occur together and that practices that will make the most intelligent use of the rainfall will also provide maximum protection against erosion.

Lack of available water for the plant at the time the plant needs it is chief among limiting factors in crop production. This is especially true of the Southwest and more particularly true of that region of the Southwest with annual rainfall less than 30 inches. Fortunate is the farmer who does not experience at some time during the hot, dry summer months a shortage of moisture for his growing crops.

A number of years ago investigators found that the wheat harvest was influenced to a marked degree by the amount of water in the soil at planting time. It has since been found that this same principle applies to many other crops. Storing water in the soil from summer rains for the use of winter wheat is no more important than storing winter or spring rains in the soil for the use of summer crops.

This bulletin reports results of 14 years' work at Substation No. 7 in a study of factors influencing run-off and erosion, and the effects of conserving water and soil in the production of cultivated crops and pasture grasses. The results are directly applicable to about 14 million acres in which Miles and Abilene soils predominate, and indirectly applicable to all regions where soil moisture at some time during the year may be inadequate for maximum plant growth or where there is danger of the soil becoming impoverished through erosion. The report deals with the slowing down or complete prevention of the movement of water over the surface of the soil; the time, rate and capacity of infiltration; water holding capacity and wilting coefficient of soils; evaporational opportunities; root zone of annuals and perennials; and other factors that may contribute to a practical use of the rainfall in producing plants and controlling erosion.

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The average annual rainfall of 21 inches is so distributed that good to fair crops may be produced at low cost when reasonable water conservation practices are employed. There is practically no effective rainfall during January, February and March and little during the first part of April. From the middle of April to the middle of June good rains usually occur, but many of these are torrential in character. If conserved they are often adequate to carry the crop through the dry, hot midsummer, the middle of June to the middle of August, and allow the plant to enter the more favorable maturing period which prevails from the middle of August through October. There is little rainfall during November and December, and the climate is mild and favorable for harvesting.

HISTORICAL

The oldest agricultural literature makes reference to the use of run-off water in irrigation. The American Indians in the semi-arid regions were proficient in the use of storm waters. Water and soil conservation practices were recognized and taught in Colonial days. During the last two decades of the Nineteenth Century the United States Department of Agriculture conducted many experiments pertaining to the use of water and prevention of erosion on cultivated lands, grasslands and in forested areas. Following the close of the World War and in the early Twenties, with prices of agricultural products at an all-time high, more attention was given by farmers and ranchmen to conserving water and soil resources than ever before. State and Federal agencies were quick and eager to cooperate and there is now well under way a National program of water utilization and soil conservation that will add stability to agriculture and preserve the soils for future generations.

The Spur Station started water and soil conservation studies in 1926 by special request of farmers, ranchmen and agricultural workers of Texas who were in need of specific information relative to terrace construction. Results of the first 3 years of the study are reported in Texas Agricultural Experiment Station Bulletin No. 411, "Factors Influencing Run-off and Soil Erosion," by Conner, Dickson and Scoates.

This early work had for its purpose a study of some of the factors involved in water and soil conservation. While many practices have been developed that are already of proven value on local farms, in adjacent counties and to less extent in adjacent states, it should be borne in mind that water and soil conservation practices are much too complex to be solved on any one experimental farm or in any single agricultural region.

DESCRIPTION OF AREA

The Rolling Plains, of which the Spur Station is representative, are generally undulating, with some rather large bodies of land that are nearly flat to gently sloping. The Abilene soils and closely related dark soils occupy large areas of nearly flat lands. The clay loams prevail in the dark group of soils. The Miles soils are in general more rolling, and the sandy types are the more extensive of this series.

The Abilene soils consist of dark brown surface soils which in places are nearly black. The soils are 4 to 10 inches deep and rest on dark-brown or chocolate-brown clay, which at a depth of 18 to 24 inches merges below into lighter-colored friable calcareous clay. Normally a layer of soft calcium carbonate occurs at a depth of 4 to 5 feet. Occasionally this is a bed of soft, almost pure calcium carbonate, while in other places it is mixed with salmon-colored or yellowish, soft, friable clay. Although the clays and clay loams of this series have a fairly open structure, which permits rapid infiltration, they have a high water holding capacity which results in a large part of the water being held near the surface where it is vulnerable to the action of the wind and sun. These heavier soils are known locally as "droughty" soils as a result of the large amount of water lost from them through evaporation.

The Miles soils, where normal development has occurred, consist of reddish-brown or brownish-red soils 4 to 12 inches deep underlain by subsoils of friable clay of a red or reddish-brown color. At a depth ranging from 18 to 24 inches the subsoils merge below into lighter-colored chocolate-red friable clay, which at 2 to 3 feet below the surface is somewhat calcareous in many places. Where the surface is sloping the subsoil frequently lies very near the surface and calcium carbonate may be found in the upper soil layers and even in the surface soil. Many areas of Miles soils that are sloping and rolling have had the surface soil almost entirely removed by erosion, even where the land has never been in cultivation. The sandier types of this soil series are the most productive soils of the region although they are not as fertile as some of the heavier types. The apparent reason for higher productivity is that these soils permit water to penetrate rapidly to lower depths, thus reducing the amount lost through evaporation and insuring a larger amount of available water for crop production.

Associated with these soils are large bodies of Vernon soils. These are red soils of the Permian Red Beds formation. They are easily eroded, and large areas have been badly damaged by washing and gullying.

The average annual rainfall at the Spur Station is 20.78 inches and is discussed in detail at other places in this bulletin. High temperatures, high wind movement and low humidity have been noted in many specific cases to cause serious plant disturbances. Observers have frequently noted the influence of hot winds on the drying of the surface soil, obtaining stands of cultivated crops, parching of pasture grasses, pollination of many crops such as corn and tomatoes, and the effect of length of day and amount of sunlight on the character of growth and composition of plant material. Planting dates of many crops have been arranged to bring the plant into fruiting under more favorable moisture, temperature and humidity conditions. These factors are all closely related to an intelligent use of the rainfall, and more intimate knowledge of them and how they function should be valuable in a study of the problems.

The absolute maximum temperature at Spur since 1912 has been 114 degrees Fahrenheit and the absolute minimum 17 degrees below zero. From May through August the maximum daily temperature is frequently above 100 degrees with an average of approximately 95 degrees. The lowest average atmospheric humidity occurs in July. Crops maturing at this time of the year frequently "burn up." The highest atmospheric humidity occurs in late September and in October. It is generally the most favorable season of the year for the maturing of crops.

The highest wind movement of the year occurs in April and plays a big part in the evaporation of moisture from the surface of the soil. The least wind movement is during August and September. The prevailing direction of the wind from March through October is out of the South and from November through February out of the North. The average date of the last killing frost in the spring is on April 3, and for the first killing frost in the fall is on November 4, giving an average frost free period of 215 days.

Approximately 30 per cent of the Rolling Plains area is in cultivation, the chief crops being cotton, grain and forage sorghums, and wheat. The remainder of the area is in native grassland, most of which has not been touched by the plow. On account of recent economic changes and the use of larger machinery the trend has been toward larger farming units, while the ranching units have tended to become smaller. Two- and three-row implements drawn by mules and tractors are the rule in row crop farming.

THE SPUR STATION

The Spur Station was established in 1909 by an act of the Texas Legislature for the study of crops and cropping practices in a new agricultural region. In 1914 livestock feeding investigations were added and studies pertaining to the factors influencing run-off and erosion were begun in 1926. The feeding investigations have been conducted in cooperation with the Bureau of Animal Industry, U.S.D.A., since 1928, and the soil and water conservation studies have been conducted in cooperation with the Soil Conservation Service. Opportunities for coordinated studies are excellent.

The Station is located one mile west of Spur, Dickens County, latitude 33 degrees north, longitude 100 degrees west, at an elevation of 2,274 feet above sea level. Spur is on the Rolling Plains, being 14 miles east of the escarpment known as the Cap Rock which forms the line of division between the High Plains and the Rolling Plains. The station comprises 414 acres, 400 of which are used for soil and water conservation studies.

SCOPE OF WORK

The plan of the work includes the following phases of the problem of water and soil conservation: (1) the effect of intensity of rainfall, slope of land and physical condition of land on water and soil losses; (2) the effectiveness of terraces and other obstructions in preventing run-off; (3) the effect on crop production of preventing run-off and also of using run-off or waste water as flood irrigation; (4) the use of furrows and ridges on pasture land as a means of conserving water and increasing grass production; and (5) loss of soil water through evaporation.

ANALYSIS OF RAINFALL DATA

Annual and Seasonal Rainfall

The average annual rainfall at Spur for the 29-year period, 1911 to 1939, is 20.78 inches, while for the 15-year period, 1911 to 1925, it was 21.39 inches. For the 14 years, 1926 to 1939, the period covered by the studies reported herein, the rainfall was 20.12 inches, a decrease of 1.27 inches per year. The average cotton yield dropped from 199 pounds to 137 pounds per acre. In this 29-year period large fluctuations have occurred in the annual rainfall, ranging from 11.09 inches in 1924 to 38.08 inches in 1926. Table 1 shows the rainfall by months and years, and Fig. 1

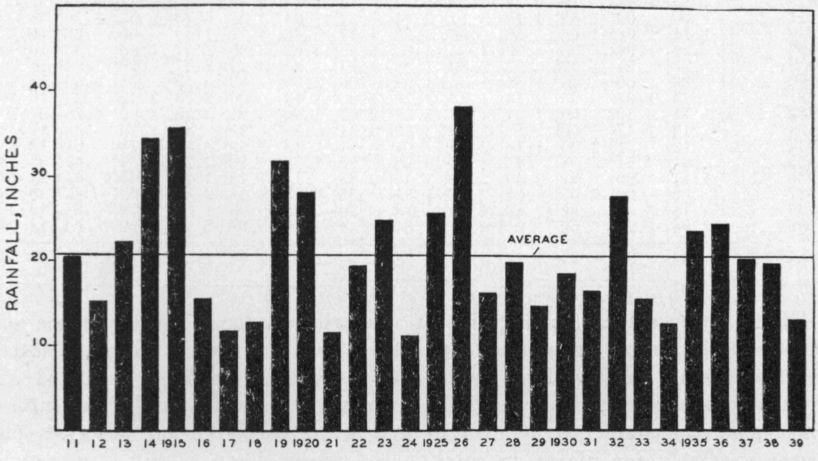

Fig. 1. The rainfall over a 29-year period. Studies in soil and water conservation were begun in 1926, the year with the heaviest rainfall on record. It was followed by 5 years of subnormal rainfall. Ten of the 14 years were below normal and the average of the 14 years is 1.27 inch below the average of the years prior to 1926.

presents a diagram of the annual rainfall and the fluctuations from year to year. The wet years were not always the best crop years, neither were the dry years always poor crop years.

The poorest crop years were usually the last of a series of dry years, or when the soil moisture had been depleted. Outstanding examples of this are 1918, the third of 3 consecutive dry years; 1930, the fourth of 5 dry years; and 1934, the second of 2 dry years. Of the 16 years having subnormal rainfall there were 6 years in which better-than-average crops were produced. Among these was 1924 with the lowest rainfall on record, 11.09 inches, in which year a good crop was produced on the station and an excellent crop in the county, as shown by Table 2. This crop, as well as the excellent crops produced in 1921, 1927, 1931 and 1933, all dry years, was benefited materially by soil moisture stored during the previous year.

Table 1. Inches monthly and annual rainfall, 1911-1939

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1911......	.16	4.61	.15	1.78	1.15	.56	4.97	1.69	1.34	1.03	.39	2.89	20.72
1912......	.00	1.15	1.02	1.05	1.99	3.14	.53	1.66	2.04	1.87	.00	.60	15.05
1913......	.04	.41	1.23	.77	.44	4.35	.70	.07	5.72	2.94	3.64	1.89	22.20
1914......	.09	.19	.33	1.99	10.58	1.28	4.70	5.89	1.41	5.23	.87	1.57	34.13
1915......	.40	2.10	3.20	7.64	2.31	4.08	.78	1.48	7.65	5.17	.00	1.05	35.86
1916......	.00	.00	.43	2.35	1.31	2.36	.56	4.01	1.12	2.63	.82	.00	15.59
1917......	.22	.51	.00	1.27	1.71	.14	2.17	1.58	4.12	.12	.07	.00	11.91
1918......	.00	.64	.30	.62	2.44	1.97	.44	1.42	.92	2.60	.20	1.37	12.92
1919......	.28	.21	3.56	3.78	4.37	2.03	2.60	2.44	4.26	7.48	.80	.00	31.81
1920......	1.31	.00	.16	.99	6.91	3.36	.75	8.34	2.20	2.49	1.11	.38	28.00
1921......	.30	1.08	.66	.00	.91	4.45	.00	.09	4.08	.00	.00	.05	11.62
1922......	.31	.00	.76	5.57	5.18	1.77	.25	1.60	1.00	1.06	1.80	.03	19.33
1923......	.05	.85	1.01	3.89	1.14	4.95	.26	1.40	1.57	6.58	2.36	.87	24.93
1924......	.00	.09	1.88	.81	1.98	.65	2.01	.87	2.00	.80	.00	.00	11.09
1925......	.34	.16	.19	4.77	2.75	1.74	3.43	7.37	3.66	.73	.22	.24	25.60
1926......	.67	.04	1.62	4.18	3.17	2.14	7.37	7.04	3.50	5.13	.52	2.70	38.08
1927......	1.10	.26	1.06	.40	.66	4.56	1.47	.78	4.22	1.19	.00	.42	16.12
1928......	.24	.96	.36	.20	4.33	1.60	5.15	3.97	.05	1.37	1.43	.33	19.99
1929......	.27	.21	1.49	.02	2.80	1.23	1.17	.33	3.74	3.07	.40	.03	14.76
1930......	.86	.00	.43	1.66	1.54	1.28	.05	2.05	.89	6.53	.75	2.56	18.60
1931......	.79	1.62	.33	2.18	1.22	1.29	1.80	1.14	.00	2.53	2.42	1.14	16.46
1932......	1.71	2.39	.00	1.91	1.43	3.38	2.67	5.55	4.24	.58	.09	3.75	27.70
1933......	.19	1.47	.00	.15	2.86	.00	2.51	3.32	3.17	.35	1.12	.45	15.59
1934......	.12	.21	2.20	1.16	2.50	.07	.11	1.18	2.52	.87	1.93	.01	12.88
1935......	.01	.61	.98	.71	4.54	6.93	.99	1.05	3.62	2.22	1.50	.62	23.78
1936......	1.11	.00	.22	2.49	2.79	1.43	2.85	.11	11.13	1.41	.48	.45	24.47
1937......	.38	.00	2.05	.86	2.92	1.31	.68	6.93	2.18	2.47	.09	.41	20.28
1938......	1.14	3.31	.82	.89	2.89	5.16	3.30	.21	.09	1.33	.78	.04	19.96
1939......	1.98	.25	.52	.29	2.07	1.80	.44	1.85	.00	2.62	.60	.64	13.06
Average...	.49	.80	.93	1.88	2.79	2.38	1.89	2.60	2.84	2.50	.84	.84	20.78

These observations have value in that they indicate the influence of preseasonal rainfall on available moisture and crop yields. Soil moisture determinations and available water studies started in 1931, reported at another place, although covering a much shorter period give basic information on the influence of rainfall and water conservation practices on water available for plants in relation to crop yields.

The Mid-Summer Depression

There is a period in mid-summer, centering in July, in which the rainfall drops sharply (Fig. 2). It is also the period of the year when evaporation is the greatest (Fig. 3) and in which cultivated summer crops and native grasses and shrubs are making the largest demands on the soil moisture reserve. An adequate reserve of moisture stored deep in the soil from preseasonal rains provides insurance against moisture shortage in mid-summer. This premise is now generally recognized as fundamentally correct and important in the 20 to 30-inch rain belt. It may have even

Table 2. Pre-seasonal, seasonal and annual rainfall, and cotton yields for Dickens county and station

Year	Annual rain-fall	Period				Station acre yield, lint	Rank	Dickens county production, bales	Rank	County acre yield, lint	Rank	Cotton acreage, Dickens county
		Sept. to Dec.	Jan. to April	May to Aug.	Sept. to Aug.							
1914	34.13	14.19	2.60	22.45	39.24	538	1	14,928	14			
1915	35.86	9.08	13.34	8.65	31.07	336	3	9,854	19			
1916	15.59	13.67	2.78	8.24	24.69	62*	20	7,337	22			
1917	11.91	4.57	2.00	5.60	12.17	167	10	5,596	24			
1918	12.92	4.31	1.56	6.27	12.14	97	16	3,178	26			
1919	31.81	5.09	7.83	11.44	24.36	422	2	15,362	13			
1920	28.00	12.54	2.46	19.36	34.36	0*	26	6,626	23			
1921	11.62	6.18	2.04	5.45	13.67	250	8	14,803	15			
1922	19.33	4.13	6.64	8.80	19.57	158	12	14,281	16			
1923	23.93	3.89	5.80	7.75	17.44	75	18	17,142	12			
1924	11.09	11.38	2.78	5.51	19.67	159	11	26,911	7			
1925	25.60	2.80	5.46	15.29	23.55	125	13	22,926	10			
1926	38.08	4.85	6.51	19.72	31.08	324	4	39,047	1			
1927	16.12	11.85	2.82	7.47	22.14	290	6	34,845	4			
1928	19.99	5.83	1.76	15.05	22.64	110	14	23,500	9	120	7	94,000
1929	14.76	3.18	1.99	5.53	10.70	21*	24	14,400	17	69	9	100,000
1930	18.60	7.24	2.95	4.92	15.11	74	19	11,600	18	60	11	93,200
1931	16,46	10.73	4.92	5.45	21.10	198	9	30,900	6	164	5	90,800
1932	27.70	6.09	6.01	13.03	25.13	61*	21	34,200	5	200	3	82,300
1933	15.59	8.66	1.81	8.69	19.16	320	5	38,800	3	260	4	103,600
1934	12.88	5.09	3.69	3.86	12.64	28	23	3,840	25	35	12	53,400
1935	23.78	5.33	2.31	13.51	21.15	99	15	19,200	11	142	6	64,800
1936	24.47	7.96	3.82	7.18	18.96	40	22	10,400	20	68	10	73,200
1937	20.28	13.47	3.29	11.84	28.60	258	7	39,100	2	235	1	79,900
1938	19.96	5.15	6.16	11.56	22.87	85	17	26,514	8	207	2	62,000
1939	13.06	2.24	3.04	6.16	11.44	10	25	11,000	21	103	8	53,300
Average	20.92	7.29	4.06	9.95	21.33	166	......	19,088	......	138	......	79,191

*Cotton crop totally or partly destroyed by hail.
Acre yield of cotton for Dickens County not available prior to 1928.
The rainfall from September through August possibly has a greater bearing on the cotton yield than rainfall during the rest of the calendar year. Note 1924, 1927, 1931, 1933, and 1937.

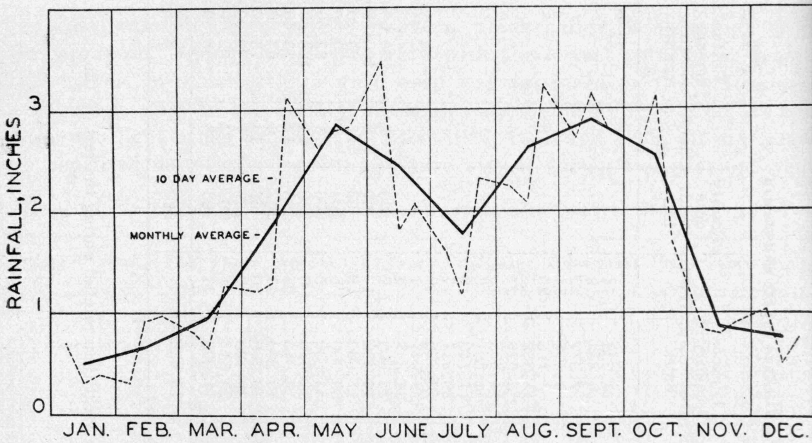

Fig. 2. Average rainfall by months and 10-day periods, 1911 to 1939. This shows the rain peaks in the spring and fall and also the mid-summer depression extending over a period of approximately 70 days.

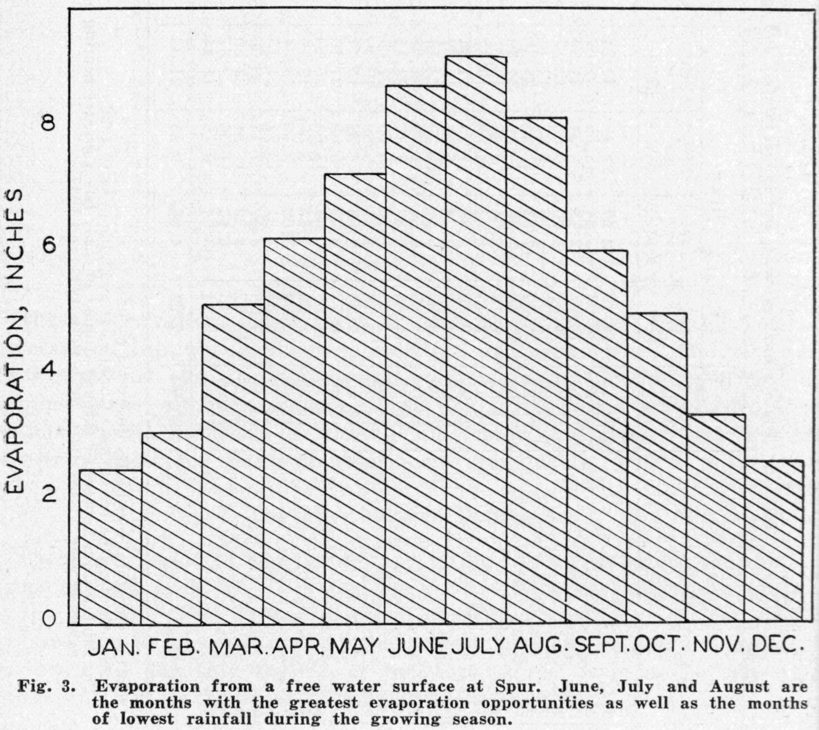

Fig. 3. Evaporation from a free water surface at Spur. June, July and August are the months with the greatest evaporation opportunities as well as the months of lowest rainfall during the growing season.

wider fields of application in more humid sections where the opportunities for water conservation are greater and where larger yields and intensive farming and ranching are of more importance due to land values and costs of operations. Certainly any section that has crops which suffer during mid-summer for water has a problem that may be at least partly solved by creating a more adequate reserve from preseasonal rains. The use of soil, to its full capacity, as a storage place for water offers excellent opportunities over wide areas in relieving the water shortage during mid-summer for plant growth.

The average monthly rainfall at Spur from 1912 to 1939 has been further analyzed by dividing the monthly rainfall into 10-day periods for the purpose of determining more definitely the length of the period of low summer rainfall and the rain peaks during the spring and fall months. The results are shown in Table 3, and in Fig. 2.

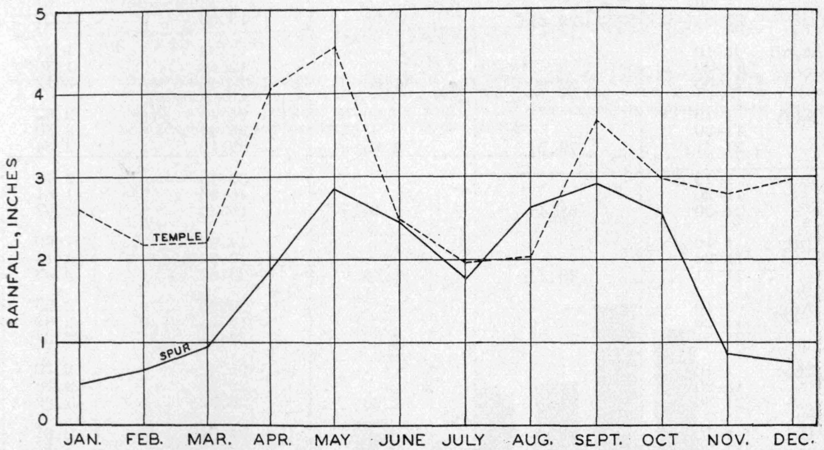

Fig. 4. Rainfall for 28-year period at Spur and Temple. Much of the Southwest is affected by the mid-summer rainfall depression.

A comparison of the average rainfall for the 10-day periods together with that of the average monthly rainfall shows that the period of low summer rainfall begins the middle of June and extends well into August, covering a period of 60 to 70 days. This is a more extended summer depression than appears to be the case when average monthly rainfall is considered.

It is important to adjust the planting date to the supply of moisture stored in the soil. Planting crops early often results in bringing the crop into the mid-summer depression in an advanced stage of maturity. Later planting, however, will bring the crop into fruiting under more favorable moisture, humidity and temperature conditions which usually prevail during the latter part of August or September. On the other hand, if there is a large supply of soil moisture at an early planting date, quick maturing crops may have sufficient time to develop before the mid-summer depression begins. Perhaps the same general principles may be applied in the more humid regions, but insect depredations and other factors may upset the practical application of such principles.

Table 3. Rainfall by 10-day periods, 1912-1939

Period		Monthly for 28 years		For 28 years	
		Total	Average	10-day total	10-day Average*
Jan.	1–10			6.80	.73
	11–20			2.99	.32
	21–31	13.91	.50	4.12	.40
Feb.	1–10			2.90	.31
	11–20			8.59	.92
	21–28	18.72	.67	7.23	.97
Mar.	1–10			7.58	.81
	11–20			6.23	.67
	21–31	26.81	.96	13.00	1.27
April	1–10			11.32	1.21
	11–20			12.18	1.30
	21–30	52.60	1.88	29.10	3.12
May	1–10			24.49	2.62
	11–20			26.09	2.80
	21–31	79.74	2.85	29.16	2.84
June	1–10			32.19	3.45
	11–20			16.93	1.81
	21–30	68.45	2.44	19.33	2.07
July	1–10			14.93	1.60
	11–20			10.99	1.18
	21–31	49.74	1.78	23.82	2.32
Aug.	1–10			20.99	2.25
	11–20			19.53	2.09
	21–31	73.73	2.63	33.21	3.24
Sept.	1–10			25.42	2.72
	11–20			29.36	3.15
	21–30	81.10	2.90	26.32	2.82
Oct.	1–10			24.34	2.61
	11–20			29.22	3.13
	21–31	71.37	2.55	17.81	1.74
Nov.	1–10			7.86	.84
	11–20			7.67	.82
	21–30	24.00	.86	8.47	.91
Dec.	1–10			9.60	1.03
	11–20			4.86	.52
	21–31	21.60	.77	7.14	.70

*Calculated to 30-day period.

Rain Periods of Over Two Inches

Practically all soil erosion takes place during rain periods of over two inches. Likewise, the opportunities for storing water deep in the soil for subsequent plant use occur with these same rains. All rain periods of over 2 inches since 1912 are listed in Table 4, and are shown graphically in Figs. 5 and 6.

The total rainfall for this 28-year period has been 581 inches, and 205

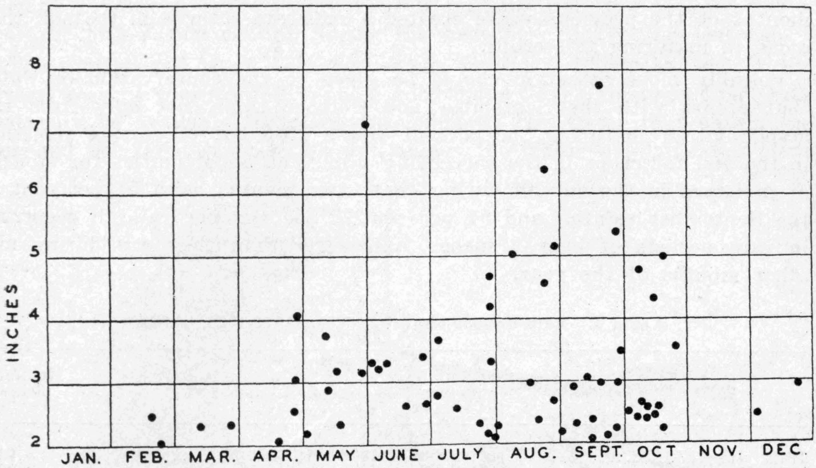

Fig. 5. Sixty-four rain periods of over 2 inches from 1912 to 1939 showing the amount of rainfall during the rain period and the time of the year it occurred. Practically all soil erosion problems and water conservation opportunities during the 28-year period occurred with these storms.

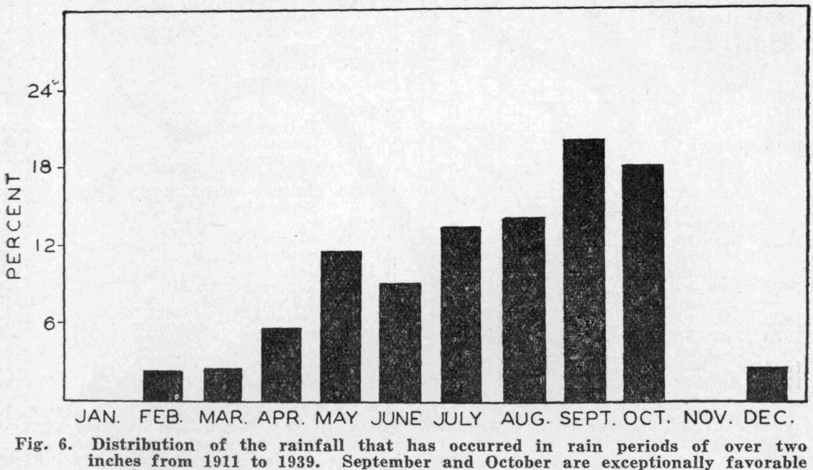

Fig. 6. Distribution of the rainfall that has occurred in rain periods of over two inches from 1911 to 1939. September and October are exceptionally favorable months for storing water for small grain, and also for building a reserve for the following year's crops.

inches, or 35 per cent, has occurred in rains of over 2 inches. In years when these heavier rain periods do not occur, or in years when they occur as torrential rains and are lost as run-off, short crops or crop failures usually result. There have been 5 years out of the 28 in which 2-inch rain periods did not occur. In two of these years, 1918 and 1934, the crops were practically complete failures. During 1924 and 1931 there were no rain periods of over 2 inches, but heavy rains during the fall months of the previous years created a moisture reserve in the soil that aided in maturing fair crops.

Possibly more attention should be given to the conservation of water that occurs with the September and October rains, not only from the standpoint of maturing the current year's crop but of storing moisture in the soil for crops in the succeeding year. The opportunities for storage of moisture in the subsoil during these two months, with 51 per cent of the September rainfall and 54 per cent of the October rainfall occurring in rain periods of over 2 inches, are better than they are during any other months of the year.

Table 4. Rain Periods of over 2 inches, 1912-1939, inclusive

		Rainfall, inches			Rainfall, inches
1912	June 17-18	2.60	1926	April 20-27	3.04
1913	June 30	2.63		July 7-10	2.55
	September 2	2.18		July 25-30	4.68
	September 25	3.48		August 16-18	2.38
	October 1-3	2.47		August 28-31	2.68
1914	May 29-31	7.11		September 26-30	2.99
	July 3	3.65		October 15-16	2.22
	August 24-30	5.13	1927	September 25-28	2.24
	October 21-25	3.54	1928	May 13-21	3.70
1915	March 9-11	2.33		July 21-31	4.16
	April 15-18	2.07	1929	September 5-10	3.03
	June 5-7	3.19		October 12-13	2.51
	September 21-25	5.39	1930	October 3-6	2.42
	October 12-17	4.97		October 13-14	2.43
1916	October 13-15	2.57		December 4	2.45
1917		0	1931		0
1918		0	1932	February 20-22	2.05
1919	March 22-24	2.35		August 15	3.00
	April 25-28	2.54		September 6-7	2.32
	May 7-11	2.88		December 22-23	2.99
	July 20	2.30	1933	July 31-Aug. 1	2.25
	September 14-20	2.98		September 13-14	2.37
	October 5-9	4.78	1934		0
1920	May 15	2.30	1935	May 13-18	3.20
	May 23	3.17		September 1-9	2.84
	August 16-23	4.62	1936	July 5-7	2.70
1921	June 2-7	3.35		September 15-22	7.72
	September 21	2.10	1937	August 18-23	6.40
1922	May 1-3	2.14		October 8-13	2.34
1923	June 8-9	3.30	1938	February 14-17	2.50
	October 13-15	4.30		June 24-26	3.38
1924		0		July 21-25	2.16
1925	April 24-27	4.04	1939	October 8-9	2.62
	July 28-31	3.35			
	August 7-9	5.01		Total	205.18
	September 14	2.04		Total, 28 years	581.77
Per cent of rainfall occurring as 2 or more inches					35.27
Total number rain periods of over 2 inches in 28 years					64

Rainfall, Run-off and Soil Water

Through the years, in Texas, the tendency has been to measure agricultural opportunities in terms of rainfall and to concede without much study that little or nothing could be done to increase the effectiveness of the rainfall. In more recent years greater importance has been placed on subsoil moisture in enabling the plant to continue development when climatic conditions cause a high rate of transpiration and to overcome a shortage of seasonal rainfall during the growing and fruiting periods.

The rainfall and river discharge shown in Fig. 7 illustrates one of the several reasons why rainfall is not a good index to the amount of moisture that may be available for plant development. The water that enters the soil, and not the total rainfall, determines the water available for plant

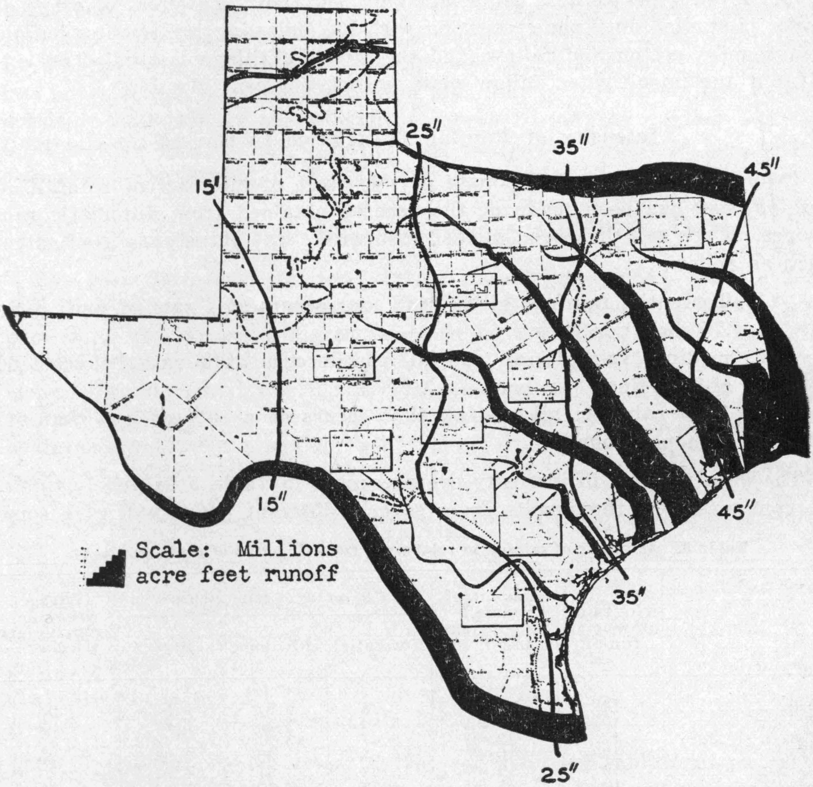

Fig. 7. Rainfall and run-off map of Texas. Water that enters the soil and not total rainfall determines the water available for plant use. The above rainfall and river discharge map shows one of the reasons why the available soil moisture is not in the same proportion as the rainfall.

use. When the river discharge is subtracted from the rainfall there is not such a wide difference in the amount of water that enters the soil in the agricultural regions of Texas. When such factors as run-off, seasonal distribution of rainfall and evaporation are considered it is easy to visualize a much narrower margin of available moisture than is indicated by rainfall records.

CONTROL PLATS

The purpose of the control plats is to give an accurate measure of the amount of water and soil lost from land having different grades and treatments. The plats are located on Miles clay loam and consist of 8 plats 6 feet wide and 96.8 feet long, or 1/75 acre in area. The effect of slope is studied on plats cropped to cotton and having the following variations in slope: level, 1 per cent, 2 per cent, and 3 per cent. The effect of crops or cover is studied on 2 per cent slope with the following treatments: buffalo grass, milo, cotton and fallow, and the effect of tillage is studied on cultivated and uncultivated fallow plats with 2 per cent slope.

Intensity of Rainfall in Relation to Run-off

In order to have some estimate of the effect of intensity of rainfall on run-off, use has been made of the records obtained from automatic rain gages. Each rain has been divided arbitrarily into three ranges of intensity as follows:

(1) Torrential rainfall: all rainfall that occurs at a rate of more than .75 inch per hour.
(2) medium rainfall: all rainfall that occurs at a rate between .40 and .75 inch per hour.
(3) Slow rainfall: all rainfall that occurs at a rate of less than .40 inch per hour.

The data relative to intensity are presented in Table 5 as yearly totals. A comparison of the results from several different years will give some

Table 5. Intensity of rainfall in relation to run-off, period of years summary

Year	No. rains producing run-off	Amount of rainfall producing run-off, in.	Character of rain, inches*			Average run-off from 8 plats, inches
			Torrential	Medium	Slow	
1926	14	25.30	8.78	6.97	9.55	7.03
1927	10	10.92	5.80	1.45	3.67	.92
1928	17	12.60	8.47	2.71	1.42	2.59
1929	10	10.17	6.01	.90	3.26	3.20
1930	9	12.46	5.58	.21	6.67	2.80
1931	10	8.00	4.17	2.39	1.44	.78
1932	12	19.65	5.27	2.29	12.09	2.74
1933	9	9.65	4.65	1.05	3.95	2.11
1934	5	5.35	3.21	.82	1.32	1.78
1935	10	13.42	7.06	2.18	4.18	4.77
1936	11	14.34	7.82	1.34	5.18	4.06
1937	6	12.63	5.41	2.23	4.99	3.35
1938	9	12.59	6.78	1.57	4.24	3.25
1939	6	7.20	3.30	1.38	2.52	1.20
Total	138	174.28	82.31	27.49	64.48	
Average	9.86	12.45	5.88	1.96	4.61	
Per cent			47.23	15.77	37.00	2.90

*Torrential—rate of more than .75 inch per hour.
Medium—rate between .40 and .75 inch per hour.
Slow—rate of less than .40 inch per hour.

indication of the effect that intensity has on run-off. In 1935 the rainfall producing run-off, the torrential rainfall, and the resulting run-off were all approximately 2½ times as much as in 1934. The close agreement of the ratios between total and torrential rainfall and run-off for the two years indicates that other factors affecting run-off were fairly uniform in these years. The rainfall producing run-off in 1930 was 12.46 inches and in 1932, 19.65 inches, with the torrential rainfall practically the same in both years. Nevertheless, the run-off in 1930 was 1.6 times greater. In 1927 and 1929 the rainfall producing run-off and the torrential rainfall were almost the same, but the run-off was 3.1 times greater in 1929. The two latter comparisons emphasize the fact that factors other than rainfall intensity have affected the amount of run-off to varying degrees and that total rainfall and torrential rainfall by no means constitute an absolute standard from which run-off may be calculated.

Influence of Tillage on Run-off and Erosion

Two plats have been fallowed during the 14-year period, 1926 to 1939. One is cultivated in the same manner and at the same time as the plats planted to row crops, while the surface of the other has not been disturbed except in clipping weeds with a hoe. Both plats have a 2 per cent slope. The surface of the uncultivated plat resembles very much some of the pasture land that has been denuded of vegetation by droughts and overgrazing. The average annual run-off from the cultivated plat has been 4.09 inches and from the uncultivated plat, 5.58 inches (Table 6).

Table 6. Influence of tillage on run-off and erosion from plats with 2 per cent grade, average 1926-1939

Treatment	Run-off, inches	Soil loss, tons per acre
Cultivated fallow	4.09	8.01
Uncultivated fallow	5.58	10.27

Thus, by cultivating and loosening the soil 1.49 inch additional water has been caused to enter the soil. The erosion losses bear approximately the same relation to each other as the water losses, that is, 8.01 tons per acre yearly from the cultivated plat and 10.27 tons from the uncultivated.

Influence of Slope on Run-off and Erosion

In this series 4 plats varying from 3 per cent slope to level have been cropped continuously to cotton. Table 7 gives the average annual run-off and erosion for a period of 14 years.

In establishing these plats it was necessary to make a fill of approximately one foot of soil at the upper end of one of the plats in order to obtain the desired 3 per cent slope. A slight fill was also made on another of the plats to obtain a 2 per cent slope. As a result of having made these fills the infiltration rate may have been increased and the run-off loss decreased accordingly. Although there is little difference in the amount of water that was lost from the 1, 2, and 3 per cent slopes, all of these treatments lost more than 2 times as much water as did the level plat. It may be inferred, therefore, that unless control measures are used the water lost from land with only a slight slope may be expected to amount to a higher percentage of the annual rainfall.

The differences in soil losses from the several plats have been more in accordance with the differences in slope than was the case with the water losses. The significance of the erosion data is that severe washing is not confined to the steeper slopes but will also occur on the more gentle slopes.

Influence of Crops on Run-off and Erosion

Vegetative cover and residue have long been recognized for their value in lessening the damage from run-off and erosion. Plant materials, either living or dead, tend to prevent the soil from being churned into a muddy

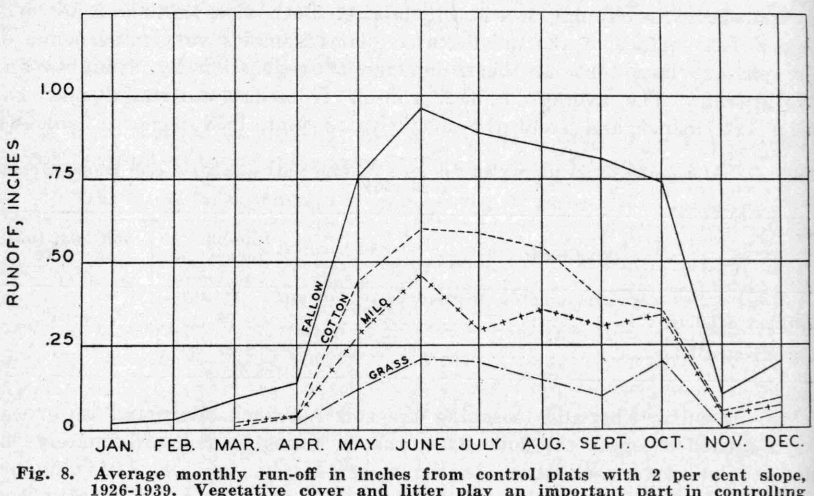

Fig. 8. Average monthly run-off in inches from control plats with 2 per cent slope, 1926-1939. Vegetative cover and litter play an important part in controlling run-off.

suspension by falling rain and to check the surface movement of water sufficient to allow greater penetration. This conception is substantiated in Table 8 by the run-off and erosion data from 4 control plats with 2 per cent grade, one each cropped continuously to cotton, milo, and buffalo grass and one continuously fallowed. The run-off and erosion have been inversely related to the amount of vegetation and vegetative litter produced by the crop. The average annual run-off from the fallow plat has been 4.09 inches while that from the grass has been only 1.04 inch; milo, 2.22 inches; and cotton, 3.09 inches. Approximately one-third of the total run-off for the 14-year period occurred on the grass plat in 1926 before a heavy turf was formed. Fig. 8 shows the effect of crops on seasonal run-off from these plats. Aside from the effect of vegetative litter produced by milo and grass, there is another highly important factor involved in determining the amount of run-off. Both milo and grass have the ability to use quickly large amounts of water and thus leave space in the soil for additional water from subsequent rains.

Table 7. Influence of slope of land on run-off and erosion from plats cropped to cotton, average 1926-1939

Slope	Run-off, inches	Soil loss, tons per acre
Level	1.30	1.97
One per cent slope	3.00	4.87
Two per cent slope	3.09	6.41
Three per cent slope	2.86	6.50

Table 8. Influence of crops on run-off and erosion from plats with 2 per cent grade, average 1926-1939

Crop	Run-off, inches	Soil loss, tons per acre
Cotton	3.09	6.41
Fallow	4.09	8.01
Buffalo grass	1.04	1.23
Milo	2.22	3.40

Observations over a long period of years indicate that erosion is affected not only by the crop grown but also by the stage of growth of the crop at the time rain comes. The canopy effect of growing plants plays an important part in determining the amount of erosion as well as run-off. The highest average soil loss has been from the fallow plat, 8.01 tons per acre yearly, or the equivalent of removing approximately .70 inch of soil from the surface during the 14-year period.

FIELD AREAS

Twelve field areas varying in size from 5.3 to 11.5 acres represent the experimental set-up for determining the effect of water and soil conservation practices under field conditions. The areas are located on Miles and Abilene clay loams and vary in slope from ½ of one per cent to 2 per cent. On those areas where water can escape, the run-off is measured at the lower end of the area with water stage recorders as it flows through V-notch weirs (Fig. 9). A description of the areas follows:

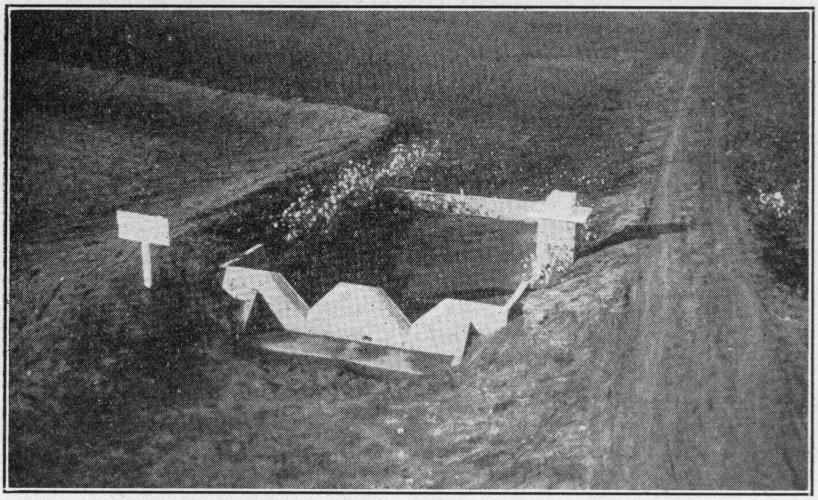

Fig. 9. One of the concrete weirs with two 90-degree notches, still pond, and water-edge recorder used in measuring run-off from the field areas.

Area 1. Contoured rows, cropped to cotton, 11.530 acres, established in 1927.

2. Rows with slope, cropped to cotton, 9.386 acres, established in 1927.

3. One-foot fall between level terraces with ends open, cropped to cotton, 10.711 acres, established in 1927.

5. Two-foot fall between level terraces with ends open, cropped to cotton, 5.807 acres, established in 1927.

6. Two-foot fall between terraces having fall of 3 inches per 100 feet along terrace, cropped to cotton, 5.323 acres, established in 1927.

7. Level terraces with ends closed to hold all water that falls on area, cropped to cotton, 6.329 acres, established in 1927.

11. Rows with slope, cropped to cotton, 8.699 acres, established in 1930.

12. Contoured rows, cropped to cotton, 8.411 acres, established in 1930.

13. Level terraces with ends closed to hold all water that falls on area, cropped to cotton, 8.644 acres, established in 1930.

14. Rows with slope, cropped to cotton, 8.532 acres, established in 1930.

15. Contoured rows, cropped to cotton, 8.505 acres, established in 1930.

16. Level terraces with ends closed to hold all water that falls on area, cropped to cotton, 7.580 acres, established in 1930.

It will be noted that rows with slope, contoured rows, and closed level terraces occur in triplicate.

Contoured Rows and Closed Level Terraces

In 1927 three field areas of approximately 9 acres in size were established on Abilene clay loam soil that had a slope of approximately one-half of one per cent. On one area the rows were run with the slope, on another the rows were laid off on the contour, and on the third area closed level terraces were constructed at vertical intervals of one foot. The last practice was generally considered to be a ridiculous experimental venture.

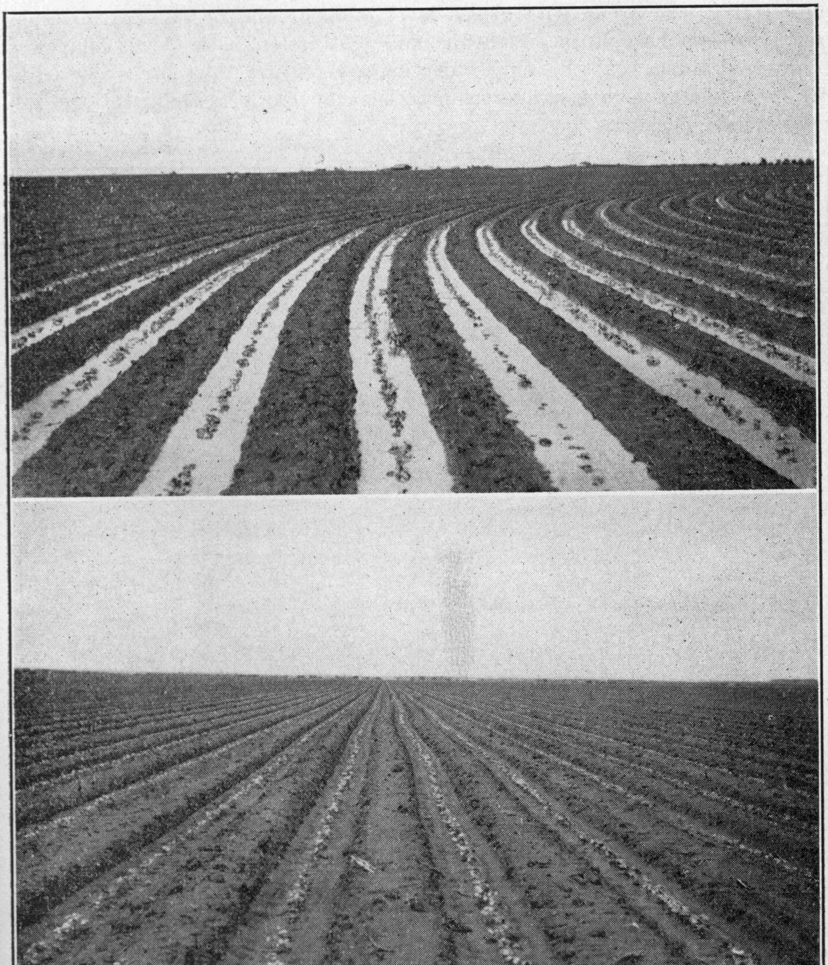

Fig. 10. Following a rain of 1.08 inch on June 4, 1937, where cotton was 4 inches high. There was no water lost from the area having contoured rows but the run-off from the area with straight rows wos .70 inch, and the slope on these rows is only ½ of one per cent. These photographs were made within an hour after the rain had stopped falling.

In 1930 three additional areas were established to duplicate the studies conducted from 1927 to 1929, and in 1933 three areas which had previously been cropped to sorghum were cropped to cotton and added to the series, and the studies carried in triplicate during the period 1933 to 1939. The effect of contoured rows and closed level terraces on run-off, crop yields and profits is shown in Table 9.

In September 1936 the rainfall was 11.13 inches. At other times during the 13-year period torrential rains have occurred, but there has been no run-off from the areas with closed level terraces and no damage to crops from excessive moisture. Planting and cultivation have been delayed a number of times, but the only objectionable feature thus far observed is the breaking of a long-standing precedent of quick field operations following rain periods.

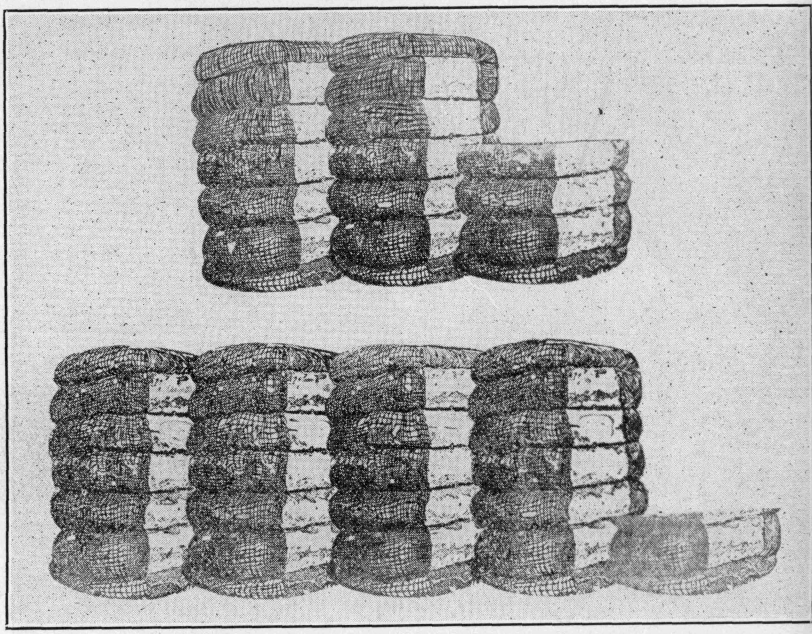

Fig. 11. Acre production of cotton over a period of 13 years. Top: straight rows having ½ of 1 per cent slope. Bottom: closed level terraces from which no water was lost. The average yearly increase from using closed level terraces was $6.21 per acre.

The average run-off from the area with the rows running with the slope has been 1.41 inches, from the area having contoured rows .88 inch, and from the closel level terraces there has been no run-off. The average yield of lint cotton per acre has been 102, 123, and 150 pounds respectively. The average annual gross acre returns over the 13-year period were increased $2.44 by contouring the rows and $6.21 through the use of closed level terraces.

Table 9. Effect of rows with the slope, rows on the contour, and closed level terraces on run-off, yield of lint cotton, and crop value, 1927-1939

Year	Rainfall, inches	Price of cotton per lb.*	Rows with the slope			Rows on the contour			Closed level terraces		
			Run-off, inches	Yield, lbs. lint per acre	Acre value	Run-off, inches	Yield, lbs. lint per acre	Acre value	Run-off, inches	Yield, lbs. lint per acre	Acre value
1927........	16.12	20.23	.38	239	$ 48.59	.15	240	$ 48.79	0	279	$ 56.72
1928........	19.99	18.97	2.88	58	11.00	3.73	111	21.06	0	217	41.16
1929........	14.76	15.40	2.52	0	....	2.13	0	....	0	0	....
1930........	18.60	9.97	.87	47	4.69	.36	60	5.98	0	90	8.97
1931........	16.46	5.97	.25	172	10.27	.03	194	11.58	0	214	12.78
1932........	27.70	7.40	1.80	0	....	.85	0	....	0	0	....
1933........	15.59	10.40	.45	391	40.66	.10	408	42.43	0	441	46.38
1934........	12.88	11.65	.69	0	....	.14	0	....	0	0	....
1935........	23.78	11.53	1.14	103	11.87	.89	199	22.94	0	219	25.25
1936........	24.47	11.83	3.32	24	2.84	1.25	36	4.26	0	44	5.21
1937........	20.28	10.90	2.08	136	14.82	.97	154	16.79	0	217	23.65
1938........	19.96	7.70	1.66	149	11.47	.73	185	14.25	0	215	16.56
1939........	13.06	9.90	.31	7	.69	.09	6	.59	0	10	.99
Total.....	243.65	....	18.35	1326	156.90	11.42	1593	188.65	0	1946	237.67
Average...	18.74	11.68	1.41	102	12.07	.88	123	14.51	0	150	18.28

*Local market prices.

Graded and Level Terraces

In 1927 two field areas of approximately 6 acres each were terraced to determine the effect of grade along the terrace on run-off and crop yields. The soil on which these areas are located is Miles clay loam which has a slope of one and one-half to 2 per cent. On one area level

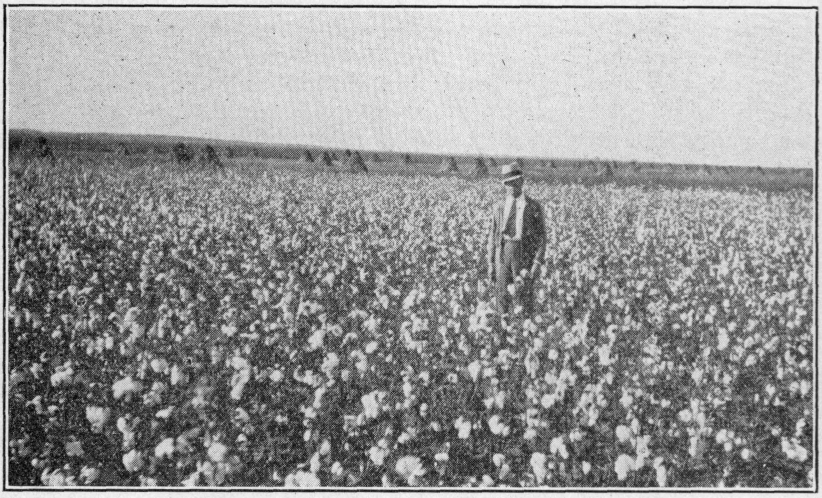

Fig. 12. Cotton crop on Area 7 (closed level terraces) in 1933. The yield was 441 pounds of lint cotton per acre, slightly less than a standard bale.

terraces with a vertical spacing of 2 feet were constructed, and on the other area terraces were constructed with a grade of 3 inches in 100 feet along the terrace with a vertical spacing between terraces of 2 feet. The rainfall, run-off and crop yields for the 13-year period, 1927 to 1939, are shown in Table 10.

Table 10. Annual rainfall, inches of run-off and yield, pounds of lint per acre, from level terraced and graded terraced acres

Year	Rainfall, inches	Level terraces		Graded terraces	
		Run-off, inches	Yield, lbs. lint per acre	Run-off, inches	Yield, lbs. lint per acre
1927	16.12	.11	226	.56	197
1928	19.99	.86	173	3.07	108
1929	14.76	1.00	0	3.31	0
1930	18.60	.70	46	2.13	33
1931	16.46	.09	190	.33	145
1932	27.70	1.12	0	2.30	0
1933	15.59	.07	442	1.43	337
1934	12.88	0	0	1.12	0
1935	23.78	.81	191	3.60	101
1936	24.47	2.55	43	3.99	36
1937	20.28	1.17	161	2.99	150
1938	19.96	.81	186	2.32	163
1939	13.06	.07	15	.42	17
Total	243.65	9.36	1673	27.57	1287
Average	18.74	.72	129	2.12	99

The average annual run-off from the level terraces with the ends open has been .72 inch, and the yield of cotton has averaged 129 pounds of lint per acre. From the area having graded terraces the average annual run-off has been 2.12 inches, and the yield of lint cotton per acre has been 99 pounds.

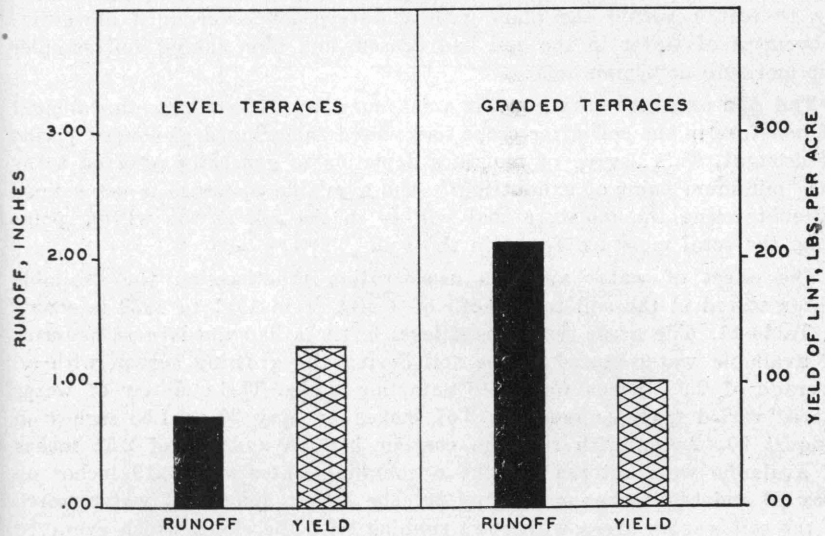

Fig. 13. **Run-off and yield of cotton from level and graded terraces, average for 13 years. The run-off has ben higher and the cotton yields lower from graded terraces.**

The terraces have an effective height of 12 inches and there has been no over-topping of either the graded or level terraces.

During the past 13 years there has been a decided tendency to reduce the grade on all graded terraces, and over much of Texas level terraces are coming into general use.

Available Water Stored in the Soil

The data on soil moisture were obtained from the previously-described field areas. Soil samples have been taken since 1931 to a depth of 3 feet at 3 locations on each area for the determination of the moisture content of the soil. Determinations were made on April 20 and thereafter at monthly intervals to September 20. In 1937 the depth of sampling was increased to 5 feet and the date of sampling extended to October 20.

For convenience in interpretation, the results of the soil moisture determination are reported as inches of available water rather than as percentages. Available water is that part of the soil moisture which may be extracted from the soil by plants.

There are two stages of moisture retention in the soil that are of vital importance to plant growth. These are (1) the field capacity of the soil for water, which is the greatest amount of water a soil will hold after the excess water has drained away, and (2) the wilting point, which represents the amount of moisture left in the soil when plants have permanently wilted.

The field capacity was determined by artificially flooding plats 10 feet by 10 feet, covering the plats with a waterproof cover until downward movement of water in the soil had ceased, and then taking soil samples for moisture determinations.

The approximate wilting point was found by determining the amount of moisture in the soil after crops had wilted following a prolonged period of drought. This degree of moisture depletion is generally referred to as the "minimum point of exhaustion." The available moisture is determined by subtracting the moisture that will be in the soil at the wilting point from the total moisture found in the soil.

The effect of water and soil conservation practices on the available water stored in the soil to a depth of 3 feet from 1931 to 1939 is shown in Table 11. The areas with closed level terraces had the largest quantity of available water stored in the soil during the growing season with an average of 2.95 inches for the 6 sampling dates. The quantity of water stored varied from as much as 3.67 inches on May 20 to 1.68 inches on August 20. Areas with rows on contour had an average of 2.51 inches of available water stored for the 6 sampling dates with 3.19 inches on May 20 and 1.34 inches on August 20. The lowest amount of water stored in the soil was on areas with rows running with the slope, which averaged 2.25 inches for the 6 sampling dates. The quantity of water stored varied from 2.71 inches on April 20 to 1.35 inches on August 20.

The largest amount of water was present in the soil during the first months of the crop season. Cotton planted during the early part of May makes but little growth for a period of 6 weeks, transpiring only a limited amount of water. With higher temperatures occurring during the latter part of June and early July, the plants develop more rapidly and use greater quantities of water. During July and August cotton plants make the heaviest demands for water, causing a marked decrease in the water stored in the first, second and third foot sections. A slight increase in the water stored in the soil usually occurs following the early fall rains.

It is evident from Fig. 14 that August is the critical month from the standpoint of available water for the cotton plant. If ample moisture is stored in the soil or enough effective rainfall occurs to maintain normal growth and development of plants, early fall rains usually enable the plant to mature a good crop.

The average yield of lint and run-off are included in Table 11 and show that .59 inches more run-off occurred from contoured areas than from areas having closed level terraces, and that the loss of water was followed by a decrease in yield from 152 pounds to 131 pounds of lint per acre. Likewise, the areas with straight rows had an average water loss of 1.20 inches and a yield of lint of only 109 pounds per acre.

Table 11. Available water, run-off and yields. Average of three field areas, rows with slope, contoured rows and closed level terraces, 1931-1939

Treatment	Depth, feet	Inches of available water							Per cent of total in each foot	Average run-off, inches	Average yield lint, lbs. per acre
		Dates of sampling									
		4/20	5/20	6/20	7/20	8/20	9/20	Average			
Rows with slope	1	1.43	1.43	1.38	1.22	.74	.95	1.19	52.89		
	2	.77	.77	.77	.69	.35	.53	.64	28.44		
	3	.51	.[illegible]1	.42	.42	.26	.37	.42	18.67		
Total	....	2.71		2.57	2.33	1.35	1.85	2.25	....	1.20	109
Rows on Contour	1	1.41	1.52	1.45	1.14	.64	.88	1.17	46.61		
	2	.91	.93	.94	.84	.26	.54	.74	29.48		
	3	.[illegible]6	.74	.68	.65	.44	.45	.60	23.90		
Total	....	2.[illegible]8	3.19	3.07	2.63	1.34	1.87	2.51	....	.59	131
Closed Level Terraces	1	1.52	1.67	1.55	1.18	.73	1.00	1.28	43.39		
	2	1.05	1.11	1.06	.96	.40	.65	.87	29.49		
	3	.89	.89	.95	.94	.55	.61	.80	27.12		
Total	....	3.46	3.67	3.56	3.08	1.68	2.26	2.95	....	0.0	152

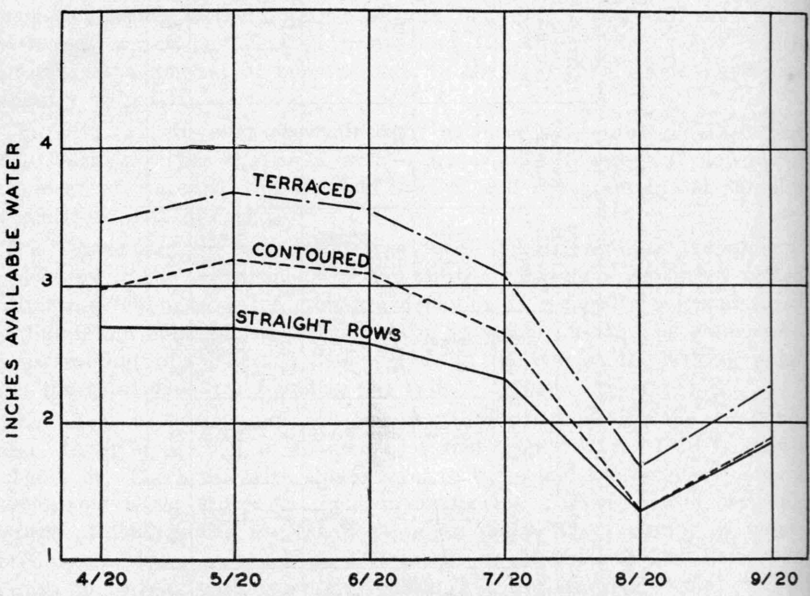

Fig. 14. Inches of available water to a depth of 3 feet in field areas cropped to cotton, average 1931-1939. The increased reserve of soil moisture on terraced and contoured land pays large dividends in crop yields.

The Relation of Available Water in the Soil at Planting Time to the Yield of Cotton

The amount of water available for plant use on May 20 (planting time) and the yield of lint in pounds per acre shown in Table 12. The data for 1932 are omitted as the crop was destroyed by hail on June 20. In this study yields over 200 pounds of lint per acre have been classed as Good, from 101 to 200 as Fair, from 31 to 100 pounds as Poor, and under 31 pounds of lint per acre as Crop Failures.

The field capacity of the clay soils on the station is approximately 6 inches of available water within the upper 3 feet. It is seldom that these soils are filled to capacity. When the available water drops below 2 inches the soil is usually too dry to plow.

When the available water was above 4 inches at planting time there were 14 good crops, 15 fair crops, 2 poor crops and no crop failures, and the average yield of lint cotton was 229 pounds per acre. With 3 to 4 inches of available water there were 13 good crops, 14 fair crops, 5 poor crops and 2 crop failures, and the average yield of lint cotton was 187 pounds per acre. With 2 to 3 inches of available water there were no good crops produced, 5 fair crops, 5 poor crops and 2 crop failures; but when the available water was below 2 inches at planting time there were no good crops produced, 1 fair crop, 1 poor crop and 24 crop failures.

Table 12. Effect of available water in upper three feet of soil at planting time on cotton yields all treatments

Inches of available water	Classification of crops								Total No. crops	Ave. yield
	Good		Fair		Poor		Failure			
	No. crops	Yield	No. crops	Yield	No. crops	Yield	No. crops	Yield		
Over 4..	14	326	15	180	2	38	0	0	31	229
3 to 4..	13	306	14	162	5	54	2	22	34	187
2 to 3..	0	0	5	171	5	51	3	0	13	85
Under 2	0	0	1	186	1	92	24	6	26	16

THE SYRUP PAN TERRACE SYSTEM

The use of run-off water for irrigation is an old and accepted practice. For centuries water has been impounded by man and diverted to fields and vineyards to supplement normal rainfall. The American Indians of the sub-humid regions were efficient in diverting water onto their fields during rainy periods. These early experiences in the use of water have been an incentive to more intensive and systematic studies relating to utilization of water which comes as rainfall.

The most forward step in water utilization at this station has to do with the diversion of flood water from higher land onto a cultivated tract that has been called the syrup pan terrace system or water trap. This syrup pan terrace system comprises 120 acres of cultivated land that has a series of terraces with alternate ends closed and the other ends partly closed for conducting water back and forth across the field as it flows toward the lower end (Fig. 17). This is a system for flood irrigation whereby the run-off water from a 1,200-acre watershed is diverted to the upper end of the field by dikes and measured in through a 40-foot rectangular weir. The tract, which is 1/4 mile wide and slightly less than 1 mile long, has an average slope of ½ of 1 per cent along the greater dimension. Thirteen terraces varying in height from 2½ to to 3 feet have been constructed on the area. The terraces are level and are spaced at a vertical interval of 18 inches. The predominating soil type is Abilene clay loam.

In order to facilitate a better distribution of water over the area a by-pass was constructed in 1937 and so designed and located that it would

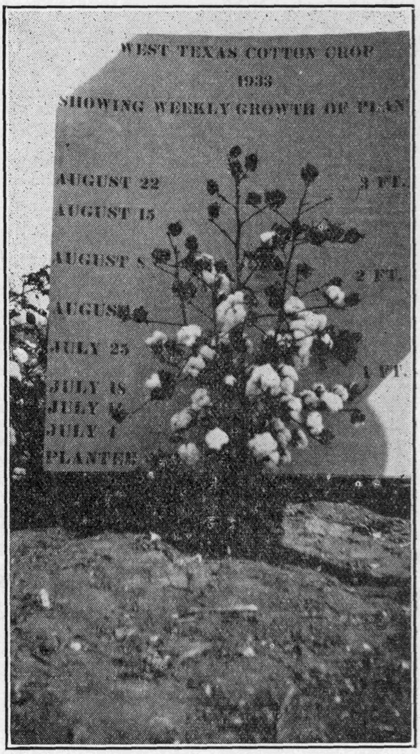

Fig. 15. A cotton plant typical of the dry year of 1933. The rainfall for the year was 15.59 inches. The large 1933 cotton crop resulted from moisture stored in the subsoil during the latter part of 1932, a year having a rainfall of 27.70 inches. The best crops are frequently made in comparatively dry years following wet years.

not be necessary for the water to flow over the upper half of the area in order to irrigate the lower half. The water is taken out through a culvert and is passed down slope on the outside and brought back into the system one-half mile below. The by-pass is designed so that the small rains can be carried through or it can be closed so as to permit all of the water to flow over the entire system. A number of flumes have been constructed through terraces where portions of the water will flow through the terraces instead of around the ends and gives irrigation to areas immediately below the terraces during and following flood periods. These flumes may be closed and all the yater discharged around the ends of the terraces. Small spur terraces built out from the border dikes have been effective in checking the velocity of flowing water and in most cases have caused a deposit of silt in the terrace outlets. It has been found that erosion is easily controlled by the use of dirt obstructions that retard the movement of water or change the course of flow. As a general rule, erosion at any point in the syrup pan system is easily controlled by placing obstructions where the water has gained sufficient velocity to cause scouring of the surface soil. It is now believed that very effective erosion

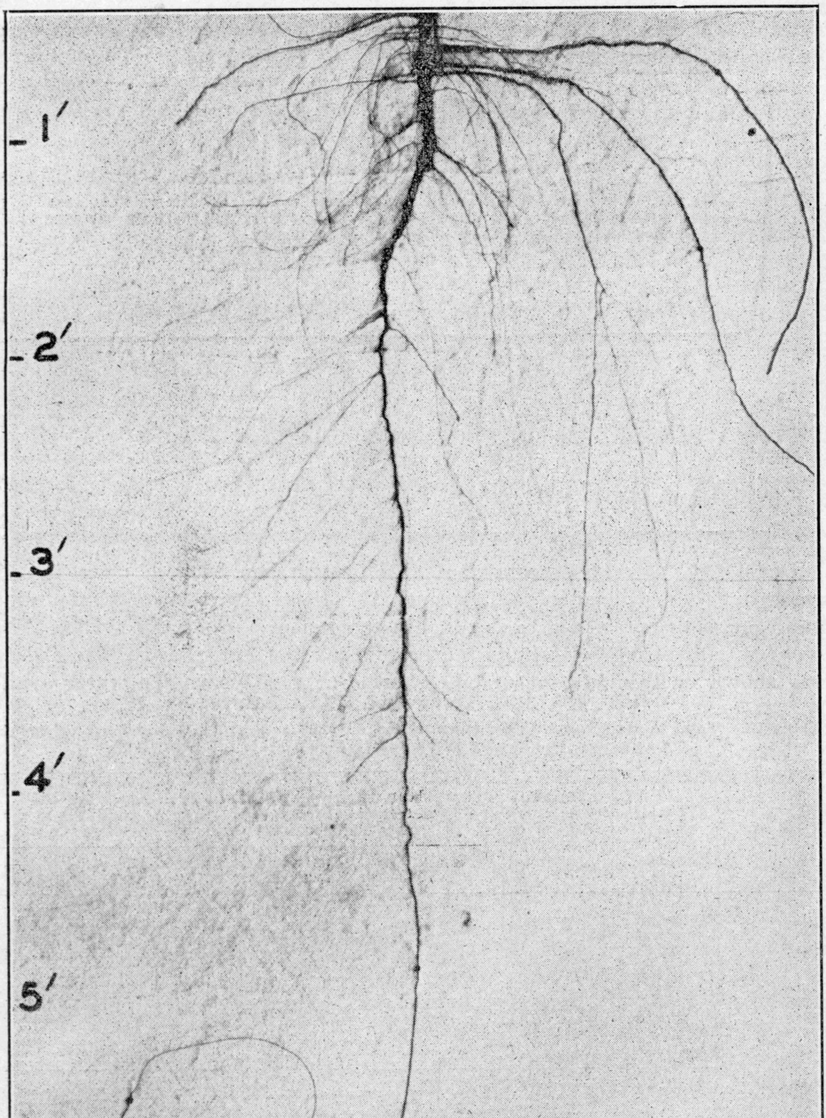

Fig. 16. A cotton plant that sent its roots 7½ feet into the soil. Cotton, wheat, sorghums and many other annuals send their roots 6 to 8 feet into the soil for water and plant food. Many of the soils have ample storage space within the root zone of the cotton plant for a large portion of the rainfall.

control can be had in the syrup pan system without the use of masonry or vegetative obstructions.

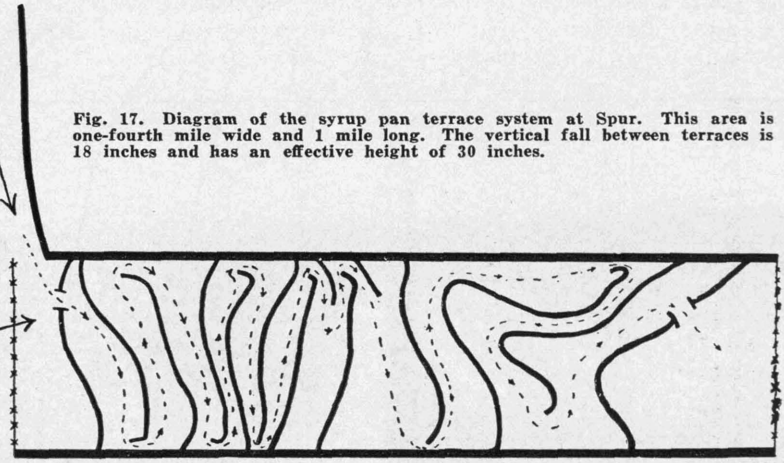

Fig. 17. Diagram of the syrup pan terrace system at Spur. This area is one-fourth mile wide and 1 mile long. The vertical fall between terraces is 18 inches and has an effective height of 30 inches.

During the 9 crop seasons that this system has been in operation 19 rains have caused water to flow onto the tract. Thirteen of these rains supplied sufficient water to flood only the upper half of the system. The other 6 rains supplied enough water to flood the entire area. These data are shown in Table 13 in summary form for each year. The water available for crop use has been increased an average of 19.3 per cent on the upper half and 12.5 per cent on the lower half. In several of the years during this period this additional water has been the difference between fair to excellent crops and crop failures. This was evident in 1936 when a planting of cotton in the flooded area that received 2.73 inches of flood

Table 13. Total rainfall, rainfall producing run-off on 1200-acre watershed and run-off caught in 120-acre syrup pan terrace system

Year	Total yearly rainfall, inches	Rainfall producing run-off on watershed, inches	Run-off from watershed, total acre inches		Inches per acre of water caught and held on	
			Caught in system	Lost from system	Upper half of system	Lower half of system
1931......	16.46	1.21	72	0	1.28	0
1932......	27.70	6.10	1327	523	8.58	7.03
1933......	15.59	3.29	223	0	3.96	0
1934......	12.88	0	0	0	0	0
1935......	23.78	5.57	745	282	5.24	3.64
1936......	24.47	8.33	922	229	8.40	4.86
1937......	20.28	6.06	988	428	5.48	5.48
1938......	19.96	1.63	65	0	.64	.64
1939......	13.06	0	0	0	0	0
Average...	19.35	3.58	482	162	3.73	2.41
% increase over rainfall.......					19.3	12.5

water during the growing season produced 146 pounds of lint cotton per acre while adjoining land on which all of the rain water was held but which received no flood water produced only 39 pounds per acre.

The use of flood water from 1937 to 1939 in the production of cotton has not, however, given the yields that might be expected. This has

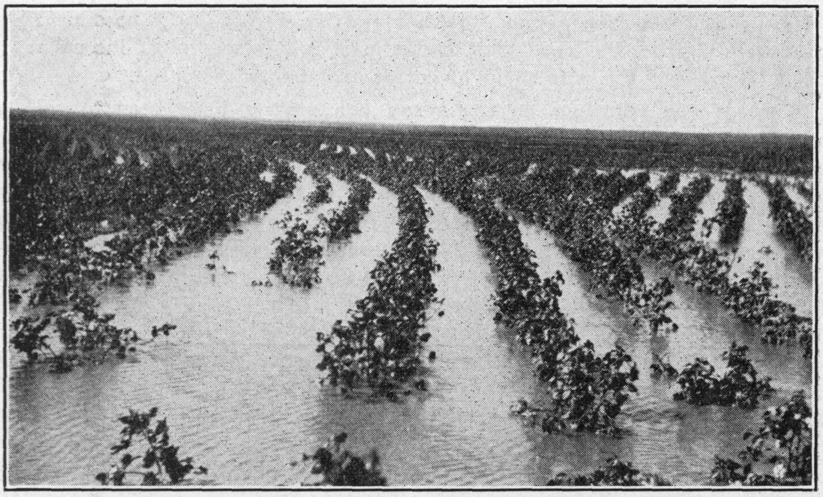

Fig. 18. This water penetrated into the soil within 60 hours and was beneficial to the current crop and also furnished a deep "bottom season" for the next year, which was very dry.

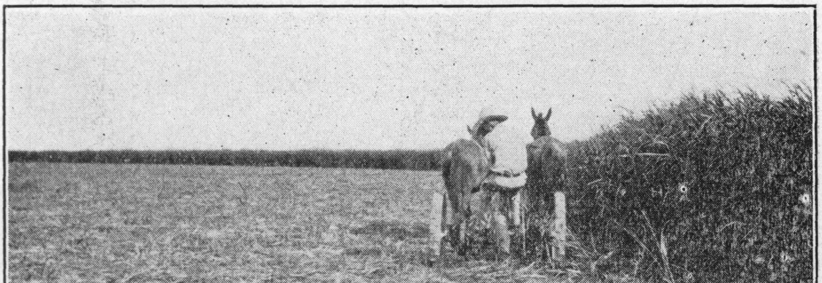

Fig. 19. A crop of Sudan grass on 39 acres of the syrup pan terrace system in 1932. Sudan was planted on May 12. On June 20 the area was flooded with 7.03 inches of water and the grass made such rapid growth that it was necessary that it be mowed in the latter part of July even though 68 head of yearling steers had been grazed on the area after the grass was 18 inches high.

been due not to a deficiency of subsoil moisture but to the depredations of insects, more especially the cotton flea hopper and the cotton bollworm. Enough is not known at present about the relation of these water conservation practices to insect damage to justify making definite statements. Quite often irrigation throughout the region has brought about an increase in the insect population in irrigated fields, and it appears that the syrup pan system is no exception. It is possible that practices may be developed whereby at least a fair control of insects may be obtained and the acre yield of cotton materially increased.

Most of the plantings in the syrup pan system have been to sorgos and grain sorghums that were used in connection with cattle feeding experiments. During the 9-year period, 6 of the years have been below normal in rainfall, and in 1934 and 1939 two of the most severe droughts in the history of the region occurred. There has been one short feed crop during this time, and in 6 of the 9 years feed crops have been exceptionally good. Yields of 10 tons of silage crops per acre are common and higher yields are frequently obtained.

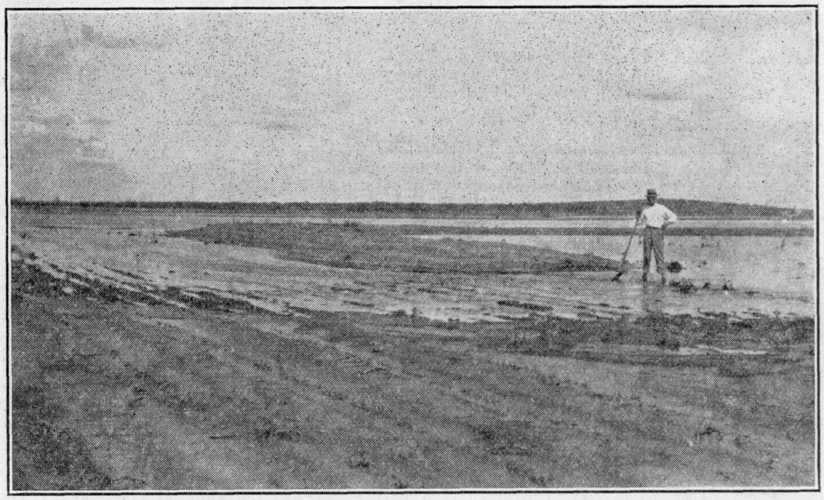

Fig. 20. A terrace in the syrup pan terrace system showing the partly closed end and the manner in which water flows to the terrace below.

Possibly one of the most interesting features connected with the syrup pan system is the cost of storing water. The initial cost of constructing terraces to store water in the soil was $1.25 per acre foot. The storage for an acre foot of water in large reservoirs ranges from $10.00 to several hundred dollars, while that for lifting an acre foot of water from irrigation wells in this region is approximately $6.00. It appears that terraces such as those constructed in this system are most economical from the standpoint of storing water in the soil of any practices in the region. It is generally believed by those who have made a complete study of water conservation problems in relation to crop production in the region that the practical procedure is to conserve the rainfall first, and the pump and reservoir irrigation start where flood irrigation ends. These cost data are possibly applicable to a large section of the country. The cost of storing an acre foot of water in the soil will be much less than the figures given above on some areas and will be so high as to be prohibitive on other areas. The main consideration is the number of acres that can be flooded from each retaining terrace. It is obvious, of course, that the more nearly level the land is, the greater the area that may be flooded with each terrace.

PENETRATION AND EVAPORATION OF SOIL MOISTURE

Depth of Moisture Penetration as Affecting Evaporation Opportunities

Reduction of evaporation opportunities may in time become an important water conservation practice. Farmers in semi-arid regions have long referred to the clay soils as "droughty soils." Land values in semi-arid regions are based more on the ability of the soil to convert a high percentage of the rainfall into water available to crops than on soil fertility. The importance of getting water sufficiently deep into the soil to make it less vulnerable to the action of the sun and wind is rapidly becoming recognized as an important factor in crop production.

The rainfall from April through December 1939 was only 10.31 inches and was so distributed that the small isolated showers had little cumulative effect in adding to the available soil moisture. The classification of the rains according to size is shown in Table 14. In April 1939 sixteen

Table 14. Record of rainfall during rain periods, April 1 to December 31, 1939

Rains classified according to size, inches					
0 to .10 inch	.11 to .25 inch	.26 to .50 inch	.51 to 1.00 inch	1.01 to 2.00 inches	Over 2 inches
.03	.18	.39	.56	1.35	2.62
.08	.15	.26	.97	1.41	
.01	.21	.34	.71		
.05	.23	....	.64		
	.12				
.17	.89	.99	2.88	2.76	2.62

Total rainfall for the period, 10.31 inches.

lysimeters were filled in duplicate with Abilene clay loam and Abilene fine sandy loam to depths of 2, 4, 8, and 12 inches, and the water that percolated below these depths was caught in containers beneath the lysimeters. The water that percolated through the different strata of soil was much less than would be expected in a normal season (Table 15). Only

Table 15. Inches of percolate from lysimeters

Date	Rainfall, inches	Depth of soil in lysimeter							
		2 inches		4 inches		8 inches		12 inches	
		Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay
5/26–27....	1.35	.45	.14	.09	....	....	....	....	....
6/28.......	1.41	.46	.03	.04	....	....	....	....	....
8/22.......	.71	.14	....	....	....	....	....	....	....
10/ 7–8.....	2.62	2.12	1.68	1.52	1.03	.85	.14	.47	0
11/28.......	.34	.03	....	....	....	....	....	....	....
12/23–26....	.64	.11	....	....	....	....	....	....	....
Total........	7.07	3.31	1.84	1.65	1.03	.85	.14	.47	0
Per cent of total rainfall.	....	32.13	17.88	15.97	9.77	8.26	1.36	4.57	0

3.31 inches, or 32 per cent, penetrated to a depth below 2 inches in the sandy soil, with 1.84 inches reaching the same depth in the clay soil. The rain of 2.62 inches on October 8 was the only rain period of the year when water penetrated to a depth of 4 inches in the clay soil. From this rain, 1.68 inch penetrated to a depth below 2 inches, 1.03 inch penetrated to 4 inches, and .14 inch penetrated to a depth of 8 inches. At no time during the year was there sufficient rainfall to cause water to penetrate to 12 inches in clay soil, and only .47 inch penetrated to this depth in the sandy soil. The opportunities for surface evaporation were practically twice as great from the clay as from the sand. Crop yields in 1939 at the Spur Station were among the lowest in the history of the station due to an acute shortage of available soil moisture.

It is very desirable that additional information be obtained on the relation of soil type and structure, methods of seed bed preparation, cultural methods, rotations, and addition of organic matter to rate of

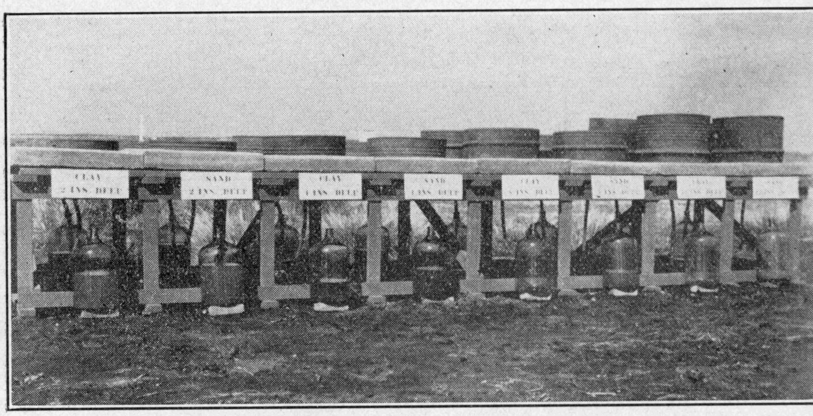

Fig. 21. Lysimeters and water percolated following rain of 2.62 inches. With a total rainfall of 10.31 inches from April 1 to December 31, 1939, only 3.31 inches penetrated to a depth below 2 inches in sandy loam and 1.84 inches in clay loam. A high percentage of the rainfall stayed close to the surface and was quickly lost through evaporation.

infiltration and depth of penetration and the relation that they may have to increasing the percentage of the total rainfall that may become soil water available for plant use.

Evaporation from the Soil

Little information is available relative to evaporation of water from the soil. Preliminary studies were started in 1937 to develop information pertaining to soil moisture losses by evaporation.

The first phase of the work was on a relatively level area of Miles clay loam that had a slope of less than ½ of one per cent. The area was levelled, and two plats, 18 feet by 34 feet, were established. An earthen border was placed around each plat to prevent run-off and also to keep outside water from entering. The plats were fallowed and the soil left undisturbed during the growing season with the exception of occasional scraping with hoes to remove weed growth.

Moisture determinations were made at 4 random locations on each plat at monthly intervals during the growing season. The samples were taken at depths of 0-6, 6-12 inches, and then at one-foot intervals to a depth of 10 feet. The total inches of rainfall, soil moisture, and evaporation are shown in Table 16.

Table 16. Rainfall during the growing season, soil moisture and evaporation in inches from fallow plats, 1937, 1938, and 1939

Period	Rain-fall	Total soil water, inches, depth 10′				Evaporation	
		Capacity	Spring	Fall	Gain or loss	Inches	% of rainfall
5/15–11/11, 1937........	15.82	37.79	27.20	35.22	8.02	7.80	49.30
5/10–10/17, 1938........	12.40	37.79	35.90	35.40	—0.50	12.90	104.03
5/12–11/25, 1939........	8.89	37.79	27.09	29.64	2.55	6.34	71.32
Total...............	37.11	....	90.19	100.26	10.07	27.04	72.86

On May 15, 1937, when the study was begun, the total water in the soil to a depth of 10 feet was 27.20 inches. The difference between the field capacity, 37.79 inches, and the total water in the soil, 27.20 inches, was 10.59 inches and represents the unoccupied storage space in the soil for rainfall. After 15.82 inches of rainfall during the growing season, on November 11, 1937, the total water in the soil had increased to 35.22 inches, or a gain of 8.02 inches. Since there was no loss of water through transpiration, run-off or percolation, the remainder of the rainfall, 7.80 inches or 49.30 per cent, may be attributed to loss as evaporation.

The study was continued in 1938 on the fallow plats which were used the preceding year. The available storage space in the soil for additional water on May 10, 1938, however, was only 1.89 inch as compared to 10.59 inches in the spring of 1937. After 12.40 inches of rainfall the water in the soil decreased .50 inch by October 17, 1938. The total loss of water, stored soil moisture in addition to rainfall, was 12.90 inches or 104.03 per cent of the rainfall. The high moisture content of the soil as shown by the limited storage space for water on May 10, 1938, along with the fact that much of the rain during the growing season fell as small scattered showers, accounts in a large measure for the high losses of moisture and also the futility of trying to store water in a soil that approximates saturation to field capacity.

On land previously cropped to cotton but fallowed in 1939, the total soil moisture increased from 27.09 inches on May 12 to 29.64 inches on November 25 after 8.89 inches of rainfall. The amount of rainfall lost through evaporation was 6.34 inches or 71.32 per cent. The average losses of water from the soil in 1937, 1938 and 1939 were 72.86 per cent of the rainfall.

The second phase of this study consisted of determining the rate of evaporation from a soil brought to field capacity. After flooding with 10 inches of water on July 25, 1939, two plats were covered with a waterproof cover to prevent evaporation until the soil moisture became stabilized as indicated by an adjacent plat treated in a similar manner but sampled at intervals of 3 days. The covers were removed on August 26 and soil samples were taken for moisture determinations and thereafter at intervals of 3 days until September 11. The samples were taken in duplicate at 3-inch intervals to a depth of 2 feet; 6-inch intervals to a depth of 4 feet; and one-foot intervals to a depth of 6 feet. The rate of evaporation and accumulated inches of water lost on a basis of 3-inch layers of soil to a depth of 72 inches are shown in Table 17.

Table 17. Rate of evaporation from Miles clay loam at field capacity

Depth, inches	Accumulated evaporation, inches				
	8/26–29	8/30–9/1	9/2–4	9/5–7	9/8–11
0–3	.33	.49	.60	.66	.65
3–6	.24	.29	.30	.28	.28
6–12	.12	.17	.16	.15	.16
12–36	.06	.06	.04	.06	.05
36–72	.03	.04	.02	.04	.05
Total	.78	1.05	1.12	1.19	1.19

The highest rate of evaporation of water took place from the surface 3 inches of soil, the loss being .33 inch in the first 3 days and .65 inch over a period of 16 days. For the same period of time the 3-6 inch layer lost .24 inch and .28 inch, while the 6-12 inch section lost .12 and .16 inch, respectively. The soil moisture content below a depth of 12 inches remained almost constant after the first 3 days (Figure 22). Although this study was conducted over a comparatively short period and during the time when evaporation losses from a free water surface were high, it does indicate definitely that a large portion of each rain, particularly small showers, may readily be lost through evaporation.

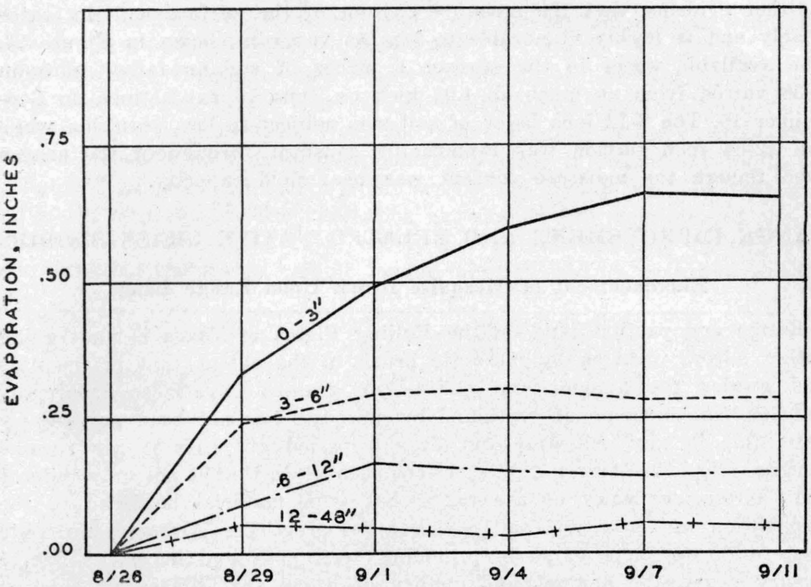

Fig. 22. Evaporation, accumulated inches of water calculated on a basis of 3-inch layers of soil, from Miles clay loam at field capacity. Moisture in the surface 3 inches and to a smaller extent in the 3-6 inch layer of soil is highly vulnerable due to the action of the sun and wind. Many small showers are lost through evaporation in a few hours after the rains have ceased.

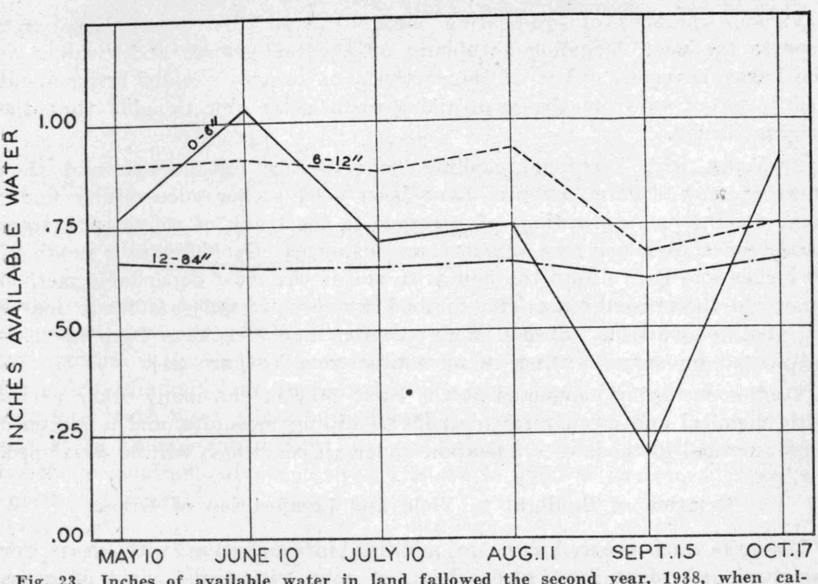

Fig. 23. Inches of available water in land fallowed the second year, 1938, when calculated on a basis of 6-inch layers of soil. The largest fluctuations in available water occurred in the surface 6 inches of soil. Soil moisture below a depth of 12 inches remained relatively constant even though at approximate field capacity.

Other evidence that the moisture content of the surface soil fluctuates widely and is highly vulnerable to loss as vapor is shown in Figure 23. The available water in the surface 6 inches of soil on fallow plats in 1938 varied from as much as 1.03 inch on June 10 to .20 inch on September 15. The 6-12 inch layer of soil was subject to less variation while the 12-84 inch section was remarkably constant throughout the season even though the moisture content was near field capacity.

RANGE IMPROVEMENT AND RELATED NATIVE GRASS STUDIES

Encroachment of Mesquite Brush Upon Range Land

Range and pasture land on the Rolling Plains of Texas is undergoing rather severe invasion by mesquite brush to the extent that in the flats and swales the amount and quality of grasses have been materially reduced. The invasion of grassland by mesquite has not been particularly noticeable in any one year, but over a period of years it has become increasingly evident that it is a serious menace in that it not only reduces the carrying capacity of the range but is a material handicap to the application of water and soil conservation practices. Although mesquite trees do have some value in providing bean pods and leaves as forage in dry years, the amount and quality of grass are reduced by shading and competition for moisture and plant food. It is the opinion of many ranchers that mesquite trees and brush in heavily infested areas have reduced the carrying capacity of the range by half.

Various methods of eradicating mesquite and other brush have been used in the past, including shrubbing off the top growth and girdling at the base; however, either of the methods of control usually bring about heavy sprouting from the base and growth more objectionable than the original brush.

Spraying with kerosene, girdling or removing top growth and then treating with sodium arsenite have been used rather successfully under some conditions. Applications of kerosene to the trunk of rough-bark trees has given a high per cent kill in some instances. Grubbing to a depth of 10 inches and then filling the hole with soil is the most dependable method known at the present time. This method is expensive unless a cheap source of labor is available. Special high-powered machines have been successfully used on some ranches in uprooting trees (Figure 24).

Studies are being conducted at the Spur Station and many other places with chemical and mechanical methods of killing mesquite, and it is hoped that practical methods of eradication under all conditions will be developed.

Relation of Sunlight to Yield and Composition of Grass

Mesquite and other brush, in addition to competing with grass for moisture and plant food, also affect the composition and yield of grass through shading. In order to obtain additional information on this point a series of latticed cages which admitted different amounts of sunlight were set in an open pasture in May 1938.

The intensity of sunlight under cages having 1-inch laths spaced 4 inches apart was reduced 38 per cent as determined by an exposure meter, and grass yields were increased. With additional shading yields were greatly reduced. When laths were spaced sufficiently close to reduce the intensity of light 85 per cent, all except 5 per cent of the plants were dead by the end of the first season. The vegetation growing in full sunlight had short, wide leaves and a dense basal cover, but as the intensity of sunlight was decreased the leaves became longer, finer in texture, and had a tendency to become spindly and tough, and the cover was markedly reduced.

Fig. 24. Machine designed for uprooting mesquite and other brush on range land. It is necessary to remove most of the root system of mesquite for the reason that this plant sprouts readily from the roots.

Chemical analyses of the harvested grass indicate that the nitrogen-free extract, fat, and ash percentages were materially reduced as the amount of shading was increased, while the protein, crude fiber, and phosphoric acid were slightly increased.

As these studies cover only two years, the second of which was very dry, the conclusions are tentative. The work will be continued through a period of years.

Contour Listing Native Grass Pastures

At the present time approximately 72 per cent of the area of Texas is used for pasture; however, only limited information is available as to the requirements, behavior and characteristics of native pasture plants. Explorers have searched the earth for new plants that would add to our agricultural wealth, and these men deserve the praise of all who are interested in agricultural development. On the other hand, it is possible that in striving to obtain new plants the potentialities of native plants that are well adapted to existing conditions have in many instances been overlooked. This is especially true of pasture plants and the neglect of buffalo grass is a specific example. It is known that buffalo grass well repays in the way of increased yields any efforts expended in its behalf. Certainly where native plants respond readily to treatment it appears worth while to determine the conditions necessary to bring about maximum production of forage on pasture land.

Recent trends in range improvement have been toward increasing the cover of palatable forage plants through the utilization of a larger portion of the rainfall. Within large areas of the semi-arid west it appears desirable to retain all of the rainfall, since range plants, especially the grasses, have the ability to use large amounts of water in the production of forage.

Most of the soils of the region are relatively deep and porous and provide ample storage space within the root zone for a large portion of the rainfall. On grassland with sparse vegetative cover, however, it is often expedient to use some kind of obstruction to check the movement of water, since the length of time that water is held on the land, as well as the infiltration rate of the soil type, determines to a large extent the amount that penetrates into the soil. Thus, the chief aim of mechanical structures is to retard the flow and effect better distribution of water over an entire area.

Studies were initiated at the Spur Substation in 1932 to obtain information on the effectiveness of contour listing of grassland in increasing vegetative cover and yield of forage. The increased production of grass resulting from this treatment was so striking that additional areas were listed in 1934 and in later years.

Before the experiments were begun the native vegetation on the pasture land consisted largely of buffalo grass (Buchloe dactyloides) with a small amount of blue grama (Bouteloua gracilis) and other grass species. Some of the more important weeds were broomweed (Gutierrezia dracunculoides), Indian wheat (Plantago Purshii and P. spinulosa), and bitterweed (Actinea odorata). The area also supported a heavy growth of mesquite brush (Prosopis chilensis) which was removed by grubbing. (Fig. 25.)

The soil is Miles clay loam with slope of 1 to 3 per cent. Some sheet erosion has occurred; however, there is no evidence of gully formation. On account of its droughty nature this soil is not well adapted to the production of cultivated groups.

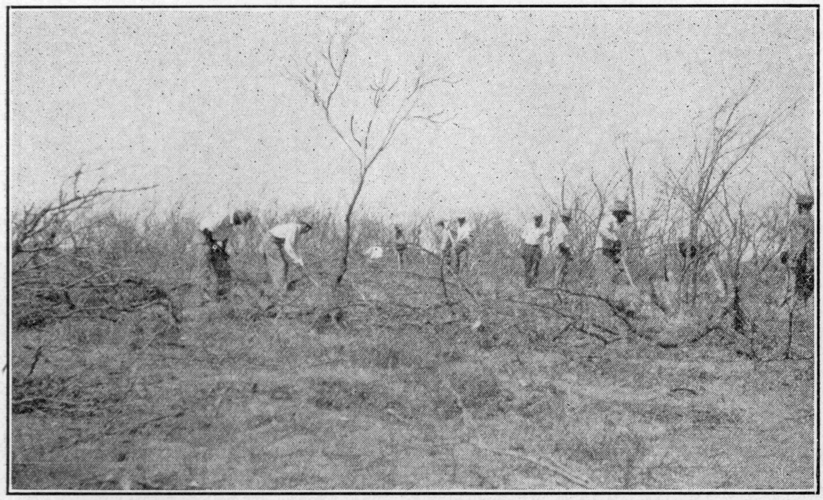

Fig. 25. Grubbing mesquite brush on a heavily infested area, a laborious and expensive operation under these conditions. Invasion of mesquite changed this open grassland in 1914 to a jungle of brush in 1932.

Yield of Native Vegetation

Plats of approximately 1 acre were solid listed on contours to a depth of 3 inches during the spring of 1932, 1934, 1936, and 1938. Comparable adjoining plats were given no treatment. A two-row tractor lister with bottoms set 39 inches apart was used in the listing operation (Fig. 26).

In order to protect representative samples of the vegetation from grazing animals, five screens, the framework of which was constructed of 2-inch by 4-inch lumber and covered with 2-inch wire netting, were located on each plat. The screens covered an area of 4 feet by 6 feet and were placed 12 inches abovethe ground level. Harvests for yield comparisons on the areas thus protected were made when the grass reached maturity or when plants became dormant because of drought.

The rapidity with which grass becomes re-established after listing depends largely upon the abundance of those species which have the ability to reproduce vegetatively. Buffalo grass, under only moderately favorable conditions, rapidly increases vegetatively by means of stolons. The upper part of Fig. 26 shows a plat of buffalo grass just after it was listed in 1926. The berm left on each side of the furrows provides sufficient grass to vegetate completely the furrows and ridges in a favorable season. The lower part of Fig. 26 shows the same plat in 1937 at the end of the second growing season after listing.

Yields from listed and unlisted plats are presented in Table 18. No yields are reported from the 1932 listing for the reason that differences in soil type preclude a comparison of the 1932 yields with those obtained from treatments made in other years. During the period of 1935 to 1938

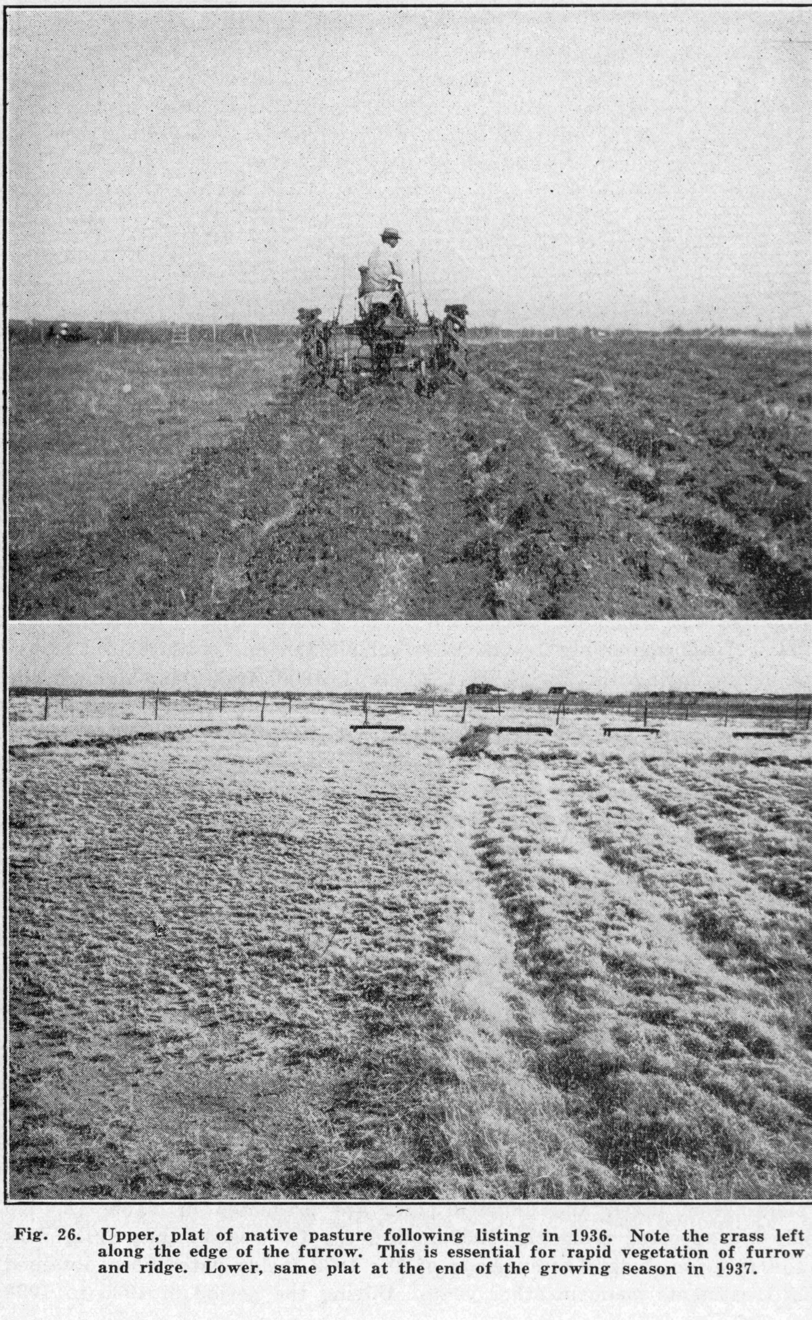

Fig. 26. Upper, plat of native pasture following listing in 1936. Note the grass left along the edge of the furrow. This is essential for rapid vegetation of furrow and ridge. Lower, same plat at the end of the growing season in 1937.

Table 18. Acre yields in pounds of air-dry grass and weeds from contour listed and unlisted grassland, 1935-1939

Treatment	1935, Grass	1936, Grass	1937		1938		1939, Grass	Average grass			
			Grass	Weeds	Grass	Weeds		1935–39	1936–39	1937–39	1938–39
Unlisted	858	592	259	30	810	403	45	513	426	371	427
Listed 1934	2424	2315	1133	76	1376	107	425	1535	1312	978	900
Listed 1936	....	1326	2159	185	1973	231	448	....	1476	1527	1210
Listed 1938	....	....	....	....	1178	491	707	....	....	....	942

an average yield of 513 pounds of air-dry grass per acre was made by the unlisted areas as compared with 1,535 pounds from the area listed in 1934. Comparable averages for shorter periods, including results from listing treatment made in later years, show that grass production was increased 2.1 to 4.1 times by listing. The highest annual yield from any one treatment, 2,424 pounds of grass per acre, was obtained in 1935 from the 1934 listing.

Yields from the plats the first year following spring listing have been consistently greater than from those not listed. The amount of grass cover destroyed during the early part of the season, as evidenced in Fig. 26, was compensated for by increased vigor, greater height, and prolonged growing season of the vegetation. In the early years of the study the increase from listing was attributed largely to the conserving of rainfall, but numerous field observations made through the years indicate that some of the increase may have been caused by the cultivation or loosening of the soil. Studies which have as their objective the isolation of some of the factors involved in this phase of the problem are now under way.

In 1935 and 1936 weeds occurred only in trace amounts and no distinction was made between grass and weeds in reporting yields for these years. Increased weed growth in 1937 and 1938, however, justified weighing and reporting grass and weeds separately. Data in Table 18 show that growth of weeds, mostly annuals, may increase the first year after listing, but these usually disappear as the furrows and ridges become vegetated with grasses. After a period of years weeds have practically disappeared on listed areas.

An interesting side light in connection with the pasture grass studies

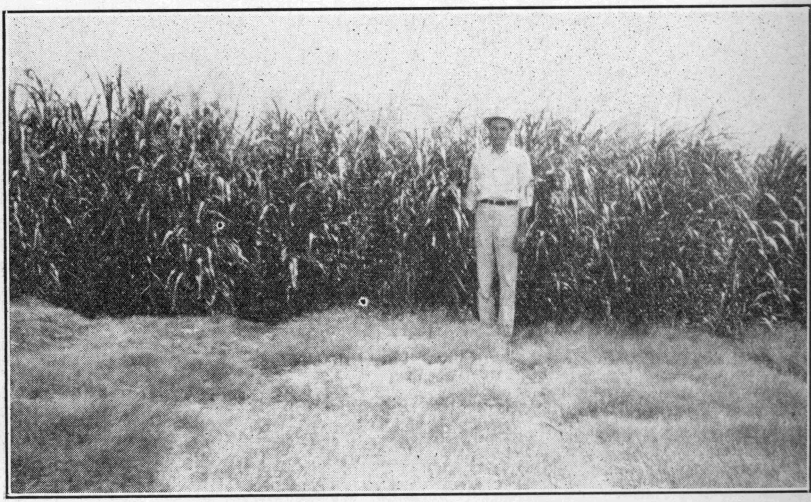

Fig. 27. Buffalo grass in the foreground produced a larger tonnage of air-dry forage than Sudan in the background. One crop of buffalo grass was harvested before Sudan was planted.

is a comparison of the yield of Sudan grass planted in 39-inch rows with the yield of buffalo grass on listed land. The average yield for 1935 and 1936, the only years in which comparisons were made, shows that buffalo grass had an advantage in yield of air-dry forage of 380 pounds per acre (Fig. 27).

Soil Moisture Content

The value of listing as a water conserving practice is revealed in the increase of available moisture and depth of penetration as shown in Table 19 by the average of monthly determinations for each year. The

Table 19. Annual and average quantities of available water in the surface 6 feet of the soil during the growing season and percentage distribution at different depths, 1937-1939

Depth of sampling, feet	Average amount of available water in the soil during the growing season, inches				Percentage of average available moisture		
	1937	1938	1939	Average	Each foot	Upper 2 feet	Lower 4 feet
Unlisted							
1.........	.86	.59	.35	.60	50.42	68.91	31.09
2.........	.39	.19	.09	.22	18.49		
3.........	.04	.08	.18	.10	8.40		
4.........	.00	.03	.16	.06	5.04		
5.........	.12	.19	.12	.14	11.76		
6.........	.00	.14	.07	.07	5.88		
Total.....	1.41	1.22	.97	1.19			
Listed 1934							
1.........	1.17	.77	.50	.81	30.80	50.57	49.43
2.........	.78	.44	.34	.52	19.77		
3.........	.62	.42	.40	.48	18.25		
4.........	.53	.26	.23	.34	12.93		
5.........	.56	.16	.06	.26	9.89		
6.........	.41	.11	.14	.22	8.37		
Total.....	4.07	2.16	1.67	2.63			
Listed 1936							
1.........	1.17	.69	.44	.77	28.73	50.00	50.00
2.........	.81	.50	.40	.57	21.27		
3.........	.78	.54	.11	.48	17.91		
4.........	.68	.37	.09	.38	14.18		
5.........	.39	.17	.06	.21	7.84		
6.........	.56	.15	.09	.27	10.07		
Total.....	4.39	2.42	1.19	2.68			
Listed 1938							
1.........	....	.75	.54	.64	32.49	54.83	45.17
2.........	....	.63	.26	.44	22.34		
3.........	....	.37	.48	.42	21.32		
4.........	....	.32	.12	.22	11.17		
5.........	....	.21	.12	.16	8.12		
6.........	....	.00	.19	.09	4.56		
Total.....	....	2.33	1.71	1.97			

average available moisture from 1937 to 1939 to a depth of 6 feet was 1.19 inch on the unlisted areas. Of this amount, 68.91 per cent was present in the upper 2 feet, while only 31.09 per cent was stored in the lower 4 feet. On grassland that was listed in 1934, 2.63 inches of available water was stored in the soil. The upper 2 feet contained 50.57 per cent of the moisture and the lower 4 feet contained 49.43 per cent. A similar increase in the supply of available moisture and in penetration was obtained on land listed in 1936 and 1938.

On numerous occasions following heavy rain periods noticeably increased moisture penetration occurred on the listed pasture areas. Determinations made before and soon after a heavy rain period in 1936 showed that the average moisture penetration was to a depth of 72 inches on the listed plats as compared to 30 inches on the unlisted, and the amount of available moisture stored was 6.67 and 2.10 inches, respectively. Fig. 28 shows accumulation of water in the furrows and the difference in penetration of moisture on listed and unlisted areas following a rain of 1.73 inch in January 1939.

Measurements made at the end of the 1938 growing season show that the following amounts of rain falling on each listed area would be retained in the furrows without allowing for any penetration: 1932 listing, .80 inch; 1934 listing, .84 inch; 1936 listing, .95 inch; 1938 listing, 1.03 inch. Although the furrows form only a small reservoir, the combined effect of a high infiltration rate and the furrows' serving as a catchment basin is to increase materially the opportunity for the penetration of large amounts of water. It is evident that with the passing of time the retentive capacity of the furrows is somewhat reduced by slowly accumulating soil sediment.

Basal Cover and Composition of Cover

Measurements of basal cover were made on meter quadrats on each plat during the growing season. The pantograph-chart method was used since it is well adapted for use in a study of the short grasses and open sod type of the other grasses. The percentage of basal cover and percentage of total cover occupied by each species were determined from the charts by means of a planimeter.

A distinct change occurred in the basal cover and composition of native vegetation following listings made in 1932 and 1934. To obtain definite information regarding those changes, 5 quadrats were located at representative points on each plat and charted in 1937 and 1938. The basal cover represents that portion of the soil surface covered by living plants. Where plant parts were less than 1 cm distant, the area was considered as being fully covered.

The most outstanding change in cover was the increase in buffalo grass following listing treatments. The average basal cover of this grass in 1937 and 1938 was 14.02 per cent on unlisted grassland and 64.96 per cent on grassland listed in 1934 (Table 20). Similar increases in cover of buffalo

Fig. 28. Upper, water held in lister furrows following a rain of 1.73 inches. Lower, moisture pentration on listed and unlisted pasture land following this rain. No run-off occurred on listed grassland.

Table 20. Average percentage, 1937 and 1938, of basal cover and total cover of native vegetation on contour listed and unlisted grassland

Species	Common name	Unlisted		Listed, 1934		Listed, 1936		Listed, 1938	
		Basal cover	Total cover	Basal cover	Total cover	Basal cover	Total cover	Basal cover	Total cover
Grasses:		21.46	68.83	70.28	94.17	75.60	93.16	48.30	91.60
Buchloe dactyloides	Buffalo grass	14.02	44.96	64.96	87.04	66.60	82.07	44.94	85.23
Bouteloua gracilis	Blue grama	.78	2.50	2.18	2.92	1.41	1.74	.60	1.14
Aristida purpurea and A. Roemeriana	Purple three awn	4.23	13.57	1.62	2.17	4.74	5.84	1.84	3.49
Hordeum pusillum	Little barley	.80	2.57	.56	.75	2.24	2.76	....	....
Schedonnardus paniculatus	Tumblegrass	.96	3.08	.52	.70	.20	.25	.60	1.14
Others	....	.67	2.15	.44	.59	.41	.51	.32	.61
Weeds:		5.41	17.35	2.60	3.48	3.13	3.86	4.43	8.40
Plantago spinulosa and P. Purshii	Indian wheat	3.46	11.10	1.62	2.17	1.34	1.65	....	....
Ledpidium densiflorum	Pepper grass	1.16	3.72	.08	.11	.38	.47	....	....
Verbena bipinnatitida	Wild verbena	Trace	Trace	.04	.05	Trace	Trace	....	....
Others	....	.79	2.53	.86	1.15	1.41	1.74	4.43	8.40
Undesirable weeds:		4.31	13.82	1.75	2.34	2.42	2.98	....	....
Actinea odorata	Bitterweed	3.82	12.25	.17	.23	.47	.58	....	....
Senecio longilobus	Threadleaf grounsel	.15	.48	.94	1.26	.41	.51	....	....
Others	....	.34	1.09	.64	.86	1.54	1.90	....	....
Total basal cover, per cent	....	31.18	....	74.63	....	81.15	....	52.73	....
Unprotected soil, per cent	....	68.82	....	25.37	....	18.85	....	47.27	....

grass were obtained from the treatments made in 1936 and 1938. It is also of interest that only 44.96 per cent of the total cover of the vegetation on the unlisted grassland was buffalo grass, as compared to 87.04 per cent on the area listed in 1934, 82.07 per cent on the area listed in 1936, and 85.23 per cent on that listed in 1938.

Listing has brought about only minor changes in the basal cover of the other grasses. Little barley (Hordeum pusillum) appears to increase the first year following listing but is gradually replaced by perennial grasses. The cover of purple three awn, which has a low palatability to most classes of livestock, seems to decrease gradually over a period of years after listing. Grassland that was listed in 1932 and 1934 shows a reduction in cover of purple three awn, while the cover of this species on grassland listed in 1936 has remained practically the same. In all cases, however, the percentage of cover provided by purple three awn in comparison to the total vegetative cover has been reduced by listing.

The basal cover of all weed species, especially that of Indian wheat, peppergrass, and bitterweed, has been appreciably reduced by listing. The marked reduction of bitterweed is of particular importance to stockmen, since this plant is poisonous to sheep.

Observations over a period of years indicate that terraces and pasture ridges spaced at wide intervals are less effective in giving a uniform distribution of moisture and increased yields of grass than solid listing. The ridges tend to remain dry and unfavorable to vegetation by turf grasses while the terrace channels are often taken by weeds and weedy grasses because of heavy accumulations of water and severe destruction of sod.

Underground Plant Materials

In making determination of root volume and weight, a column of soil 15 inches square and 66 inches deep was removed in 6-inch layers, and the roots carefully removed from the blocks by washing the mass over a fine screen with a spray of water. The determinations of volume were made while the roots were water soaked, but excess water was removed from the root surfaces with blotters.

Determinations of root volume and weight were made at two locations selected at random on an unlisted area and on the area listed in 1934. Roots were reported by weight on oven-dry basis and by volume in cubic centimeters of water displaced (Table 21). The root system was 63.63 per cent greater in volume and 78.91 per cent greater in dry weight from the listed than from the unlisted plat. Likewise, the maximum penetration of roots was to a depth of 66 inches and 44 inches on the two plats, respectively.

A visual representation of the amount of roots found at different depths is shown in Fig. 29. The slightly darker shade of color of the roots from the unlisted plat is the result of the large number of dead roots found in the mass. Since roots exist in the soil in all stages of decomposition, it

Table 21. Volume and weight of underground plant materials from contour listed and unlisted grassland, 1936

Depth, inches	Water displaced, c.c.		Oven-dry material, grams	
	Listed*	Unlisted	Listed*	Unlisted
1–6	464	259	95.14	45.14
8–14	60	56	11.33	10.49
16–22	27	25	7.19	7.03
24–30	15	13	3.87	3.78
34–40	12	10	1.96	1.34
42–48	9	Trace	1.38	.11
50–56	6	0	.52	0.0
60–66	1	0	.07	0.0
Total	594	363	121.46	67.89
Increase, per cent	63.63	....	78.91	

*In 1934.

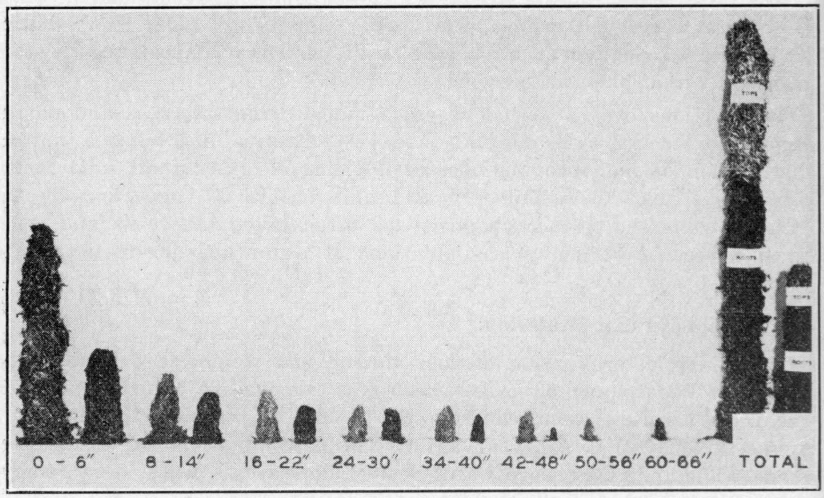

Fig. 29. Showing the roots washed from a layer of soil 15 inches square and 6 inches deep on listed and unlisted grassland. These treatments are shown in Fig. 26 and data on amounts of roots in Table 21. Water conservation on grassland causes a deeper penetration of roots, a larger mass of roots, and fewer dead roots in dry years. This root material was collected at the end of a dry summer and most of the roots from the unlisted area were dead as shown by the darker color. Over a mile of roots have been found under a square foot of good buffalo grass.

is not to be expected that all of the underground materials are living; however, at every depth the unlisted land has a much higher proportion of dead materials than that which was listed. The roots from the listed plat were relatively free from dead materials and for the most part appeared to be in a vigorous growing condition.

The amount of plant materials and the ratio of roots to tops are shown in Table 22. The weight of roots from either of the treatments far exceed the weight of forage. The ratio of tops to roots on listed and unlisted plats is 1:3.50 and 1:6.38, respectively. In the case of the unlisted plat the ratio of tops to roots is wide, probably recause of the larger proportion of dead roots present.

Table 22. Amount and ratio of oven-dry plant materials from contour listed and unlisted grassland, 1936

Treatment	Oven-dry materials per acre, tons			Ratio of tops to roots
	Dry grass	Roots*	Total	
Listed in 1934	1.066	3.732	4.798	1:3.50
Unlisted	.327	2.086	2.413	1:6.38

*Depth, 66 inches.

Difference in ability of plants to use water

The ability of plants to withdraw water from the soil possibly influences run-off and erosion to a greater extent than do canopy, organic matter or other mechanical obstructions furnished by the aboveground plant parts. This is illustrated in Fig. 30, which shows the average available water to a depth of 5 feet on contoured grassland and contoured cotton

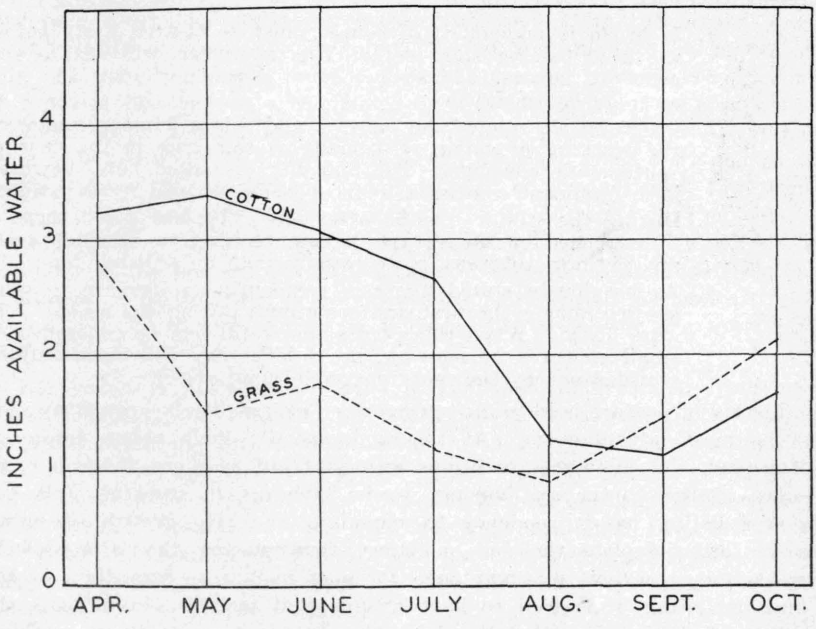

Fig. 30. The seasonal use of soil water by cotton and native grass on contour listed areas, 1937 to 1939. Possibly no other plant can use as large quantities of water over a long growing period as grass.

land from 1937 to 1939. With approximately the same amount of available water in the soil in early spring, the grass drew heavily on the reserve moisture during April while the cotton used little water until July. The grass made room in the soil for the relatively heavy spring rains that centered in May.

The disposal of excess water from cultivated fields where plants that are sluggish in the use of water are being grown is an important problem in run-off and erosion control. Opportunities for using some or all of this excess water are frequently close at hand. Perennial pasture and meadow grasses seldom have sufficient water for maximum plant growth throughout the growing season and will, in many cases, respond to flood water from cultivated fields. A close-growing, fibrous-rooted crop capable of using large quantities of water in seasons of the year when row crops use little or no water may furnish the answer in strip-cropping practices in row crop regions.

Some General Observations on Listing

The foregoing discussions have had to do with a specific method of pasture management and the benefits accruing therefrom. In justice to those who wish to follow the procedure that has been outlined or any variation of it, it is well to state here some of the objectionable features of this method of range or pasture improvement that have been observed during the past 8 years.

1. If brush is present, it of course must be cleared away before the land can be solid listed. This operation will cost a few cents to several dollars per acre, depending upon the kind and density of brush.
2. On extensive ranges the furrows and ridges hamper somewhat the working of cattle. Especially is this true in the case of "automobile cowboys." The difficulty presented here, however, is insignificant compared to the benefits derived from listing.
3. During the winter months after the grass has cured there is a tendency for the forage in the furrows to become musty and perhaps to decay more rapidly than on unlisted land.
4. As previously stated, there is frequently an increase in weed growth during the first and sometimes during the second year after listing. When this occurs the weeds can be controlled on small pastures by mowing, or, if left, they will eventually be crowded out by the more desirable plant species.

Listing of pasture land in the spring when grasses begin growth appears to be most advantageous. At this time usually little or no forage is destroyed, soil moisture conditions are likely to be more favorable and many of the winter and spring weeds have ceased growth. Fall and winter listing has a tendency to stimulate an early growth of weeds which often deplete the soil moisture, thus placing the later-growing grasses at a serious disadvantage. In most instances, regardless of the time of listing, it is well to have a supply of moisture in at least the surface foot of soil so that the desirable grasses may rapidly re-establish themselves and crowd out weeds.

Buffalo Grass Selections

In the spring of 1934 eighty-eight selections of buffalo grass were set out in the grass nursery. The location of this area is such that it receives considerable flood water during rain periods, thus making an almost ideal condition for the growth of grass. By mid-summer of 1935 the plants had covered the 25 square feet allotted to each. Data on yield and vegetative characteristics have been taken each year. Only 3 of the selections were harvested in 1935, and the yield of these selections through 1939 is shown in Table 23. It will be seen that in the second year after sodding

Table 23. Yield of air-dry forage from buffalo grass selections, pounds per acre

Selection number	1935	1936	1937	1938	1939	Average
2-9	7,818	6,900	2,059	2,730	0	3,901
4-8	9,665	7,427	5,793	3,525	0	5,282
7-7	12,336	8,650	6,165	5,896	0	6,609
Average	9,940	7,659	4,672	4,050	0	5,264

one of the selections produced at the rate of 12,336 pounds of air-dry grass per acre. The average yields of the 3 selections show also that there has been a gradual decline in grass production after the second year. The quantity of grass produced in 1939 was too small to be harvested, but this was due largely to conditions of extreme drought. The decline in grass production was accompanied by a decline in vigor of plants, loss of basal cover, shorter seed stalks and shorter growth of grass. It has been observed since 1915 that when lawns or other areas were sodded to buffalo grass the grass would reach a peak of production a few years after sodding and then after a period of 8 to 10 years die out almost completely. No exact explanation for the occurrence of this condition is available at the present, but on the basis of the results obtained from the treatment of pasture land it is evident that cultural and mechanical treatments play an important part in reviving and promoting the growth of buffalo grass.

The yields of buffalo grass seed in 1937 and 1938 ranged from over 3,000 pounds per acre to less than 200 pounds. The weight of 100 seed from the selections varied from 1.06 gram to .27 gram. Studies made in 1937 show that out of 1,500 burs or spikes from 30 selections 17.07 per cent contained no caryopses (the grains or kernels enclosed in the spike), 28.13 per cent contained one, 42.13 per cent contained two, and 12.67 per cent contained three or more. The per cent germination under laboratory conditions was from zero to 28.00 per cent, with an average for all selections of 10.24 per cent.

The variations observed in height and character of foliage, color of leaves, pollen and seed production, and seasonal growth of individual

Fig. 31. A view of buffalo grass selections showing staminate (male) plants in bloom. The pistillate (female) plants produce seed just above the surface of the soil.

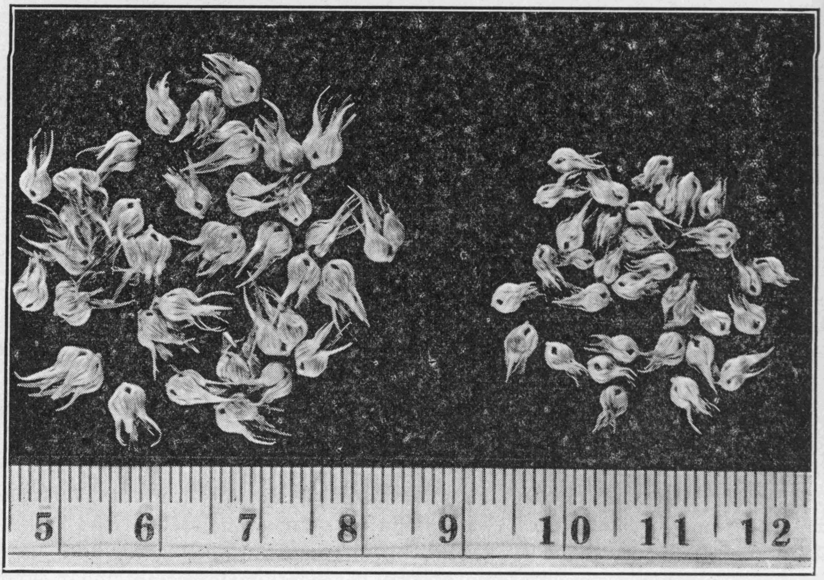

Fig. 32. Showing the variation in size of burs produced by two selections of buffalo grass (centimeter scale). Similar differences exist in weight of seed, character of growth, yields, and height seed is produced above the ground.

selections indicate that buffalo grass is composed of many types, each of which may become more or less prominent under certain environmental conditions and that by selection definite types of plants may be isolated that are particularly suited to special conditions.

Sodding and Seeding Native Grasses

Native grasses are easily transplanted, and with a little care a very high percentage survive. When 4- to 6-inch cubes of buffalo grass sod were transferred to cultivated land and given a good watering, less than 5 per cent failed to survive. Bunch grasses have been transplanted as successfully as sod grasses. Spring is possibly the best season of the year for transplanting grasses; however, they have been moved successfully at all seasons of the year at the Spur Station. With favorable moisture conditions, buffalo grass sodded on 3-foot centers developed a solid turf during one growing season.

Many attempts have been made during the period 1935 to 1939 to re-establish buffalo and blue grama grasses on grassland, abandoned fields and nursery plats. Seed have been broadcast, drilled, spread with manure and straw from a manure spreader, planted in rows with cotton planters and planted by hand. Satisfactory stands have been obtained only when land was placed in a good state of cultivation, and when moisture conditions were favorable at planting time and for several weeks following germination.

Selections and strains of the more important species of grasses which occur under pasture and range conditions in this region were obtained locally and also from various sections of the Great Plains and seeded in the spring of 1938.

Observations made in 1938 and 1939, both very dry years, showed that selections of little blue stem, big blue stem, side-oats grama, buffalo grass, Indian grass, switch grass, and sand dropseed from northern areas tended to have heavier basal cover, finer leaves and stems, were relatively early maturing but lacked vigor and drought and heat resistance when compared to those of local or southern origin. This is especially true when compared with selections from Southern Texas, New Mexico, and Arizona. These observations indicate that for re-seeding purposes native grass seed, in most instances, should be obtained locally or from southern portions of the Great Plains rather than from the northern portions.

Effect of Different Clipping Treatments on the Yield and Chemical Composition of Buffalo and Blue Grama Grasses

In the spring of 1937, eighteen plats 5 feet square were seeded to buffalo grass and a like number to blue grama. By covering the plats with burlap and sprinking frequently with water excellent stands were obtained. Clippings at different heights and frequencies were made in 1938 and 1939 to determine the effect on the yield, chemical content and basal cover of these two grasses. The clippings were made with mule shears. In some instances the plants failed to make sufficient growth and clippings were not obtained.

Yields.—Removing the vegetation at intervals of eight weeks at a height of ½ inch above the ground produced the highest yield, 3616 pounds of air-dry buffalo grass per acre, and blue grama produced the highest yield, 4,040 pounds, when clipped once at the end of the season. The lowest yield of both grasses was obtained from plats clipped every 2 weeks at a height of ½ inch and from those clipped every 4 weeks at a height of 1½ inch. There were no marked differences in average yields when clippings were made at a height of ½ inch at intervals of 4 weeks, 8 weeks, twice each year, or once at the end of the season. The average yield of the 18 plats for the two years was 3,182 pounds of air-dry buffalo grass per acre as compared to 3,153 pounds for blue grama (Table 24).

Table 24. Effect of clipping at different heights and frequencies on the annual and average yield of buffalo and blue grama grasses, 1938 and 1939

Frequency of clipping	Height of clipping, inches	Acre yield, pounds of air-dry grass								
		Buffalo grass			Blue grama			Average Buffalo & blue grama		
		1938	1939	Ave.	1938	1939	Ave.	1938	1939	Ave.
Two weeks....	1/2	4970	241	2606	5291	280	2786	5130	260	2695
Four weeks....	1/2	6692	333	3512	6674	229	3452	6683	281	3482
Four weeks....	1 1/2	4265	265	2265	4684	458	2571	4474	362	2418
Eight weeks...	1/2	7468	208	3838	6665	125	3395	7066	166	3616
7/19, 11/22...	1/2	7396	65	3730	5273	80	2676	6334	72	3203
11/22.........	1/2	6147	137	3142	7807	274	4040	6977	205	3591
Average.......	....	6156	208	3182	6066	241	3153	6111	224	3168

Chemical Composition.—Clippings obtained during the spring, summer, and fall were made into composite samples for each treatment in 1938 and the air-dry plant materials analyzed for crude protein, ether extract, ntrogen-free extract, crude fiber, ash, lime, and phosphoric acid.

The chemical content of buffalo and blue grama grasses was essentially the same and the data will be discussed together (Table 25). The vegetation clipped at intervals of two weeks had the highest protein, ether extract, and phosphoric acid contents. The nitrogen-free extract increased inversely with the frequency of clipping, with the highest percentage occurring in grass harvested once at the end of the season. The percentages of ash, crude fiber, and lime apparently were not greatly affected by clipping treatments.

The protein and fat contents were highest during the spring, April 1 to June 10, somewhat lower in the summer, June 11 to August 19, and reached a low point for the season in the fall, August 20 to November 22. On the other hand, the crude fiber, ash, and nitrogen-free extract increased

Table 25. Chemical analysis of air-dry buffalo and blue grama grasses clipped at different heights and frequencies in 1938

Nutrients	Frequency of clippings													
	Spring				Summer					Fall				
	2 wks.	4 wks.	4 wks.*	8 wks.	2 wks.	4 wks.	4 wks.*	8 wks.	Mid-season	4 wks.	4 wks.*	8 wks.	Mid-season	Season
Buffalo Grass														
Total dry matter	94.11	93.96	94.16	94.03	93.50	93.57	94.08	94.07	92.67	....	92.76	....	92.75	92.82
Protein	16.05	13.45	12.83	11.03	13.60	11.75	11.19	10.54	8.17	....	6.63	....	7.90	6.60
Fat	1.78	1.70	1.62	1.61	1.79	1.68	1.61	1.46	1.22	....	2.05	....	1.59	1.22
Crude Fiber	22.49	23.28	22.74	24.67	23.44	23.17	23.01	23.78	23.17	....	22.30	....	22.59	23.41
Nitrogen-free extract	42.27	44.37	44.34	45.94	42.60	45.42	46.96	46.30	47.22	....	48.95	....	49.70	47.31
Ash	11.52	11.16	12.63	10.78	12.07	11.55	11.31	11.99	12.89	....	12.83	....	10.97	14.28
Lime—CaO	.48	.54	.60	.51	.58	.61	.67	.64	.54	....	.70	....	.51	.47
Phosphoric acid–P_2O_5	.58	.49	.47	.42	.60	.52	.53	.47	.36	....	.29	....	.24	.27
Blue Grama														
Total dry matter	94.26	94.25	94.34	94.31	93.55	93.48	93.63	93.57	93.68	93.30	92.94	92.81	92.78	92.80
Protein	15.10	13.10	13.21	12.17	14.12	12.15	11.80	10.93	8.81	9.18	7.77	9.32	7.28	6.35
Fat	1.56	1.50	1.47	1.58	1.43	1.49	1.39	1.42	1.39	1.35	1.42	1.34	1.25	1.28
Crude Fiber	24.92	25.55	25.36	24.98	28.47	28.72	28.77	29.15	28.96	24.79	26.43	25.51	26.32	28.57
Nitrogen-free extract	42.71	44.49	44.17	46.37	39.48	41.26	42.59	42.56	44.85	46.98	46.71	45.69	46.73	44.99
Ash	9.47	9.61	10.13	9.21	10.05	9.86	9.08	9.51	9.67	11.00	10.61	10.95	11.20	11.63
Lime—CaO	.49	.57	.61	.54	.46	.54	.59	.45	.45	.59	.61	.52	.49	.38
Phosphoric acid–P_2O_5	.48	.44	.47	.42	.58	.53	.52	.48	.41	.26	.26	.23	.24	.22

*Plats clipped at a height of 1½ inch, all other clipped at ½ inch.

gradually from a low point in the spring to the highest amount in the fall. The phosphoric acid tended to remain constant during the spring and summer but decreased markedly in the fall. Lime remained about the same throughout the season.

The short duration of this study does not reflect the cumulative effects of different clipping treatments on yield, basal cover and vigor of plants but does indicate that frequent removal may reduce the total production for the season. On the other hand, removing the herbage at intervals of about 8 weeks produced the highest yields of dry matter. It appears very likely that grazing to simulate clipping at intervals of approximately 8 weeks will produce the highest amount of nutrients when yield and chemical composition of the vegetation are taken into consideration.

WATER CONSERVATION ON FARMSTEADS, PARKS AND HIGHWAYS

Many of the principles of water conservation that have been discussed with special reference to crops and grassland are equally applicable to

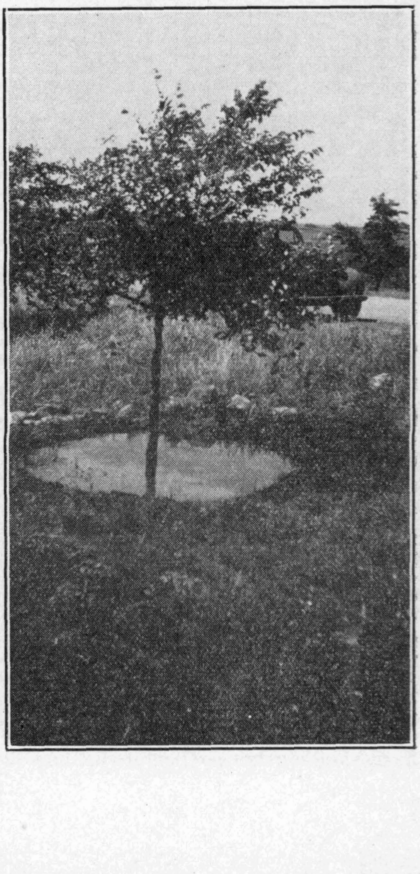

Fig. 33. The State highway beautification program is benefited by intelligent conservation of run-off water from the pavement.

gardens and orchards. Urban communities, schools, churches, parks and farmsteads offer splendid opportunities for water conservation in beautification programs.

The State Highway Department is already making extensive use of the water along the highways in growing trees and shrubs. Fig. 33 shows Chinese elms planted on a very steep, gravel slope where the production of any vegetation is most difficult. A quarter of an inch of rain on the nearby pavement fills the water catchment near this elm tree.

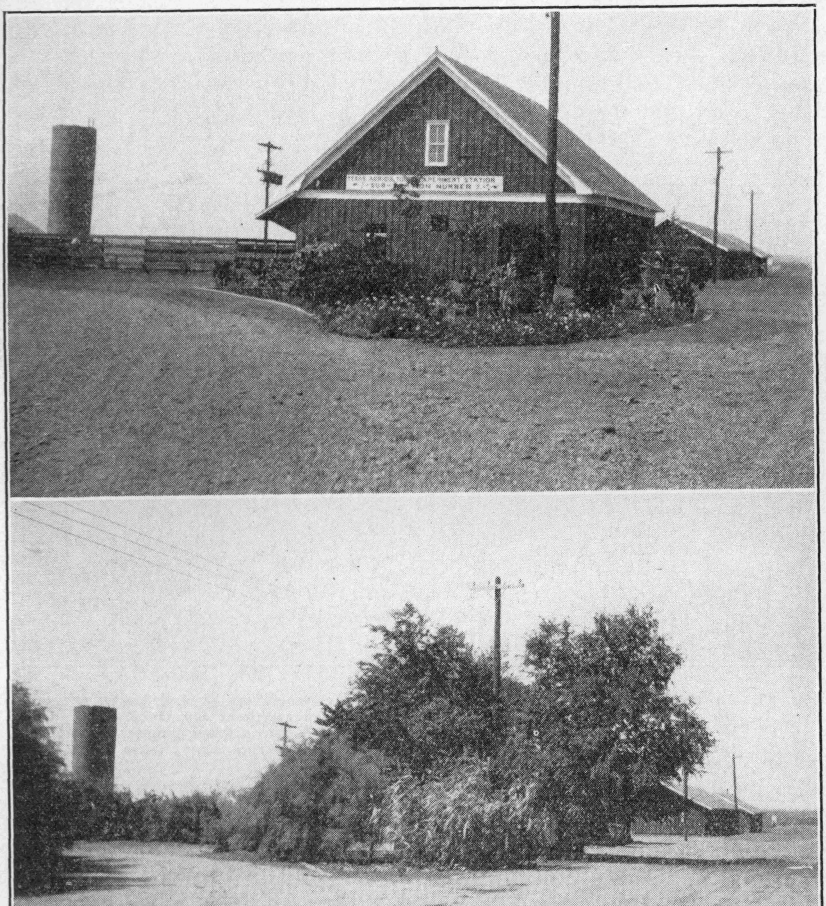

Fig. 34. At the Spur Station trees and shrubs were planted in a sunken bed to hide the barns from the main entrance. The above photographs show the site before planting and 6 years after planting. Irrigation consisted of water that drained off the gravel driveway.

Many thousands of trees have been planted in West Texas in recent years in parks along the highway and on the farmsteads and little embankments made on the lower side hold the water until it has time to penetrate. At the Spur Station, trees and shrubs were planted in a sunken bed to hide the barns from the main entrance. Fig. 34 shows the planting at the time it was made in 1930 and the same view 6 years later. The run-off from the gravel driveways on the Station is diverted into this small water trap, and it is estimated that some 50 to 60 inches of water per year soaks into the soil for the benefit of this planting.

Officers of the Methodist Church at Spur calculated the value of the rainfall on their churchyard, at the prevailing municipal water rate in Spur, to be $87.50 per year. The churchyard was terraced so as to hold all the water and there has been no run-off since 1933. It is one of the beauty spots of West Texas (Fig. 35).

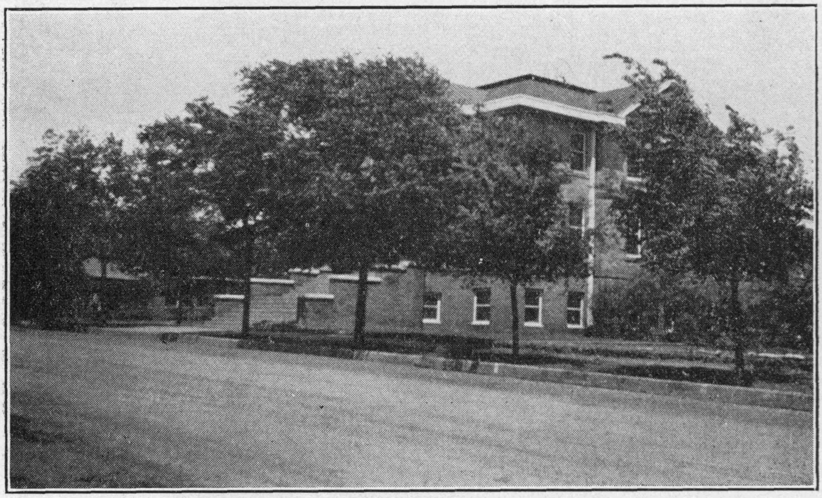

Fig. 35. In the Methodist churchyard at Spur, the concrete walks and curbs are on the same level, making a water catchment between them for trees. The yard is terraced so as not to lose a drop of water. The church people calculated that the value of the rainfall on this churchyard, if run through the municipal water meter, had a value of $87.50 yearly.

One of the practical methods of water conservation in urban communities that is coming into rather general usage is to build the street curb and the sidewalk on the same level and to use the rainfall falling on the sidewalk to irrigate the space between the walk and the curb. This practice doubles the efficiency of the rainfall in growing trees and shrubs.

There is an unlimited opportunity in beautifying Texas, when the rainfall is used to the best advantage, in the production of trees, shrubs and annuals. The communities and individuals that do not have access to a reserve water supply for irrigation may do much in conserving water in the soil from the rains as they occur. The people of the cities and towns may also do much to reduce the water used in irrigation by conserving the rainfall.

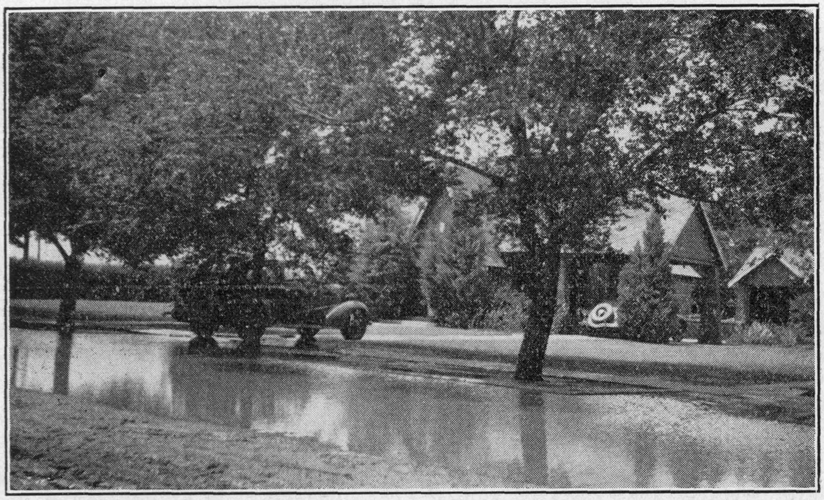

Fig. 36. The owner of this home in Spur refuses to let the City Commission install drainage to take this rain water away. It soaks into the soil within 24 to 48 hours and is used by these beautiful Chinese elms.

SUMMARY

A report is given of the results of 14 years' work at Substation No. 7, Spur, Dickens County, Texas, in a study of factors influencing run-off and erosion and the effect of conservation practices on plant growth. The station is located in the Rolling Plains of Texas, and the results are directly applicable to parts of 44 counties and 14 million acres of soils of the Miles, Abilene and related soil series and indirectly applicable to all of the sub-humid portion of Texas.

The average annual rainfall for the 29-year period, 1911 to 1939, is 20.78 inches. Violent fluctuations have occurred ranging from 11.09 inches in 1924 to 38.08 inches in 1926. Over 80 per cent of the rainfall comes during the growing period of summer crops and is usually adequate for producing good crops if conserved.

Wet years have not always been the best crop years. Dry years following wet years have frequently been excellent crop years. One of the best cotton crops produced on the station and in the county was in 1924, the year having the smallest rainfall on record. There was, however, heavy rainfall during the preceding fall months.

During the last 29 years there have been 64 rain periods in which the rainfall amounted to more than 2 inches. These rains furnished excellent

opportunities for conserving water. Thirty-three of these 64 rain periods occurred during August, September and October and were of especial value in replenishing subsoil moisture.

Total rainfall and torrential rainfall by no means constitute an absolute standard from which run-off may be calculated.

During the 14-year period, 1926 to 1939, the erosion from a plat with 2 per cent slope and planted to cotton was at the rate of 89.74 tons per acre, 52 per cent of which occurred in six rain periods.

On fallowed plats with a 2 per cent slope cultivation has decreased the average annual run-off by 1.49 inches and soil losses by 2.26 tons.

The average annual run-off from plats with a 2 per cent slope has been 1.04 inches from grass, 2.22 inches from milo, 3.09 inches from cotton, and 4.09 inches from fallow. Soil losses have been in practically the same ratio as water losses.

The average annual run-off from level terraces with the ends open has been .72 inch, and the yield of cotton has been 129 pounds of lint per acre. From an area having terraces with a 3-inch fall along the terrace the run-off was 2.12 inches and the yield of lint cotton per acre was 99 pounds.

The average run-off from areas with rows running with the slope was 1.41 inches, from areas having contoured rows .88 inch, and from closed level terraces there was no run-off. The average yield of lint cotton per acre was 102, 123 and 150 pounds, respectively. The gross acre returns per year over a 13-year period were increased $2.44 by contouring the rows and $6.21 by the use of closed level terraces.

The amount of available water in the upper 3 feet of soil has been determined on the 20th of each month from April through September since 1931. The greatest amount of water occurred on May 20 and the least on August 20. Field areas having rows with the slope had an average of 2.25 inches of available water throughout the summer period, areas having contoured rows had 2.51 inches, and areas with closed level terraces had 2.95 inches.

Storing preseasonal rainfall in the soil for use of crops during the dry mid-summer is of utmost importance in the region. A close relationship exists between the available water in the soil at planting time and the yield of lint cotton. The average yield of lint was 229 pounds per acre with more than 4 inches, 187 pounds with 3 to 4 inches, 85 pounds with 2 to 3 inches, and 16 pounds when there was less than 2 inches of available water in the soil at planting time.

By diverting the run-off from a 1,200-acre watershed onto a 120-acre syrup pan terrace system the water for use on the system has been increased approximately 16 per cent, and crop yields have been increased 2 to 3 times. The sorghums and sorgos apparently can use this extra water to a better advantage than some of the other row crops.

On small fallowed areas bordered to prevent run-off the evaporation from the soil surface during 1937, 1938 and 1939 was 70.47 per cent of the rainfall of the 3 years.

The rainfall from April through December 1939 was 10.31 inches. Only 3.31 inches of this on sandy loam soil and 1.84 inches on clay loam soil penetrated to a depth of 2 inches. Opportunities for surface evaporation throughout the year were very high.

Mesquite brush on range land presents a serious problem in that the amount and quality of grass is reduced by shading and by competition for moisture.

On grassland solid listed on contours, increases in available soil moisture and depth of penetration have been reflected in higher yields of grass, greater basal cover, and the tendency of the listed areas to remain green longer during periods of deficient rainfall. Areas listed in 1934 have yielded an average of 1,535 pounds of air-dry grass per acre as compared with 513 pounds from unlisted areas.

The variations observed in height and character of foliage, color of leaves, pollen and seed production, and seasonal growth of individual selections of buffalo grass indicate that this grass is composed of many types, each of which may become more or less prominent under certain environmental conditions and that by selection definite types of plants may be isolated that are particularly suited to special conditions.

Sodding has been done successfully with most species of native grasses, but seeding has been successful only under the most favorable conditions of soil moisture and temperature.

Clipping experiments with native grasses indicate that removal of the herbage at intervals of approximately 8 weeks will produce the largest amount of nutrients when both yield and chemical composition of the vegetation are taken into consideration.

In brief, the chief aim of water conservation at this station is to develop a flexible system of water management on agricultural and range land that will reduce risks due to adverse climatic conditions and tend to stabilize production through periods of deficient rainfall. This applies not only in years such as 1934 when rainfall was below normal every month but also to the mid-summer depression of rainfall which occurs over all parts of Texas in almost every year.

The endeavor to store water when and where it falls and to supplement this with flood water from waste land and thus to build up a reserve supply is one that pays large dividends for the time and effort expended.