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Conservation and Utilization of Soil Moisture

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UNITED STATES DEPARTMENT OF AGRICULTURE

The TEXAS AGRICULTURAL AND MECHANICAL COLLEGE SYSTEM
GIBB GILCHRIST, Chancellor

THE FRONT COVER PICTURE

Aerial photo of the Spur station 12 hours after a highly torrential rain of 2.54 inches on June 19, 1946.

← Farmstead which does not show.

(2) Ten-acre cotton field with rows up and down the slope. Note accumulation of runoff at lower end of field.

(3) Ten-acre field with contour rows and closed level terraces. Note uniform distribution of water over field.

(4) Field area that received runoff water from a 300-acre water-shed.

(5) Shows location of highway culvert that drains water onto station land.

(6) Water from land with a slope of 1 to 2 percent broke terraces and later spread over field area 8.

(7) Land with 0.5 percent slope that did not get wet because of heavy runoff.

(8) The syrup-pan terrace system made maximum use of flood waters from a 1,200-acre watershed.

(9) Land devoted to production of wheat and sorghums. The slope varies from 1 to 3 percent.

(10) Experimental grazing pastures.

(11) Mesquite control studies, including grazing trials on cleared and uncleared pastures.

ACKNOWLEDGMENTS

The authors wish to make acknowledgment to the late R. E. Dickson, formerly superintendent of Substation No. 7, for the development and supervision of the early phases of research on moisture conservation; to B. C. Langley, former agronomist, for his valuable assistance and suggestions; and to W. F. Turner, former agronomist, and P. T. Marion, associate animal husbandman, who have assisted with certain phases of the studies.

Acknowledgment also is made of support received from the Soil Conservation Service, U. S. Department of Agriculture, in certain phases of this study from 1936 through 1945.

DIGEST

Conservation and utilization of moisture is of major importance on the heavy soils of the Rolling Plains since water is the principal limiting factor affecting crop production. Research by the Texas Agricultural Experiment Station, Substation No. 7 near Spur, reported in this bulletin, shows that the amount and character of rainfall, soil type, plant residues, slope of land, tillage and conservation practices are the factors that largely govern the amount of water that is stored in the soil for plant use.

Contouring and terracing to prevent runoff and erosion have significantly increased the amount of available moisture in the soil and the yield of cotton from it. The use of flood waters, crop residues and tillage offer additional means of increasing the amount of water that is stored for plant use.

Preseasonal rainfall from November 1 to June 1 and seasonal rainfall from June 1 to October 31 provide general information on the moisture content of the soil for an area. Measurement of the amount of water stored in the soil, or the depth of moisture penetration, gives a reliable index of soil moisture which may be used by the farmer on his individual farm.

The close relationship between the amount of available moisture stored in the soil at planting time and the yield of cotton indicates that a high moisture content in the soil is followed by a high yield and a low content by a low yield. Thus, the amount or depth of moisture may be used as a guide to probable cotton yields on the heavy soils of the region. The knowledge of likely crop prospects based on moisture stored in the soil offers a means of adjusting cropping plans and farming operations to make the best use of available moisture.

These findings show that every effort should be made to use conservation practices that will bring about a greater storage of moisture in the soil to help stabilize crop production and to reduce the hazards of farming in a 20-inch rainfall belt.

CONTENTS

Conservation and Utilization of Soil Moisture

C. E. Fisher and Earl Burnett *

CROP PRODUCTION on the Rolling Plains of West Texas is governed largely by the amount of water that is available for plant growth. Soil fertility is seldom a factor in crop production on the heavier soils that occupy much of the area. The sandy soils of the area are usually lower in fertility and occasionally respond to soil fertility practices when rainfall is above normal (8, 10).[1]

In most years, rainfall is adequate for the production of crops but erratic distribution, with torrential rains followed by long dry periods, make it desirable to conserve a maximum amount of water for crop use. The soils generally are relatively porous, deep and have ample water holding capacity to store large amounts of rainfall for plant use if steps are taken to prevent heavy runoff and to reduce evaporation. The use of conservation practices, contour planting in combination with closed level terraces, diverting and spreading of flood water and other related practices has significantly increased the depth of moisture penetration and the amount of water stored in the soil. This additional accumulation of moisture has materially increased the yields of crops and reduced the hazards of farming.

Major emphasis in this bulletin is placed on factors that influence the accumulation and utilization of soil moisture. Results of 27 years of research at Substation No. 7 on moisture conservation are reported. Early work on runoff and water conservation on the Rolling Plains was published by Conner, Dickson and Scoates (1) and Dickson, Langley and Fisher (3). These findings are directly applicable to some 14 million acres of heavy soils on the Rolling Plains and indirectly to heavy soils in other regions where lack of moisture limits crop production.

Water conservation research at Spur includes factors that influence the accumulation of soil moisture by reduction of runoff and evaporation, the utilization of soil moisture by crops, the relationship between available moisture in the soil at planting time and the yield of cotton, the effect of preseasonal and seasonal rainfall on the yield of cotton and the effect of conservation practices on cotton production, runoff and available soil moisture.

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[1]Numbers in parentheses refer to literature cited.

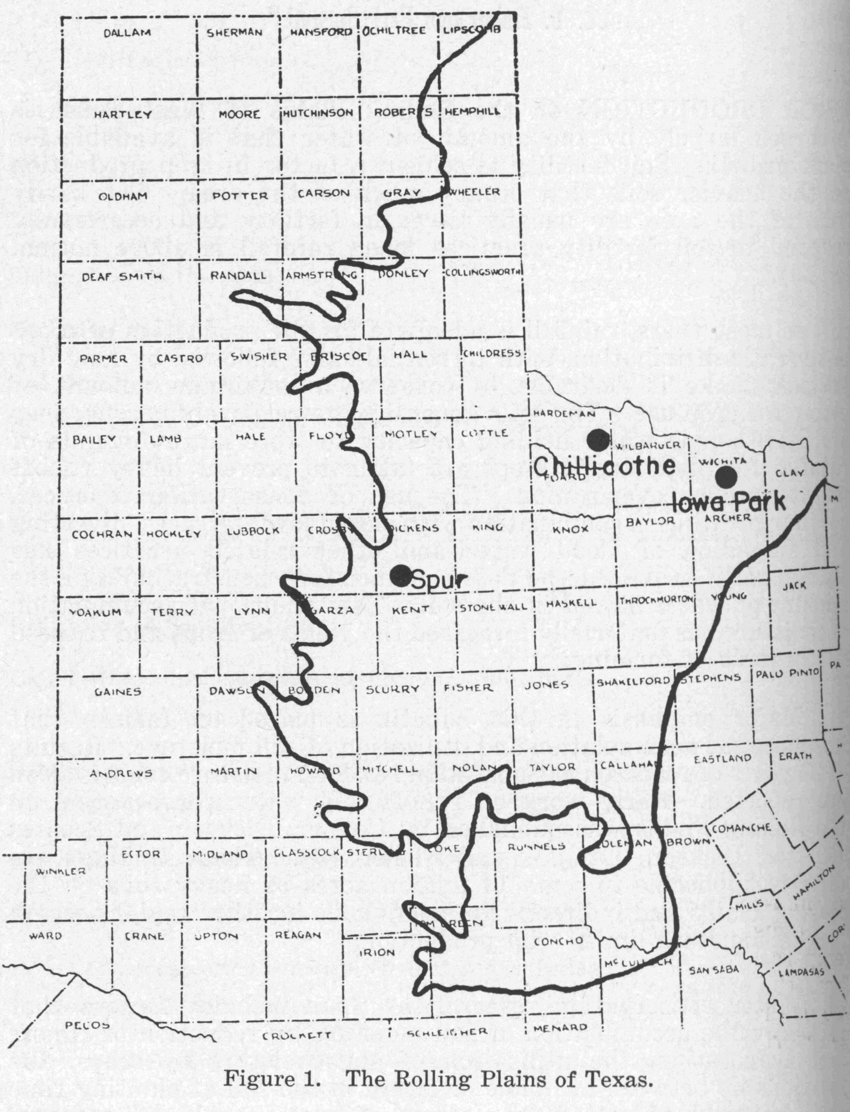

Figure 1. The Rolling Plains of Texas.

DESCRIPTION OF THE AREA

The Rolling Plains occupy approximately 30 million acres in Northwest Texas and Central Oklahoma, Figure 1. The elevation ranges from 1,000 feet on the east to over 2,500 feet on the west. Generally, the area is rolling but there are numerous areas of nearly level, undulating or only gently rolling topography. Rough, broken land occurs frequently along the main water courses and is largely devoted to grazing and livestock production. The smoother land is used principally for the production of cultivated crops.

Table 1. **Average monthly and annual evaporation, wind movement, and mean, mean maximum, mean minimum temperatures and rainfall at the Spur station, 1911-52[1]**

Item	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or average
Evaporation, inches	2.44	2.99	5.11	6.30	7.19	8.66	8.84	8.16	6.04	4.78	3.30	2.48	66.35
Wind movement, miles	4684	5038	6118	6211	5863	5249	4331	3837	3932	4021	4426	4471	58,181
Temperature													
Mean	41.5	45.9	52.5	61.9	70.0	78.6	81.6	80.9	73.3	63.3	51.2	43.0	62.0
Maximum	56.6	61.4	69.1	77.8	84.6	93.1	95.9	95.6	87.5	78.3	66.6	57.5	77.0
Minimum	26.5	30.4	35.8	46.0	55.3	64.1	67.3	66.1	59.2	48.3	35.9	28.5	47.0
Rainfall, inches	.56	.79	.86	1.85	2.87	2.55	2.00	2.47	2.82	2.33	.85	.89	20.85

[1]Evaporation records are for 1916-52. Wind movement records are for 1917-52.

Substation No. 7 of the Texas Agricultural Experiment Station at Spur lies near the western edge of the Rolling Plains. The average rainfall at the station from 1911 to 1952 was 20.85 inches and is closely similar to that of 16 other weather reporting stations located throughout the Rolling Plains.

The area has extremes of rainfall, temperature, evaporation and wind movement, Tables 1 and 2. Long periods without effective rainfall are common. The rains are often heavy and torrential, and produce much runoff.

An important feature of the rainfall distribution pattern is the mid-summer depression which usually extends from June 15 to August 15. This depression coincides with a period of high temperatures which cause heavy moisture losses by evaporation from the soil at a time when plants are making rapid growth and require large amounts of water. During this critical period, crops deteriorate rapidly unless there is ample water stored in the soil or enough effective rainfall occurs.

The annual evaporation from a free water surface was slightly over 66 inches, with extremes of 81 inches in 1934 and 52 inches in 1941. The highest evaporation occurs during June, July and August, when high temperatures and hot winds prevail and the relative humidity of the air is low. It is common to have 40 or more days during the summer when the maximum temperature exceeds 100° F. The absolute maximum temperature recorded at

Spur was 114 degrees F, and the absolute minimum 17° below zero.

The greatest wind movement occurs during March, April and May, and is lowest in August and September. The prevailing direction of the wind is from the south from March to October and from the north from November to February. The average frost-free season of 216 days extends from April 2 to November 5, which is long enough for the normal maturing of commonly-grown crops.

The soils of the Rolling Plains belong to the Reddish Chestnut great soil group. The surface soils are typically red to reddish-brown or brown to very dark brown in color. The red to reddish-brown soils are found on the more sloping areas, while the associated brown to very dark brown soils occupy the flatter areas. The principal series of the red to reddish-brown soils are Miles, Vernon, Weymouth and Tillman. The surface texture of these soils ranges from sand to clay. The subsoils are highly calcareous and often have a zone of calcium carbonate at varying depths. Soil productivity ranges from moderate to low, varying with depth of soil and moisture conditions.

Table 2. Monthly and annual rainfall, Spur, 1911-52

Year	Jan.	Feb.	March	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	1.99	.53	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	T	.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	T	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	T	.22	2.49	2.79	1.43	2.85	.11	11.13	1.41	.48	.45	24.47
1937	.38	T	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
1940	.16	1.14	.00	1.79	1.17	1.06	.07	3.24	.41	1.34	3.16	.04	13.58
1941	.88	1.64	2.04	4.17	6.94	4.12	2.94	1.46	9.90	7.90	.21	.67	42.87
1942	.06	.33	.31	3.67	1.63	3.44	1.60	3.40	3.88	2.82	.17	1.79	23.10
1943	.10	.00	.32	1.14	2.81	2.95	5.36	.00	2.37	.31	.80	1.64	17.80
1944	1.77	1.78	.12	.89	2.49	2.50	2.51	2.34	1.18	1.07	1.95	2.72	21.32
1945	.89	1.04	.34	.58	.08	3.30	4.29	1.78	4.27	2.12	.69	.21	19.59
1946	1.05	.19	.36	1.40	1.57	3.33	.05	3.71	2.48	2.78	.32	1.68	18.92
1947	.60	.00	1.51	1.27	6.43	2.01	.00	.28	.15	.65	2.14	2.03	17.07
1948	.18	2.28	.15	.57	2.00	4.78	1.30	.89	.07	1.58	.45	.08	14.33
1949	2.50	.43	1.78	1.62	5.28	4.63	2.45	4.06	2.71	2.64	.00	1.08	29.18
1950	.35	.38	.01	1.94	4.92	3.16	3.91	.90	6.23	.00	.04	.02	21.86
1951	.27	.35	2.19	.81	3.01	2.88	2.30	5.82	1.29	2.29	.03	.00	21.24
1952	.70	.21	.23	3.33	1.36	.06	2.81	.46	1.22	.00	1.25	.86	12.49
Mean	.56	.79	.86	1.85	2.87	2.55	2.00	2.47	2.82	2.33	.85	.89	20.85

Abilene, Roscoe and Spur are the principal series of the brown to very dark brown soils. These soils are generally heavier than the red soils since they occupy the flatter areas and have poorer internal drainage. They are less subject to wind erosion than the associated red soils and are usually more fertile, but tend to be drouthy.

The heavier soil types generally have good water-holding capacity and are deep enough for adequate moisture storage. Most of the shallow soils are not in cultivation except where they occur in association with the deep soils. The sandier types often produce higher yields with average rainfall because losses from runoff and evaporation are much lower than on the heavy soils. The most desirable soil for crop production on the Rolling Plains is one with a sandy loam surface texture underlain by a sandy clay subsoil. A soil of this type can take up water readily to prevent runoff, yet has ample water-holding capacity to carry crops through the mid-summer depression.

Cotton is the principal cultivated crop grown on the Rolling Plains. Wheat is grown extensively, especially in the northern part. Sorghums are well adapted and are grown extensively but largely as a second choice to cotton, depending on the type of farming, moisture and economic conditions. Crops of minor or local importance are oats, barley, rye, alfalfa, castor beans and peanuts. Approximately 70 percent of the land is in native grass and is largely devoted to the production of cattle.

METHOD OF STUDY

The effect of slope, crops, tillage and character of rainfall on runoff and erosion was determined on small plots on Tillman clay loam. Measurements of soil moisture, runoff and yield were made on large field plots on Abilene clay loam with 0.5 to 2 percent slope. The conservation practices used on land planted continuously to cotton included rows with the slope, contoured rows and contoured rows supplemented with closed level terraces. There was one replication of these practices on field areas from 1927 to 1929; three replications of each practice from 1930 to 1945 and one replication from 1946 to 1952. In addition, four field areas with terraces that had variable grades and different vertical intervals were included in the study from 1930 to 1946.

Soil moisture determinations were made at monthly intervals from April 20 to October 20 on the experimental areas of the station. The samples for moisture determinations were taken from 1-foot layers of soil. The sampling depth was 3 feet from 1930 to 1936, 5 feet from 1937 to 1939 and 6 feet from 1940 to 1952.

Since all of the moisture present in the soil can not be utilized by plants, only that portion that is available for plant growth is reported. The available moisture was determined by the following procedure: Total moisture percentage is determined by oven drying. This percentage is converted to inches by use of the formula $I = \frac{m\,w}{5.196}$ where I is the inches of water in one foot of soil; m is the percentage (expressed as a decimal) of soil moisture; and w is the weight (pounds) per cubic foot of oven-dry soil. The quantity 5.196 is the weight (pounds) of a square foot of water 1 inch deep and at a density of 62.35 pounds per cubic foot (density of water at 60 degrees F.) (11).

The lowest point to which crops normally reduce the moisture in the soil, designated as the minimum point of exhaustion, was determined for each foot-section of soil by averaging the moisture content at times during the growing season when it was certain that the supply of available moisture was exhausted and the crop was suffering for water. The difference between the total moisture present in each foot of soil and the minimum point of exhaustion represents the amount of available moisture present (6).

SOIL MOISTURE ACCUMULATION

Conservation practices that increase the amount and depth of penetration of moisture make better use of the soil as a storage place for water and offer excellent opportunities for increasing crop yields and reducing evaporation, runoff and erosion. In the Rolling Plains it is seldom that the soil is wet to a depth of 6 feet which includes the root zone of most cultivated crops. Some factors that have been studied at Spur which influence the accumulation of moisture in the soil include the amount and character of rainfall, soil type, crops, plant residues, slope of land, tillage and conservation practices.

Amount and Character of Rainfall

The annual rainfall at Spur for the 43-year period, 1911 to 1952, was 20.85 inches. Large fluctuations have occurred in the annual

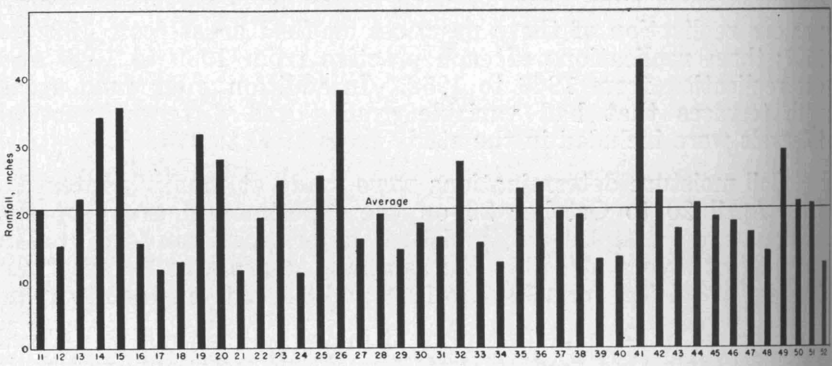

Figure 2. Distribution of annual rainfall at Spur, 1911-52.

rainfall, varying from 11.09 inches in 1924 to 42.87 inches in 1941, Figure 2. Above normal rainfall has not always favored good crops; neither has below normal rainfall always indicated poor crops. Good to excellent crops have been produced in the dry years of 1921, 1924, 1927, 1931 and 1947 with the benefit of timely rainfall and moisture stored in the soil during the previous season.

Total rainfall during the season gives a general picture of moisture conditions but it is not a reliable index to the amount of water that may be available for plant use. Long time studies show that 61 percent of the annual rainfall produces runoff, varying from .57 to 10.66 inches with an average of 3.55 inches per year, Table 3. This alone represents a loss of 17 percent of the annual rainfall. In addition, another 2.74 inches, or 13 percent of the rainfall, is lost as small, ineffective showers. If some provision is not made to control or prevent runoff losses, the amount of effective rainfall is reduced from 17.82 to 14.27 inches. Losses due to evaporation and weed growth still further reduce the amount of rainfall that eventually becomes stored moisture for use in crop production.

The character of rainfall—whether torrential, moderate or low in intensity—greatly influences runoff and thus the amount of water that accumulates in the soil for plant use, but the relationship is not always clearly evident. Such factors as total

Table 3. **Amount of annual rainfall lost as runoff and ineffective showers, Spur, 1926-52**

Year	Annual rainfall	Runoff, inches[1]	Ineffective showers[2]	Effective rainfall[3]
1926	38.08	7.13	3.51	27.44
1927	16.12	.57	6.59	8.96
1928	19.99	3.19	5.47	11.33
1929	14.76	3.46	3.59	7.71
1930	18.60	2.78	2.63	13.19
1931	16.46	.77	3.76	11.93
1932	27.70	3.13	1.48	23.09
1933	15.59	2.28	2.37	10.94
1934	12.88	2.17	1.69	9.02
1935	23.78	5.21	1.87	16.70
1936	24.47	4.69	2.80	16.98
1937	20.28	3.30	2.99	13.99
1938	19.96	3.16	2.23	14.57
1939	13.06	1.44	3.70	7.92
1940	13.58	2.84	2.64	8.10
1941	42.87	10.66	2.89	29.32
1942	23.10	4.46	2.02	16.62
1943	17.80	3.45	2.68	11.67
1944	21.32	1.66	2.89	16.77
1945	19.59	4.79	3.36	11.44
1946	18.92	3.63	1.91	13.39
1947	17.07	2.17	1.27	13.63
1948	14.33	2.58	1.12	10.63
1949	29.18	8.01	1.88	19.29
1950	21.86	5.22	1.75	14.89
1951	21.24	2.02	2.92	16.30
1952	12.49	1.08	1.98	9.43
Total	555.08	95.85	73.97	385.25
Average	20.56	3.55	2.74	14.27
Percent of total rainfall		17.27	13.33	69.41

[1]Runoff from land with 2 percent slope in continuous cotton without conservation practices.
[2]An arbitrary designation for rains of less than .25 inch.
[3]Total rainfall less runoff and ineffective showers.

amount of rainfall, physical condition of the soil, crop grown, moisture content of the soil and other factors tend to influence the amount of runoff. Table 4 shows that of the annual rainfall of 12.68 inches that produced runoff, 5.92 inches were torrential, 1.82 inches moderate and 4.93 inches fell as gentle or slow rain.

The greatest opportunities for storing water in the soil and preventing floods and erosion are closely associated with rain periods of 2 inches or more. Thirty-five percent of the annual rainfall from 1912 to 1952 occurred in rain periods of 2 inches or more. Most of these 2-inch rain periods occur in September and October, Figure 3. Conservation of water from these heavy rain periods benefits the current crop and stores water in the soil for future use.

The distribution of rainfall during the year and the amount of available water in the soil to a depth of 3 feet on cotton land from April 20 to October 20 are shown in Figure 4. Monthly rainfall is usually low, less than an inch, during the winter, then it increases with a peak in May and September. The mid-summer depression of rainfall extends from June 15 to August 15 when crops normally require the most water.

Figure 4 shows that soil moisture accumulates over a period of about 8 months, beginning about October 1 and reaching a peak on May 20. It is then depleted by crops during June, July, August and September. From May 20 to August 20, the growth of cotton requires more water than normally can be expected from rainfall.

Table 4. Intensity of rainfall at Spur in relation to runoff, 1926-47

Year	No. rains producing runoff	Amount of rainfall producing runoff, inches	Character of rain, inches[1]			Average runoff 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	.91
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
1940	5	5.71	2.66	.28	2.77	2.52
1941	12	34.46	16.90	3.06	14.50	11.31
1942	12	18.22	8.25	2.18	7.79	3.73
1943	5	10.34	6.70	1.35	2.29	3.84
1944	7	6.65	3.74	.93	1.98	1.17
1945	5	10.42	4.18	.60	5.64	4.27
1946	4	9.74	3.75	3.23	2.76	3.04
1947	4	9.10	1.84	1.00	6.24	1.73
Average	8.72	12.68	5.92	1.82	4.93	3.28
Percent total rainfall producing run-off			46.69	14.35	38.88	25.87

[1]Torrential—intensity of more than .75 inch per hour.
Medium—intensity between .40 and .75 inch per hour.
Slow—intensity of less than .40 inch per hour.

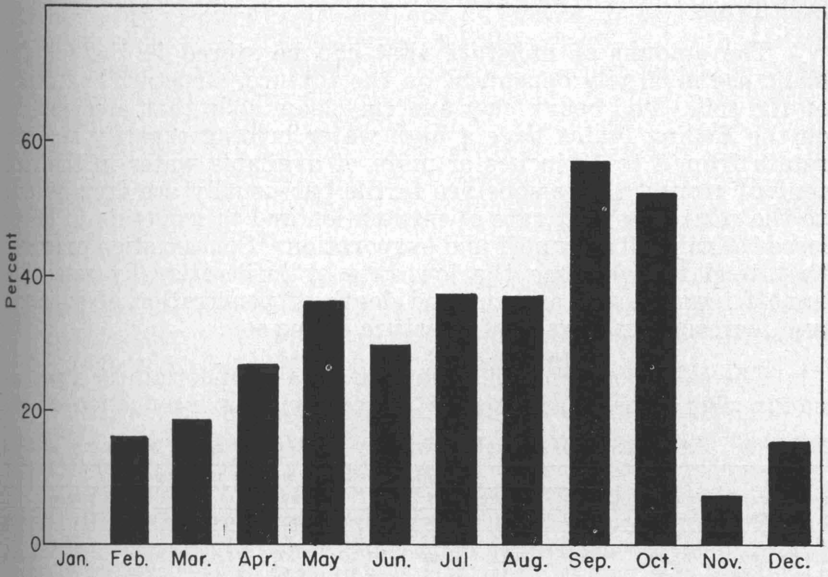

Figure 3. Distribution of monthly rainfall that has occurred in rain periods of over 2 inches, 1911-52.

If any soil moisture has accumulated prior to planting, it serves as a reserve to be used by the plants to supplement rainfall.

In the event little or no soil moisture has accumulated prior to planting, the crop will be entirely dependent on above normal and timely distribution of rainfall. The heaviest use of water by crops occurs during the mid-summer depression of rainfall. Only once in the 22-year period has the summer rainfall been ample to produce good crops without an adequate moisture reserve in the soil at planting time.

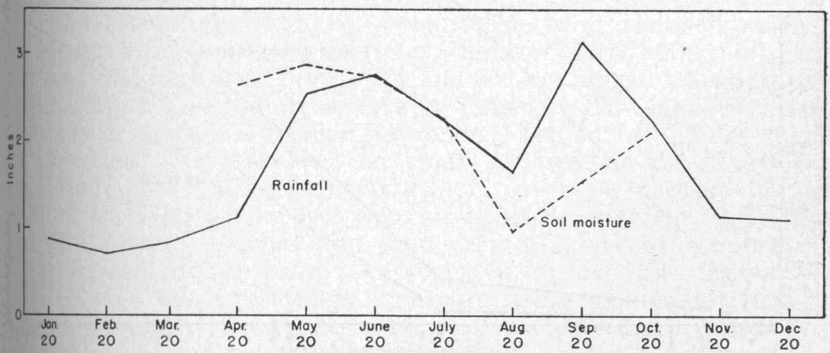

Figure 4. Average rainfall and average available soil moisture in the surface 3 feet, by monthly periods, 1930-52.

Soil Types

The amount of moisture that can be stored in the soil for plant use is largely dependent on the texture, structure and depth of the soil. The heavy clay and clay loam soils that predominate on the Rolling Plains have a high water holding capacity and can retain from 8 to 12 inches or more of available water in the root zone of crops. These soils are fertile but usually are drouthy due to the relatively slow rate of infiltration and to moderate to heavy losses of rainfall as runoff and evaporation. Conservation practices that tend to overcome the low rate of infiltration by retarding runoff increase the amount and depth of penetration of moisture and increase the storage of moisture in the soil.

The sandy or light soils that are usually underlain by a porous sandy clay subsoil are highly prized for crop production in the

Table 5. Total inches of percolate from lysimeters at Spur, summary 1939-43

Size of rain, inches	Total rainfall, inches	Depth of soil and manure in lysimeter								
		2 inches			4 inches			8 inches		
		Sand	Clay	Manure	Sand	Clay	Manure	Sand	Clay	Manure
0 to .50	25.18	.82	.65	2.17	.60	.37	1.77	.44	.08	1.46
.51 to 1.00	22.00	6.97	2.71	12.82	1.76	.53	12.61	.41	.10	10.84
1.01 to 2.00	25.42	11.68	9.10	17.94	7.81	4.52	17.54	3.33	1.78	16.21
2.01 to 3.00	16.75	11.05	8.98	14.15	8.50	6.46	13.37	5.61	2.94	12.51
3.01 & over	18.31	12.77	10.91	15.91	10.70	9.31	15.87	8.89	8.01	14.89
Total	107.66	43.29	32.35	62.99	29.37	21.19	61.16	18.68	12.91	55.91
%		40.20	30.00	58.50	27.30	19.60	56.80	17.40	12.00	51.90

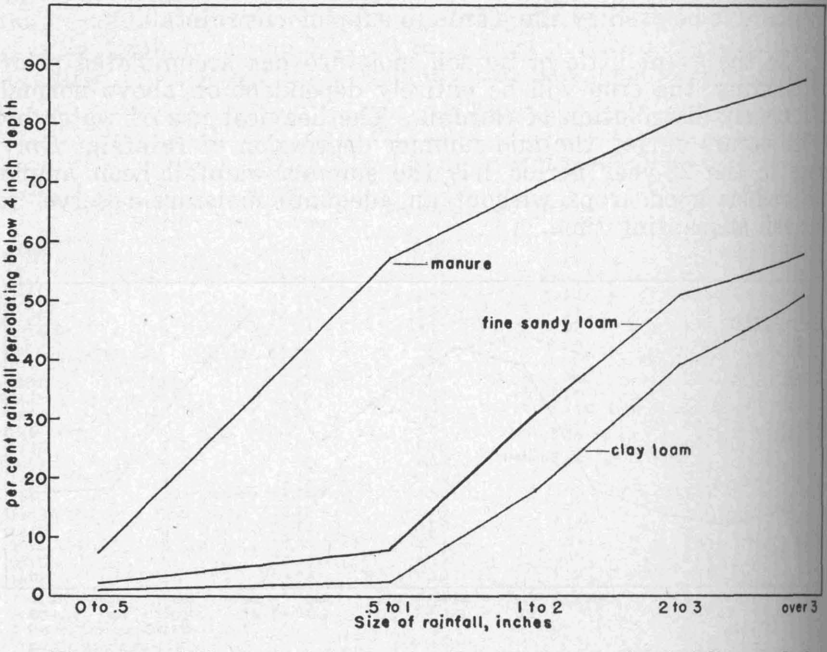

Figure 5. Effect of size of rainfall on percent of rainfall percolating through 4-inch layers of three materials.

region. These soils are usually not as fertile as the heavy clay soils, but since they absorb water readily runoff is not a serious factor. Since moisture tends to penetrate deeper on these sandy soils, evaporation losses are small and crops often benefit from light showers. On the heavy clay soils, these small showers are seldom effective. Generally, when rainfall is below normal, the sandy soils are usually the most productive and dependable; however, the more fertile clay soils produce the highest yields when rainfall is above normal.

Since the heavy soils usually occupy flatter slopes and receive runoff from steeper surrounding areas, more water is available for these soils than the total rainfall might indicate. The increased penetration of water helps counteract the high evaporation losses.

To show the amount of rainfall that might be expected to penetrate to various depths in soils of different texture, a series of lysimeters were filled in duplicate with clay loam and fine sandy loam to depths of 2, 4 and 8 inches. Four lysimeters were filled with well-decayed manure to the same depths as the mineral soil materials. The water that penetrated below the various depths was measured. It was found that 30 percent of the annual rainfall penetrated the clay loam, 40 percent penetrated the sandy loam and 58 percent penetrated the manure to a depth of 2 inches, Table 5. Figure 5 shows the effect of the amount of rainfall on the percent that penetrated below a depth of 4 inches of a clay loam soil, fine sandy loam and well-decayed manure. Under field conditions, where heavier runoff usually occurs on clay soils, even greater differences in penetration of moisture could be expected between the sandy and clay loam soils. The larger amount of rainfall which penetrated through the well-decayed manure strongly suggests the possibility of using mulches and crop residues that will increase the amount of moisture penetration on clay soils.

Evaporation

The loss of moisture by evaporation from the soil surface is relatively high. A measure of the combined effect of high temperature, high wind movement and low humidity on evaporation losses from a free water surface is shown in Table 1. Moisture losses from the soil are much lower since the surface is dry much of the time. Nevertheless, on small fallowed areas of Abilene clay loam bordered to prevent runoff, over 60 percent of the rainfall that fell during a 2-year study at Spur failed to become stored moisture. Similar and even greater losses by evaporation from the soil surface have been reported on the High Plains (5) (7). During the hot summer, moisture losses of one-half inch or more may occur from the surface 6 inches of clay soils by evaporation within a few days after a rain. The moisture stored below a depth of 6 inches, however, is relatively stable and losses due to evaporation are negligible (3). These data show that losses due to evaporation may be reduced by increasing the depth of moisture penetration. On sandy loam soils, a given amount of rainfall will penetrate to greater depths and losses by evaporation will be less than from clay loam soils (8). Farming practices that prevent rapid runoff, leave the surface cloddy to permit rapid penetration (6) and maintain a good cover of crop residues on the surface (4) aid deeper penetration of moisture and greatly increase the amount of water available for plant growth.

Crops and Slope

The crop grown and the slope of the land are additional factors that influence runoff and soil moisture accumulation.

Table 6. Effect of crops on runoff and soil loss on land with 2 percent slope, Spur, 1926-51

Crop	Average annual runoff, inches	Average annual soil loss, tons per acre
Cotton	3.65	7.2
Grain sorghum	2.76	3.8
Fallow	5.00	15.5
Buffalo grass	.94	.8

A good cover of buffalo grass offers the most effective means to reduce runoff, followed in effectiveness by grain sorghum, cotton and then fallow, Table 6. The canopy effect, litter and vegetative residues of grass, sorghum and wheat, when maintained on or near the soil surface, lessen the impact of raindrops, offer resistance to movement of water over the surface and reduce losses from drying winds (7). These crops use large amounts of water rapidly over a greater part of the season and leave storage space

Table 7. Effect of slope on runoff and soil loss on land in continuous cotton, Spur, 1926-51

Slope percent	Average annual runoff, inches	Average annual soil loss, tons per acre
0	1.99	2.3
1	3.71	5.4
2	3.65	7.2
3	3.88	8.2

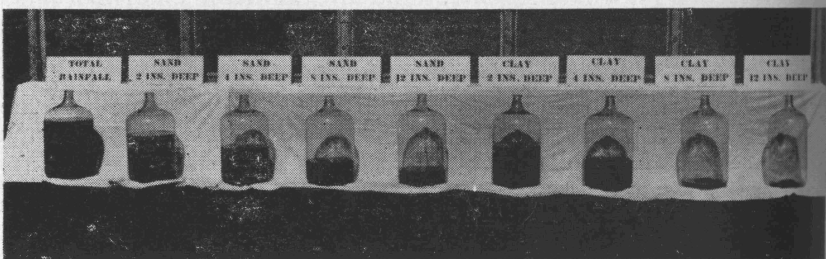

Figure 6. Relative amounts of water that percolated various depths of fine sandy loam and clay loam soils following a rain of 2.62 inches. Deeper penetration of moisture on the sandy soils helps reduce losses from evaporation.

in the soil for more moisture. Cotton, on the other hand, does not provide much vegetative residue and uses water more slowly, except during July and August. On clean tilled land in cotton and other low-residue crops, including fallow, provision should be made to reduce runoff and evaporation to permit the maximum penetration of moisture.

Soil moisture penetration and accumulation generally tend to decrease as the slope of the land increases. The relative runoff and erosion losses from small plots are shown in Table 7. The slope of the plots was established by the movement of soil and the results probably do not reflect actual losses that might occur under field conditions. The greatest increase in runoff occurred when the slope was increased from level or zero to 1 percent. Erosion, on the other hand, increased markedly with each increase in the slope of the plots.

Conservation Practices

The effects of the foregoing factors often may be modified appreciably by the use of conservation practices to increase the amount of water available for plant use. Research was undertaken at Spur in 1926 to determine the effect of terracing, contouring and water spreading on soil moisture content, runoff and yield of cotton. The effect of these practices in increasing the depth of moisture penetration and accumulation is shown in Table 8. For the 16-year period, 1937-52 the total available water in the upper 5 feet of soil on May 20 was increased from 3.06 inches from straight row farming to 3.33 and 3.72 inches, respectively, by contouring and contouring supplemented with closed level terraces. In some years, there was more available moisture on areas with rows in the direction of the slope because the limited growth of cotton the previous year resulted in a carryover of moisture.

On relatively level areas of land, contouring supplemented with closed level terraces also greatly reduced or actually prevented

Table 8. Effect of conservation practices on the total available moisture in the upper 5 feet of soil at Spur on May 20

Year	Available moisture, inches		
	Rows with slope	Rows on contour	Rows on contour supplemented with closed level terraces
1937	4.64	4.48	5.16
1938	4.82	5.10	5.50
1939	1.23	.66	.76
1940	1.12	1.90	1.45
1941	6.03	6.27	4.88
1942	7.27	6.78	7.00
1943	4.53	4.78	5.09
1944	2.18	1.62	2.22
1945	2.13	2.06	2.10
1946	2.17	3.54	4.13
1947	4.10	4.84	5.87
1948	1.85	1.66	2.31
1949	2.35	4.35	4.73
1950	1.07	1.06	3.30
1951	1.50	2.33	2.81
1952	1.97	1.83	2.29
Total	48.96	53.26	59.60
Average	3.06	3.33	3.72

runoff and markedly increased the yield of cotton. The use of runoff water to increase the available moisture in the soil has materially increased the yield of cotton, wheat, sorghums and native grass. Other conservation practices, such as crop residue management and tillage, which help maintain a cloddy surface, play an important part in determining the amount of available water stored in the soil.

Exploratory studies with crop residues of sorghum applied to cotton land over a 2-year period show that the depth of moisture penetration was greatly increased. Application of 20 tons of air-dry sorghum litter per acre increased the yield of lint cotton from 106 to 228 pounds on land with a 0.5 percent slope when the rows ran in the direction of the slope. On land that was contoured and terraced to prevent runoff, the yield of lint cotton was increased from 331 pounds to 402 pounds per acre by the application of litter.

On land that has more than 1 percent slope, a combination of contouring with closed level terraces, supplemented with crop residue management and desirable tillage practices, will usually furnish the best opportunity for increasing the amount of water stored in the soil.

UTILIZATION OF SOIL MOISTURE

The quantity of soil moisture that may be utilized by a crop is largely determined by the length of its growing season, depth and nature of the root system, soil texture and the amount and distribution of rainfall. The native grasses and associated plants commonly found on rangelands of the Rolling Plains can utilize soil moisture throughout the winter and summer, thus providing a large potential reservoir for moisture. The native grasses have long, fibrous root systems that will utilize soil moisture to depths of 4 to 6 feet or more. Cotton requires a long season for normal growth and development, yet, unlike native grass, it makes its greatest demand for water over a 90-day period from about June 20 to September 20 during the blooming and heavy fruiting stage of growth, Figure 7. Cotton has a root system that will utilize soil moisture to a depth of 3 to 5 feet; under some conditions it may remove moisture in the subsoil to depths of 6 feet or more. The well-developed, deep root system and the indeterminate fruiting habit of cotton enable it to withstand considerable drouth and high temperature and still produce good to excellent yields.

Sorghums have fibrous root systems that utilize soil moisture effectively in the upper 2 to 3 feet of soil but do not utilize moisture as deeply as cotton, wheat or native grasses. Ample moisture at the heading stage is needed to produce satisfactory yields.

Occasionally, favorable distribution of rainfall following planting will bring about heavy vegetative growth of cotton and sorghum with poorly-developed, shallow root systems. If an ample supply of subsoil moisture is available, cotton and sorghums can withstand the drouth and high temperatures which prevail during the latter portion of the season (9). On the other hand, if the available moisture in the soil is low, cotton and sorghums deteriorate rapidly with the onset of drouth, since the above-ground growth is too large to be sustained by the shallow root system and limited available moisture supply. Root systems of cotton, buffalo grass, wheat and mesquite that have been removed from Abilene clay loam soils during seasons when subsoil moisture was well above normal are shown in Figures 8, 9 and 10.

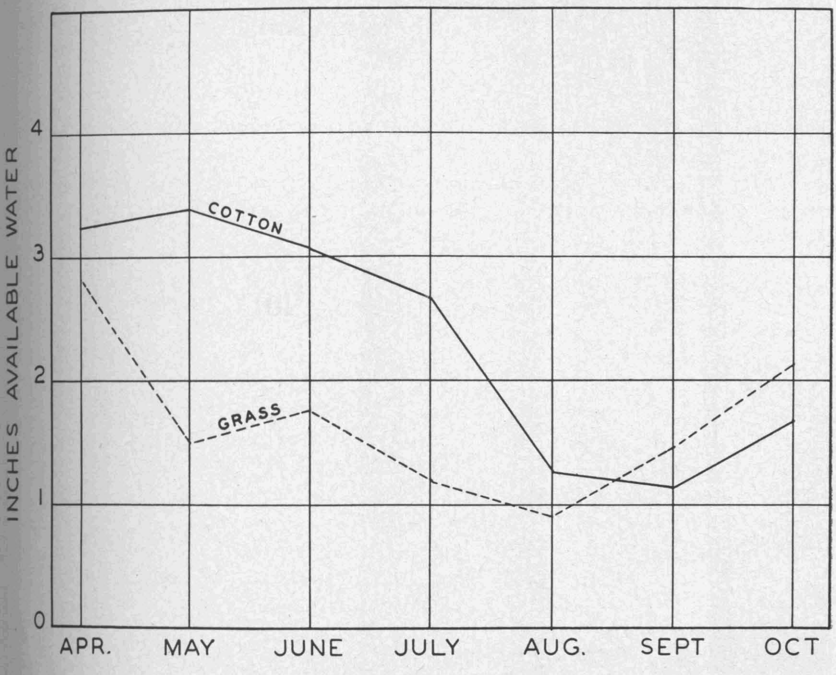

Figure 7. Seasonal use of soil water by cotton and native grass.

EFFECT OF AVAILABLE MOISTURE AT PLANTING TIME ON THE YIELD OF COTTON

The amount of available water stored in the soil on land continuously planted to cotton is normally highest during the spring. It declines to a low point during the latter part of July and August, when high temperatures prevail and cotton plants begin fruiting and require large amounts of water to sustain growth and development. If ample moisture is stored in the soil at planting time, it serves as a reserve for such deep-rooted plants

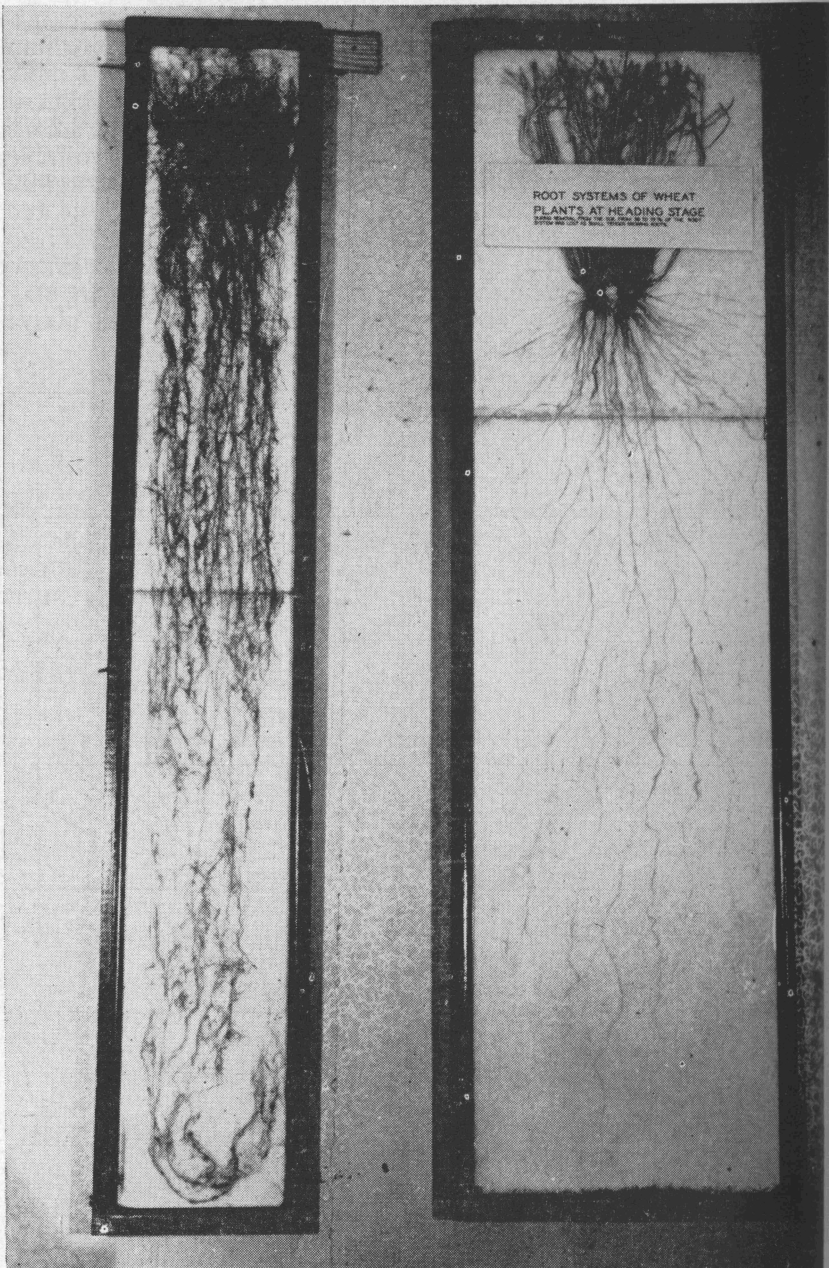

Figure 8. Root systems of buffalo grass and wheat that extended to depths of over 6 feet when moisture was stored in the subsoil.

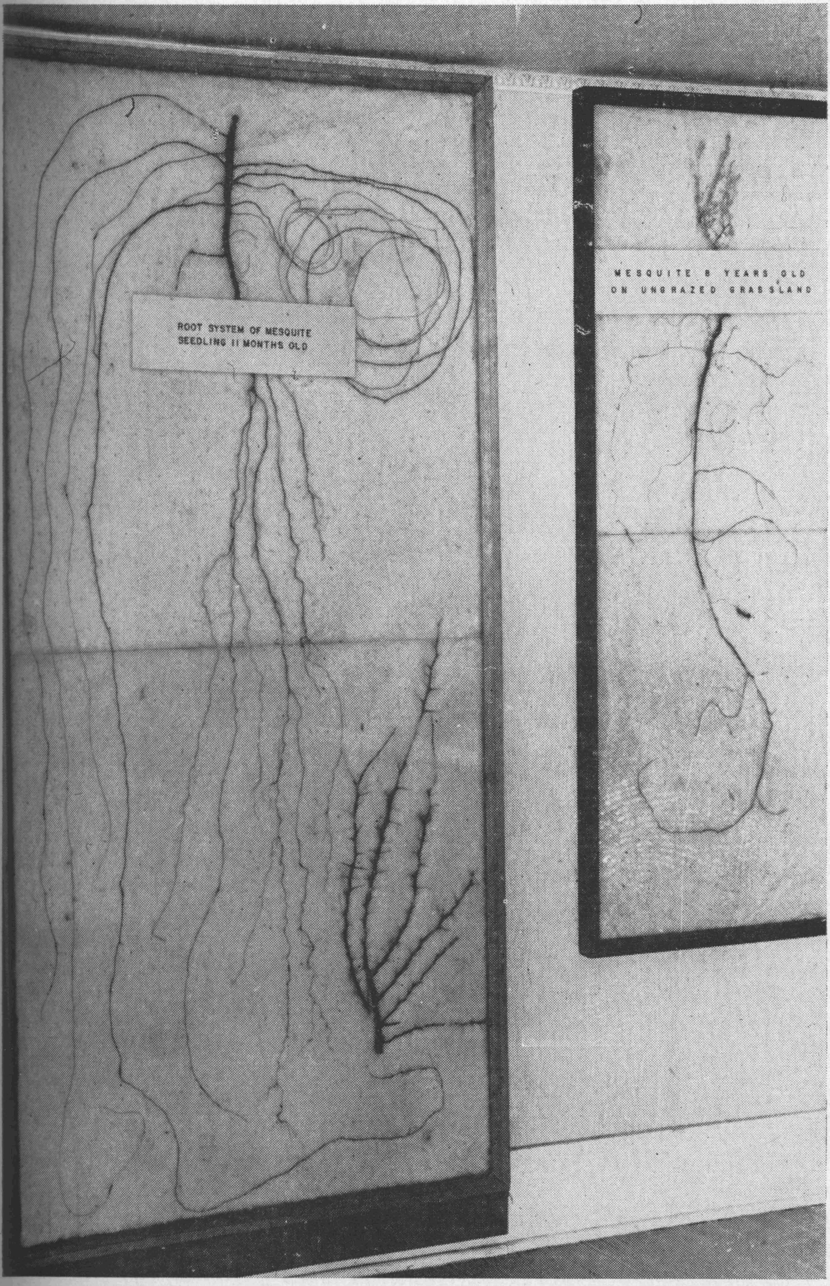

Figure 9. Root system of mesquite seedling and above-ground growth of mesquite seedling. Deep soils offer excellent opportunities to store large amounts of water in the soil for plant use.

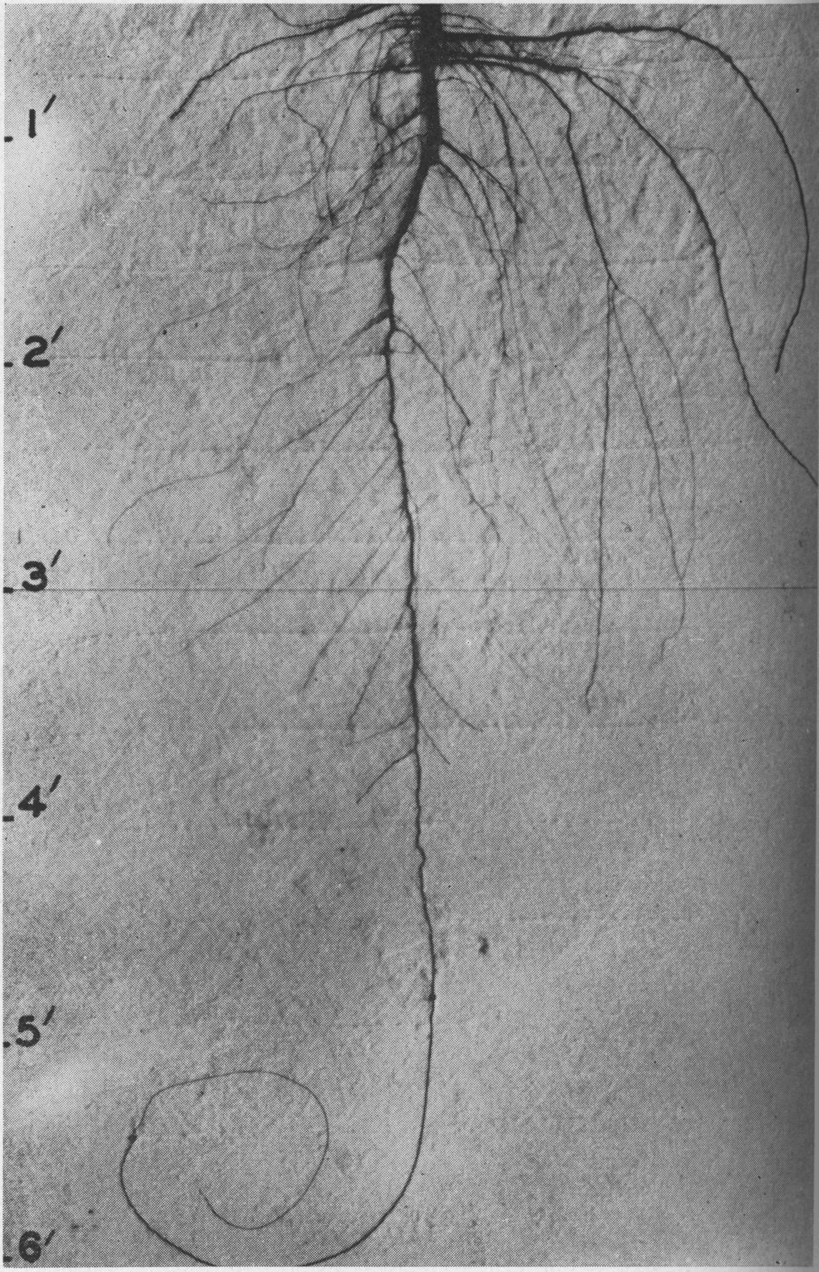

Figure 10. Root system of cotton when the soil was wet to a depth of 6 feet at planting time. The moisture stored below a depth of 1 foot serves as a reservoir for plants during periods of scanty rainfall.

as cotton when summer rainfall is scanty or poorly distributed. The close relationship between the average amount of available water stored in the soil on May 20, normally the optimum time for planting cotton at Spur, and the average yield of cotton for the 22-year period, 1930-52, is shown in Figure 11. Cotton was destroyed by hail in 1932 and the data for that year are omitted.

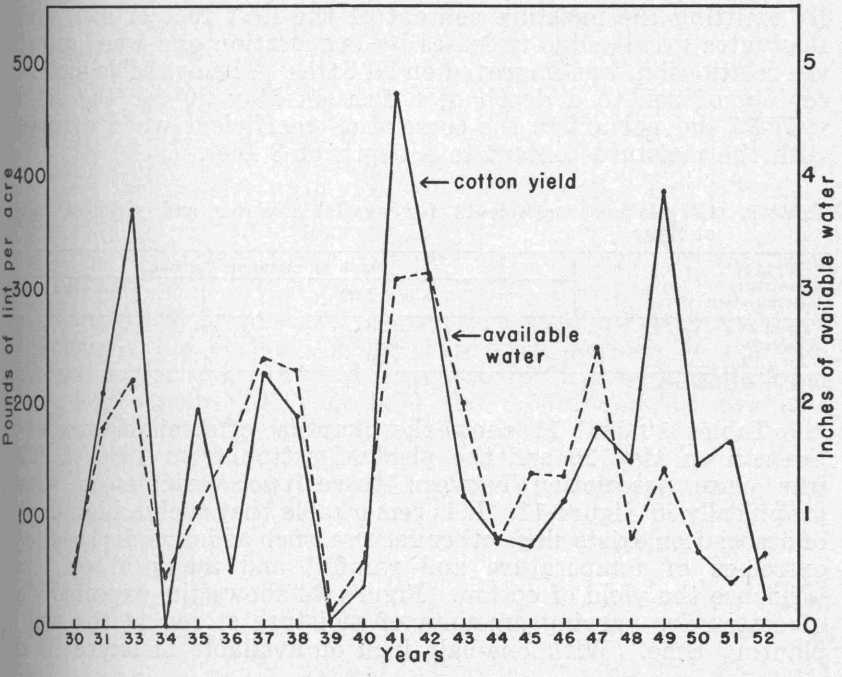

Figure 11. Available moisture in the second and third foot of soil at planting time and yield of lint cotton, 1930-52.

There were only 2 seasons during the 22-year period when the amount of available water at planting time gave only a fair indication of the probable yield of cotton. A combination of early heavy vegetative growth of cotton followed by extremely high temperatures in August greatly reduced the expected yield in 1936. The other instance occurred in 1949 when almost ideal distribution of summer rainfall in ample amounts provided sufficient moisture to produce an excellent crop of cotton with only an average amount of available moisture stored in the soil on May 20. This favorable rainfall condition, combined with only an average amount of moisture in the soil at planting time, occurred only once during the 22-year period.

The relation between the amount of available moisture at planting time and the yield of cotton may be expressed mathematically as a correlation coefficient. This relation was determined for available moisture content of the soil to a depth of 3 feet from 1930 to 1952 on April 20, May 20 and June 20. The highest correlation coefficient, 0.747, between available moisture and yield of cotton was found for the moisture content of the second and third feet of soil on May 20, Table 9. The relationship between available moisture and cotton yield was slightly lower for determinations made on June 20 and much lower for those on April 20. By omitting the moisture content of the first foot of soil, which fluctuates greatly due to losses by evaporation and weed growth, the relationship was improved on all dates. The available moisture content of soil to a depth of 5 feet on May 20 for the period, 1937-52, did not affect the correlation coefficient when compared with the moisture content to a depth of 3 feet.

Table 9. Correlation coefficients for available water and yield of cotton at Spur

Date of moisture determination	Depth of sampling the soil	
	0 to 3 feet	2nd and 3rd foot
April 20	.565[1]	.578[1]
May 20	.690[1]	.747[1]
June 20	.660[1]	.723[1]

[1]Highly significant.

Tables 10 and 11 show the quantity of available water in the soil on May 20 and the yield of cotton from 1930 to 1952. The close association between these two variables is shown graphically in Figure 11. It is remarkable that such a high degree of association exists since other factors, such as insect depredations, extremes of temperature and rainfall and many others, may influence the yield of cotton. Figure 12 shows the expected yield of cotton for varying amounts of moisture stored in the soil at planting time. With one-half inch of available moisture in the

Table 10. Available soil moisture by field areas in the second and third feet at planting time (May 20), Spur, 1930-52

Year	Available soil moisture, inches											
	1	2	3	5	6	7	9	11	12	13	14	15	16
1930	.25	.02	.41	.74	.99	1.62	.25	.25	.43	.64			
1931	2.00	1.44	2.11	1.86	1.99	1.89	2.46	1.06	2.30	2.55			
1933	2.39	2.10	2.52	1.74	2.06	2.05	2.61	2.29	2.39	2.89	2.29	2.36	3.29
1934	.12	.53	.91	.50	.66	.65	1.06	.00	.28	1.07	.81	.64	.81
1935	1.06	.60	1.74	1.58	2.02	2.04	2.61	.80	1.87	1.76	.68	1.80	1.50
1936	1.60	1.49	1.81	.90	1.63	1.68	1.37	.57	1.76	1.27	.85	1.68	.86
1937	2.34	2.64	2.26	2.27	2.36	2.20	2.52	2.01	2.07	2.60	2.16	2.81	3.00
1938	2.30	2.21	2.04	2.56	2.80	2.31	2.44	2.12	1.45	2.87	1.24	2.13	2.10
1939	.11	.19	.71	.18	.53	.11	.50	.89	.44	.29	.09	.59	.12
1940	.65	.47	1.09	.22	.05	.57	.68	.60	.93	.55	.39	.80	.76
1941	2.87	3.15	2.89	2.94	2.75	3.21	3.45	2.49	2.69	2.61	2.60	3.46	3.93
1942	3.04	3.31	3.06	2.85	2.23	2.97	3.17	2.20	2.72	2.41	2.48	3.10	2.97
1943	2.21	1.82	2.30	1.56	1.10	1.94	2.09	1.43	1.70	2.52	1.35	2.67	2.02
1944	.69	.77	.58	.96	.30	.75	.37	.39	.61	.31	.61	.90	.76
1945	1.31	1.55	1.67	1.68	1.18	1.16	1.67	1.02	1.27	.82	.98	.78	.66
1946	1.18	.99				1.79							
1947	2.25	2.21				3.02							
1948	.60	.69				1.05							
1949	1.19	.69				2.25							
1950	.29	.25				1.31							
1951	.48	.24				.38							
1952	.64	.51				.69							
Total	29.57	27.87	26.10	22.54	22.65	35.29	28.62	18.12	22.91	25.16	16.53	23.72	21.78
Av	1.34	1.27	1.74	1.50	1.51	1.60	1.91	1.21	1.53	1.68	1.27	1.82	1.68

Table 11. Yield of cotton on field areas, Spur, 1930-52

Year	Yield of cotton, pounds lint per acre												
	1	2	3	5	6	7	9	11	12	13	14	15	16
1930	34	9	37	46	33	104	129	85	87	75			
1931	202	186	186	190	145	229	242	159	187	199			
1933	340	325	371	442	337	441	521	339	426	435	510	459	463
1934	0	0	0	0	0	0	0	0	0	0	0	0	0
1935	186	118	127	191	101	270	254	98	191	185	92	221	201
1936	50	39	38	43	36	55	51	16	31	39	17	27	39
1937	193	186	170	161	150	292	242	98	122	143	125	146	215
1938	176	147	163	186	163	236	182	150	191	201	150	189	208
1939	2	6	8	15	17	2	0	15	15	27	0	0	0
1940	41	21	40	61	39	52	82	30	51	51	27	57	62
1941	497	442	442	429	451	478	421	388	433	419	341	421	415
1942	331	285	255	306	285	310	260	288	303	274	275	331	288
1943	106	77	125	105	102	162	128	121	123	136	99	114	149
1944	78	61	102	89	96	96	89	85	98	114	73	93	117
1945	58	63	80	71	82	89	76	59	68	79	53	55	84
1946	136	116				177							
1947	167	150				211							
1948	125	108				190							
1949	430	193				534							
1950	125	111				187							
1951	159	99				229							
1952	16	8				46							
Total	3452	2750	2154	2335	2037	4390	2677	1931	2326	2377	1762	2113	2241
Av.	157	125	144	156	136	200	178	129	155	158	136	163	172

second and third feet of soil, the average yield per acre has been 57 pounds of lint cotton. When there was one inch of available moisture in the soil, the yield increased to 89 pounds of lint per acre. For amounts of 2.00, 3.00 and 4.00 inches of available moisture at planting time, the yields were 187, 330 and 518 pounds of lint per acre, respectively. Each additional amount of water greatly increased the yield of cotton, especially when the

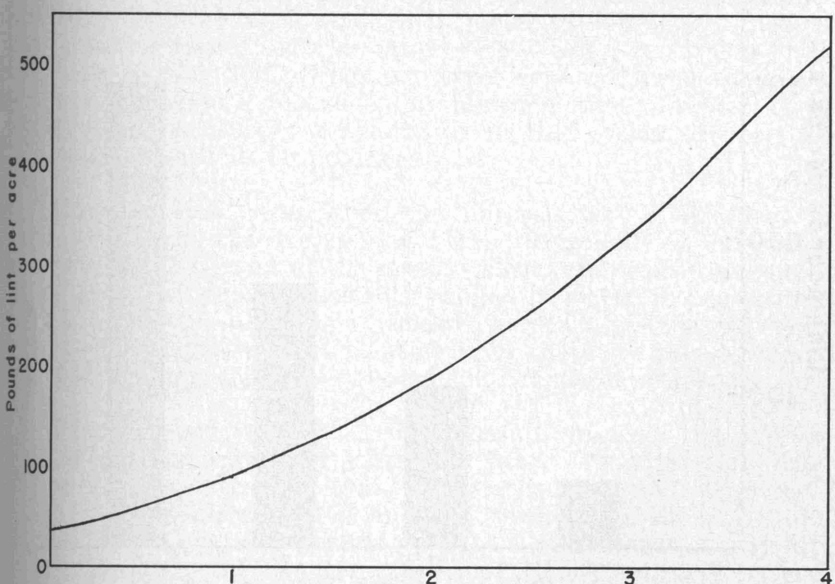

Figure 12. Relation between available soil moisture at planting time and yield of lint cotton, 1930-52.

available moisture was above the minimum amount required for normal growth.

RELATION OF DEPTH OF SOIL MOISTURE AT PLANTING TIME TO THE YIELD OF COTTON

Even though the quantity of available soil moisture at planting time serves as a reliable yardstick of probable cotton production, it is a measure that is difficult to use. Certain basic information, such as field capacity, minimum point of exhaustion and volume weight of the soil, must be known to determine the amount of available moisture in the soil. For widespread use by the grower,

Table 12. Relation between depth of soil moisture at planting time and yield of cotton, Spur 1930-52

Depth of moisture feet	No. of cases	Av. yield lint lbs. per acre	Percent of cases when yield was			
			0-99 lbs.	100-199 lbs.	200-299 lbs.	300 lbs.
1	64	44	91	8	2	0
2	37	104	57	41	0	3
3	53	170	25	49	17	9
4	56	300	0	29	23	48
Total	210	32,534				
Av.		155	44	30	11	16

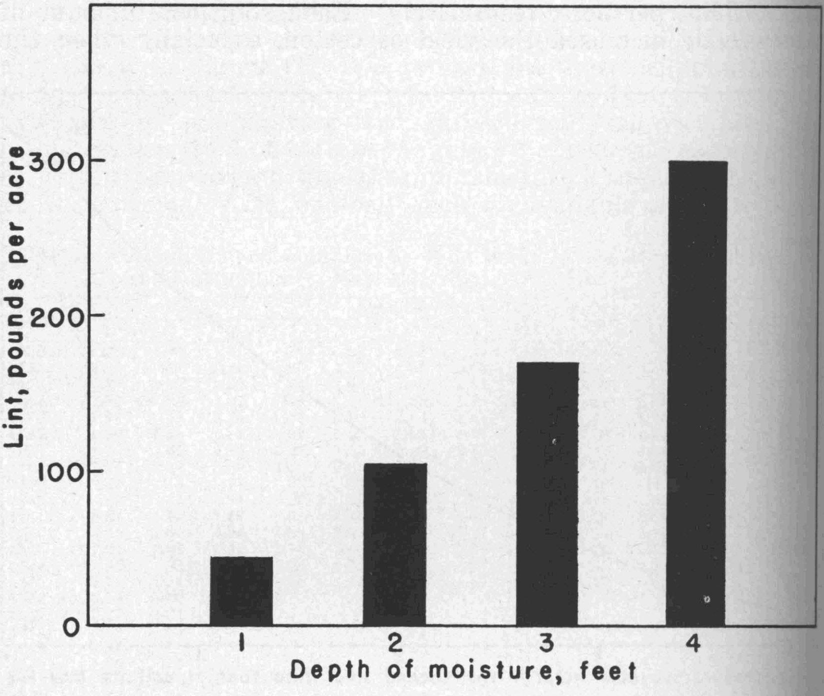

Figure 13. Effect of depth of soil moisture at planting time (May 20) on the yield of cotton.

a simple and easy method of evaluating soil moisture is needed. Fortunately, the depth of moisture is a good measure of the amount of water stored in the soil (2, 6). When water penetrates a dry soil, the first foot must be wet to its carrying capacity before any water can reach the second foot. The same holds true for movement of water to the soil layers at lower depths. The change from a wet to a dry zone of soil usually occurs within only a few inches and can be easily observed. If the soil contains enough moisture to form a firm ball when pressed between the fingers, it may be considered wet. Analysis of available moisture data in view of depth of penetration showed that any foot-section of the soil that contained more than one-half inch of available moisture should be considered wet. Thus, if the first foot contained more than one-half inch available moisture and the second foot showed less than one-half inch, the soil was considered to be wet only 1 foot deep. The same method was used to determine the depth of moisture in the second and third foot layers of soil. For the fourth foot, the soil was considered wet when the third foot contained more than 1 inch of available water.

The effect of depth of soil moisture at planting time on the yield of cotton is shown in Table 12 and Figure 13. Of a total of 210 plot-years, there were 64 cases when moisture was only a foot deep or less at planting time. The average yield of lint cotton was 44 pounds per acre; in 91 percent of the cases, the yield was less than 100 pounds of cotton. Timely rainfall during the summer in 8 percent of the cases resulted in yields of 100 to 200 pounds, and in only 2 percent of the cases were yields over 200 pounds. No yields of over 300 pounds per acre were produced when the soil was wet only 1 foot deep at planting time. Under these conditions, there is only 1 chance in 10 that yields of over 100 pounds of cotton will be produced.

There were 37 cases when the soil was wet 2 feet deep at planting time and the average yield was 104 pounds of lint cotton per acre. In 57 percent of the cases, yields were below 100 pounds and in 41 percent of the cases they ranged from 100 to 200 pounds. Only 3 percent of the crops yielded over 300 pounds per acre. With moisture 2 feet deep at planting time, there are only 4 chances out of 10 that the yields will exceed 100 pounds of cotton per acre.

When the soil was wet 3 feet deep (53 cases), the average yield of lint cotton was 170 pounds per acre. Twenty-five percent of the crops produced less than 100 pounds of cotton, 49 percent produced yields between 100 and 200 pounds and 26 percent of the yields were over 200 pounds per acre. With 3 feet of moisture at planting time, the chances are 3 to 1 that yields will be over 100 pounds and 1 to 3 that yields will be above 200 pounds of cotton per acre. There is 1 chance in 10 that the yields will be above 300 pounds.

When the soil was wet 4 feet deep at planting time (56 cases), the average yield was 300 pounds of lint cotton per acre. None of the crops produced less than 100 pounds per acre and 71 percent produced over 200 pounds. Forty-eight percent of the crops yielded over 300 pounds. The odds of producing yields of over 200 pounds are approximately 3 to 1 with no yields below 100 pounds.

EFFECT OF PRESEASONAL RAINFALL ON THE YIELD OF COTTON

There is a close relation between preseasonal rainfall and the yield of cotton. During most seasons, moisture accumulates in the soil on land planted to cotton from rainfall received during the winter and spring when no crop is grown on the land. Occasionally, however, moisture may remain in the soil from late summer and fall on land continuously planted to cotton because of heavy rainfall, or as a result of crop failures, poor stands or other reasons.

Table 13 shows the amount of preseasonal moisture and the yield of lint cotton for the 35-year period, 1914-52. If the crops are classified into groups with varying amounts of total rainfall received during the period November 1 to June 1, a good indication

Table 13. Preseasonal rainfall and yield of cotton, Spur, 1914-52

Year[1]	Total rainfall, Nov. 1 to June 1, inches	Average yield of lint cotton, lbs. per acre
1913-14	18.71	538
15	18.09	336
17	4.53	167
18	4.07	97
19	13.77	422
21	4.44	250
22	11.87	158
23	8.77	75
24	7.99	159
25	8.21	125
26	10.14	324
27	6.70	290
28	6.51	110
30	4.92	49
31	9.43	206
33	8.51	369
34	7.76	0
35	8.79	191
36	8.73	48
37	7.14	224
38	9.55	186
39	5.93	3
40	5.50	38
41	18.87	472
42	6.88	309
43	6.33	115
44	9.49	78
45	7.60	70
46	5.47	143
47	11.81	176
48	9.35	141
49	12.14	386
50	8.68	141
51	6.69	162
52	5.86	23
Average	8.84	188

[1]The cotton crops were destroyed by hail in 1916, 1920, 1929 and 1932. Therefore these years are omitted.

of the yields of cotton is obtained. The average rainfall from November 1 to June 1 was 8.84 inches. Table 14 shows that when the rainfall was less than 8.00 inches, the average yield of cotton tended to be below normal, and when rainfall was above 8.00 inches above average yields were produced. Thus, with a total rainfall of 4 to 8 inches from November 1 to June 1, the yield was 126 pounds of lint cotton per acre. If the rainfall ranged from 8 to 12 inches, the average yield increased to 188 pounds, and to 427 pounds per acre when the rainfall from November 1 to June 1 exceeded 12 inches.

Even though there is a close relationship between the amount of preseasonal rainfall and the yield of cotton, the large number of poor crops produced when rainfall was above normal and several good crops when rainfall was below normal, indicate this measure of estimating yields of cotton is not too reliable, even though easily

Table 14. **Effect of preseasonal rainfall, November 1 to June 1, on lint cotton yields, Spur, 1914-52**

Rainfall, inches	Number of cotton crops producing				Average yield of lint cotton per acre
	0-100 lbs.	100-200	200-300	300 & over	
4.00 to 8.00	7	6	3	1	126
8.00 to 12.00	4	7	1	2	188
12.00 or over	0	0	0	5	427

made. Such factors as moisture stored in the soil prior to November 1, losses of rainfall due to runoff and evaporation from the soil, especially following small ineffective showers, losses due to weed growth and occasional late growth of cotton, make it desirable to determine the actual amount of water in the soil, or at least the depth of moisture penetration.

EFFECT OF SUMMER RAINFALL ON THE YIELD OF COTTON

Once cotton is planted, the amount and distribution of rainfall during the summer is of great concern to the grower. Even though available soil moisture at planting time greatly influences the yield of cotton, it is not presumed that high yields can be produced without any summer rainfall. If ample amounts of well-distributed rainfall should occur throughout the growing season, the amount of moisture in the soil at planting time would have little or no influence on yields. Rainfall during the summer and yield of cotton from 1914 through 1952 are shown in Table 15. The data from 1930 through 1952 show, however, that there is little likelihood of producing high yields of cotton when either available moisture at planting time or summer rainfall, from June 1 to October 31, is well below the average, Table 16. The highest average yield, 239 pounds of lint cotton per acre, was produced when both the available moisture at planting time and summer rainfall were above normal. If soil moisture was above normal at planting time and the summer rainfall was below normal, the average yield was 198 pounds of lint cotton. The yield dropped to

142 pounds per acre when soil moisture at planting time was below normal and was followed by above normal rainfall during the summer. If both available soil moisture at planting time and summer rainfall were below normal, the yield averaged only 71 pounds of lint cotton per acre.

Table 15. Summer rainfall and yield of lint cotton, Spur, 1914-52

Year[1]	Total rainfall, June 1 to October 31, inches	Average yields of lint cotton, lbs. per acre
1914	18.51	538
1915	19.14	336
1917	10.68	167
1918	8.13	97
1919	7.35	422
1921	8.62	250
1922	5.68	158
1923	14.76	75
1924	6.33	159
1925	16.93	125
1926	25.18	324
1927	12.22	290
1928	12.14	110
1930	10.80	49
1931	6.76	206
1933	9.35	369
1934	4.75	0
1935	14.81	191
1936	16.93	48
1937	13.57	224
1938	10.09	186
1939	6.71	3
1940	6.12	38
1941	26.32	472
1942	15.14	309
1943	10.99	115
1944	9.60	78
1945	15.76	70
1946	12.35	143
1947	3.09	176
1948	8.62	141
1949	16.49	386
1950	14.20	141
1951	14.58	162
1952	4.55	23
Average	11.92	188

[1]The cotton crops were destroyed by hail in 1916, 1920, 1929 and 1932. Therefore, these years are omitted.

Table 16. Effect of summer rainfall on the yield of lint cotton at Spur, with varying amounts of available moisture at planting time

Available moisture at planting time	Rainfall, June 1 to Oct. 31	No. cases	Yield of lint cotton, lbs. per acre
Above average	Above average	55	239
Above average	Below average	50	198
Below average	Above average	35	142
Below average	Below average	70	71

EFFECT OF CONSERVATION PRACTICES ON COTTON PRODUCTION, RUNOFF AND SOIL MOISTURE

The use of conservation practices to store greater quantities of water in the soil offers unlimited possibilities to reduce runoff and erosion, increase yields of crops and stabilize farming on the Rolling Plains. The effect of terracing and contouring on runoff, available soil moisture, yields of lint cotton and gross returns is shown in Table 17. Cotton has been grown continuously on the

Table 17. Effect of conservation practices at Spur on runoff, available soil moisture at planting time (May 20), yield of lint cotton and value of crop

Year	CONSERVATION PRACTICES												
	None (Rows with Slope)					Rows on Contour				Rows on contour supplemented with closed level terraces			
	Rainfall, inches	Runoff, inches	Moisture, inches[2]	Yield, lint, lbs. per acre	Acre value, dollars[3]	Runoff, inches	Moisture, inches[2]	Yield, lint, lbs. per acre	Acre value, dollars[3]	Runoff, inches	Moisture, inches[2]	Yield, lint, lbs. per acre	Acre value, dollars[3]
1927	16.12	.38	[1]	239	55.14	.15	[1]	240	55.37	0	[1]	279	64.27
1928	19.99	2.88	[1]	58	12.66	3.73	[1]	111	24.23	0	[1]	217	46.36
1929	14.76	2.52	[1]	0[4]	00	2.13	[1]	0[4]	00	0	[1]	0[4]	00
1930	18.50	1.49	.02	9	1.08	.72	.25	34	4.07	0	1.27	104	12.47
1931	16.46	.36	1.44	186	12.57	.05	2.00	202	13.66	0	1.89	229	15.47
1932	27.70	2.83	[1]	0[5]	00	1.70	[1]	0[5]	00	0	[1]	0[5]	00
1933	15.59	.90	2.10	325	37.42	.31	2.39	340	37.88	0	2.05	441	50.78
1934	12.88	.79	.53	0[6]	00	.28	.12	0[6]	00	0	.65	0[6]	00
1935	23.78	3.06	.60	118	16.82	2.55	1.06	186	26.51	0	2.04	270	38.47
1936	24.47	3.98	1.49	39	5.65	1.99	1.60	50	7.27	0	1.68	55	7.98
1937	20.28	4.16	2.64	186	23.53	2.07	2.34	193	24.42	0	2.20	292	36.95
1938	19.96	3.24	2.21	147	14.01	2.18	2.30	176	16.78	0	2.31	236	22.50
1939	13.06	.50	.19	6	.70	.20	.11	2	.24	0	.11	2	.24
1940	15.58	2.28	.47	21	2.29	.90	.65	41	4.47	0	.57	52	5.66
1941	42.87	12.60	3.15	442	79.12	13.17	2.87	497	88.97	0	3.21	478	85.55
1942	23.10	2.91	3.31	285	58.38	.68	3.04	331	67.79	0	2.97	310	63.48
1943	17.80	2.87	1.82	77	18.75	1.64	2.21	106	25.80	0	1.94	162	39.44
1944	21.32	.98	.77	61	16.21	.19	.69	78	20.74	0	.75	96	25.51
1945	19.59	3.53	1.55	63	17.28	2.41	1.31	58	15.92	0	1.16	89	24.42
1946	18.75	[1]	.99	116	42.48	[1]	1.18	136	49.82		1.79	177	64.85
1947	17.07	[1]	2.21	150	54.12	[1]	2.25	167	60.36		3.02	211	79.93
1948	14.33	[1]	.69	108	38.17	[1]	.60	125	54.17		1.05	190	67.17
1949	29.18	[1]	.69	193	56.67	[1]	1.19	430	126.25		2.25	534	147.38
1950	21.86	[1]	.25	111	51.59	[1]	.29	125	58.09		1.31	187	86.92
1951	21.24	[1]	.24	99	40.71	[1]	.48	159	65.39		.38	229	94.19
1952	12.49	[1]	.51	8	2.25	[1]	.64	16	5.34		.69	46	15.23
Total	518.73		27.87	3047	657.90		29.57	3793	843.54		35.29	4886	1095.22
Av.	19.95	2.75	1.27	117	25.30	1.95	1.34	146	32.44	0	1.60	188	42.12

[1]Records not available.
[2]In second and third feet of soil.
[3]Based on actual prices received on local market for lint and seed.
[4]Crop destroyed by hail in September.
[5]Crop destroyed by bollworms.
[6]Crop failed because of drouth.

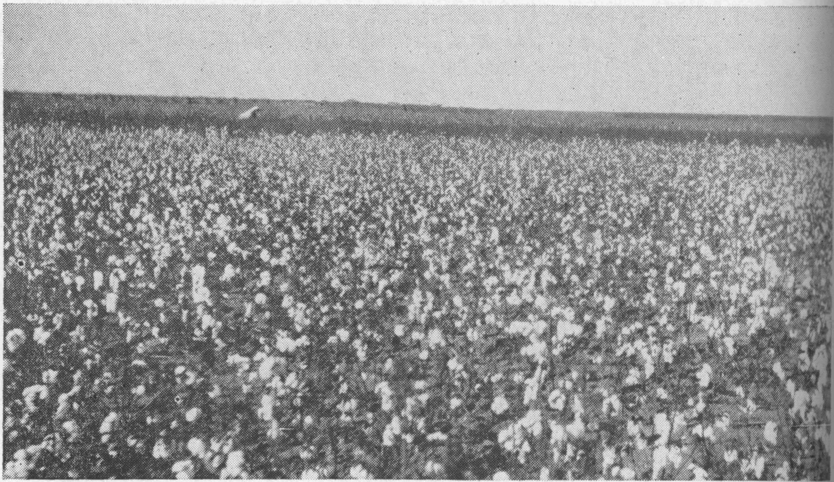

Figure 14. Cotton crop that produced 441 pounds of lint per acre on land that was contoured and terraced to prevent runoff and erosion. An excellent "bottom season" of moisture at planting time was largely responsible for the high yield of cotton. Over a 26-year period, the average yield has been 188 pounds on land that has been farmed on the contour with closed level terraces.

field plots since 1927. The erratic nature of the rainfall is reflected in extreme variations in runoff, soil moisture and yields of cotton.

The practice of contouring reduced runoff from 2.75 inches for straight-row farming on land with 0.5 percent slope to 1.95 inches and increased the yield of cotton 29 pounds per acre. The increased annual gross returns for contour farming over straight-row farming

Figure 15. Cotton crop that produced 61 pounds per acre on land with straight rows and "no bottom season of moisture" at the time of planting. The average yield over a 26-year period has been 117 pounds of lint per acre on land farmed with rows up and down the slope. The average runoff has been 2.75 inches.

averaged $7.14 per acre. Since little or no additional labor was necessary to farm on the contour, the increased return may be considered clear profit. The use of closed level terraces in conjunction with contouring prevented runoff, increased the yield of cotton 71 pounds per acre over straight-row farming and increased the moisture content of the soil. In addition to the control of runoff and erosion, the annual value of the increased

Figure 16. 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 was .70 inch, and the slope on these rows is only 0.5 percent. These pictures were made within an hour after the rain had stopped falling.

cotton production was $16.82 per acre from the use of closed level terraces and contour farming. The portion of the increased annual return attributed to terracing, $9.68 per acre, far exceeds the average cost of $5.00 to $8.00 per acre required once every 10 years for building and maintaining terraces.

The prevention of runoff by the use of closed level terraces largely accounts for the increased cotton production. Reducing the runoff by one acre-inch increased the acre yield of lint approximately 26 pounds with a value of $5.51. The value of one acre-foot of water saved averaged $66.12.

The average moisture content of the second and third feet of soil at planting time on closed level terraced areas was 1.60 inches, as compared with 1.27 inches on areas with rows in the direction of the slope. Moisture stored in the subsoil is less subject to losses by evaporation and weed growth, hence leaving a greater amount of moisture available to deep-rooted crops such as cotton. The value of subsoil moisture is indicated by the fact that each additional inch of moisture stored in the subsoil at planting time increased the average yield of lint cotton approximately 107 pounds per acre.

On the land that was contoured and terraced to prevent runoff and erosion, the highest yield of cotton, 534 pounds per acre, was produced after 23 years of continuous cotton production. On contoured land, relatively high yields also were produced after a long period of cotton production. On areas with straight rows, the highest yield, 442 pounds, was produced after 15 years of continuous cotton production.

The heavy clay loam soils have not responded to applications of nitrogen and phosphorus fertilizer, even when moisture conditions have been highly favorable.

VALUE AND USE OF SOIL MOISTURE INFORMATION

Since the productivity of heavy soils on the Rolling Plains is largely dependent on available moisture stored in the subsoil, every effort should be made by farmers to conserve most of the rainfall. Effective methods include contouring, terracing, water spreading, management of crop residue, tillage practices and other means that reduce runoff, increase depth of moisture penetration and reduce evaporation.

The close relation between the amount of available moisture at planting time and the yield of cotton may be used by the farmer as a valuable guide for planning his farming operations. This information also serves as a valuable yardstick for business and industry connected with agriculture in the region. Information on the likelihood of producing poor, fair and good to excellent

Figure 17. Use of level terraces to spread water and prevent runoff has paid big dividends on land with less than 1 percent slope. Above, a station field following a 5-inch rain. Below, a crop of Early Hegari produced on the land that year.

yields of cotton at planting time permits adjustments to be made early enough in the season, according to probable yield and returns from different crops, to help stabilize farming and business.

The grower, business man and others whose economy is largely dependent on cotton production, should determine the amount of preseasonal rainfall during the winter and early spring. This information will serve as a general guide for the area of the amount of moisture that likely will be stored in the soil at planting time, but will vary according to amount of runoff, character of rainfall, previous crop, slope, soil type, preparation of the land and other factors. In most instances, extremes of rainfall, either above or below normal, will give some indication of crop prospects.

The grower will necessarily obtain the greatest benefit from soil moisture information by actually determining how deep the soil is wet in his fields. If the soil is wet to a depth of 4 feet or more prior to the planting of cotton, the grower has an excellent chance to produce good to excellent yields with little likelihood of failures. Undoubtedly, he should expand his normal cotton acreage to take advantage of the favorable moisture conditions. Every opportunity should be taken to use good cultural practices to obtain maximum yields. In some instances, this might well

Figure 18. Tillage implements that leave the soil cloddy and maintain crop residues near the surface help reduce runoff, aid deep penetration of moisture and reduce evaporation.

mean the trial of fertilizers, use of special weed control measures, preparation for the control of insects and the use of other practices that might benefit the crop when there is sufficient moisture to produce high yields.

If the soil is wet to a depth of 3 feet at planting time, the acreage of cotton may be expanded if the price outlook is favorable. The odds are about 3 to 1 that yields will be greater than 100 pounds of lint per acre and 1 to 3 that yields will exceed 200 pounds. Every effort should be made to manage the production of cotton from the standpoint of cultural practices and insect and weed control measures.

In those years when the soil is wet 2 feet deep at planting time, the grower has approximately a 1 to 1 chance of producing over 100 pounds of lint cotton per acre. The likelihood of producing less than 100 pounds is somewhat greater than of producing over 100 pounds. The grower probably should plant cotton on the most productive land and, perhaps, reduce his cotton acreage, depending on economic conditions and the opportunity to utilize other crops that require less labor and which fit into the farm operations. Expenses and outlay of capital should be curtailed since the prospects of a good cotton crop are relatively poor. Such crops as late planted grain sorghum, soil-building crops and forage sorghums offer good possibilities of reducing costs of production when moisture conditions are unfavorable. In some instances, fallow during the summer to improve moisture conditions may be desirable for the fall seeding of wheat, or clean fallow may be used to control badly-infested fields of Johnson grass. The general theme of farming under these conditions should be one of reducing expenditures and utilizing what moisture is available for temporary and short-season crops.

When the soil is wet less than 1 foot deep at planting time, the odds are about 9 to 1 that the yield of cotton will be less than 100 pounds per acre. There is little likelihood of producing yields above 200 pounds of cotton. Under these conditions, curtailment of expenditures should usually be the goal for all farm operations. Only the most suitable areas of land should be planted to cotton unless other crops cannot be produced and utilized profitably. The use of fallow, sorghums, soil-building and grazing crops, or others that can be grown and harvested at low cost, offer the best means of coping with the unfavorable moisture conditions.

Even though the probability of producing good to excellent crops of cotton is largely governed by the amount of preseasonal moisture and subsoil moisture at planting time, with average summer rainfall, there always remains some chance of producing good crops. The adjustment of cotton acreage to the probable yield outlook should serve, however, as a valuable guide to make the best use of moisture, equipment, land and other resources.

SUMMARY

Crop production on the heavy soils of the Rolling Plains is chiefly governed by the amount of water available for plant growth. Soil fertility seldom influences crop yields, except on the lighter sandy soils when rainfall and soil moisture are more favorable.

Since available moisture limits crop production, major emphasis is placed on factors that influence the accumulation and utilization of soil moisture.

Results of 27 years of research at Substation No. 7 near Spur on moisture conservation studies are reported in this bulletin. The soils on which these studies were made include Abilene, Tillman and Weymouth clay loams with slopes ranging from 0.5 to 2 percent. The findings are applicable to 14 million acres of heavy soils on the Rolling Plains of Texas and indirectly to other areas where moisture limits crop production.

The average annual rainfall for the 42-year period, 1911-52, was 20.85 inches. Extremes of rainfall have ranged from 11.09 inches in 1924 to 42.87 inches in 1941. Seventy-two percent of the annual rainfall occurs from May 1 to November 1 and is characterized by two peaks, one in May and one in September, with a depression extending from June 15 to August 15.

Soil moisture accumulation is influenced largely by the amount and character of rainfall, soil type, evaporation, crops, plant residues, slope of land, tillage and conservation practices.

Total rainfall is not a reliable index of the amount of moisture available for plant use. Sixty-one percent of the annual rainfall produced runoff varying from .57 to 10.66 inches, with an average loss of 3.55 inches. Another 2.74 inches of the rainfall are lost as small, ineffective showers. For rainfall causing runoff, 5.92 inches were torrential, 1.82 inches were moderate and 4.93 inches fell as gentle rain. Thirty-five percent of the annual rainfall from 1912 through 1952 occurred in rain periods of 2 inches or more, with the highest percentage of 2-inch rain periods occurring during August, September and October. Conservation of water from these heavy rain periods reduces runoff and erosion, benefits crops and offers excellent opportunities to store water in the soil for future plant use.

The clay loam soils have a high water-holding capacity and provide an excellent storage place for moisture if steps are taken to reduce runoff and evaporation. Moisture losses by evaporation from the soil are relatively high but may be reduced by the use of practices that will increase the depth of moisture penetration and reduce losses from the surface.

A good cover of buffalo grass provides the most effective means to reduce runoff and erosion. Clean cultivated crops, such as cotton or fallow, require the use of conservation practices to control runoff and erosion.

Contouring supplemented with closed level terraces increased the yield of cotton, depth of moisture penetration, and the amount of water stored in the soil and reduced runoff and erosion.

Applications of sorghum residues increased the depth of moisture penetration, the amount of available moisture in the soil and the yield of cotton. The greatest increase from the use of crop residues was obtained on land with rows running with the slope. A combination of contouring and terracing supplemented with crop residue management appears to offer the best means for increasing the amount of water that is stored in the soil.

Native grasses and associated plants utilize soil moisture to depths of 4 to 6 feet throughout much of the year, thus, providing storage space for additional moisture in the soil. Cotton has a deep root system and uses moisture heavily during a 90-day period from June 20 to September 20. Sorghums have fibrous root systems that utilize moisture heavily to a depth of 2 to 3 feet at the heading stage of growth.

The close relationship between the amount of available moisture stored in the second and third feet of soil at planting time and the yield of cotton is indicated by a highly significant correlation coefficient of .747. A high moisture content of soil at planting time is followed by a high yield, and a low content by a low yield. Thus, amounts of 1.00, 2.00, 3.00 and 4.00 inches of moisture stored in the soil at planting time, indicate the likelihood of producing 89, 187, 330 and 518 pounds of lint cotton per acre, respectively.

There also is a close relationship between the amount of available water stored in the soil and the depth of moisture penetration. Cotton produced an average of 44. 104, 170 and 300 pounds of lint per acre when the soil was wet 1, 2, 3, and 4 feet deep, respectively, at planting time.

The odds of producing over 100 pounds of lint cotton per acre were about 1 to 10 when the soil was wet 1 foot deep at planting time, approximately 1 to 1 when the soil was wet 2 feet deep and 3 to 1 when the soil was wet 3 feet deep. The chances for producing over 200 pounds of lint cotton per acre were approximately 1 to 48 when the soil was wet less than 2 feet deep at planting time, and 3 to 1 when the soil was wet 4 feet deep.

The amount of preseasonal rainfall from November 1 to May 31 gives a general indication of the amount of moisture that is stored in the soil at planting time but is less reliable than soil moisture determinations. Rainfall from June 1 to October 31 influences the yields of cotton less than the amount of moisture stored in the soil at planting time.

Farming the land on contour supplemented with closed level terraces significantly increased the yields of cotton and reduced runoff and erosion. Contouring alone increased the yield of lint cotton an average of 29 pounds per acre over straight-row farming while contouring with closed level terraces increased the yield 71 pounds.

The annual increased gross returns from farming land of 0.5 percent slope on the contour with closed level terraces was $16.82 per acre over land farmed with straight rows. In addition, there was no runoff or erosion on the contoured and terraced land.

Since the productivity of the heavy soils on the Rolling Plains is largely dependent on the amount of moisture stored in the soil, the use of conservation practices will reduce runoff and erosion, increase yields and help stabilize crop production.

Knowledge of the moisture stored in the soil provides a yardstick for adjusting the acreage of crops and farming operations to enable the grower to make the best use available of moisture and resources.

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