Moisture Use by Cotton in the Piedmont of Georgia

John F. Thornton
MEMBER ASAE

IRRIGATION of crops on farms in Georgia and other southeastern states is increasing rapidly. Technical data on soil-water-plant relationships, crop-yield responses, and other phases of irrigation practices are urgently needed. In the southeastern states, engineers, agronomists, and soil scientists are engaged in the development of needed guides in the design of irrigation systems. The three basic design factors for irrigation-water application are (a) evapotranspiration, (b) infiltration or the rate at which the soil will absorb water, and (c) available capacity or the amount of water available to plants that can be stored by the soil in the root zone. A thorough search of the literature revealed insufficient data on these three basic factors. Many systems have been overdesigned to compensate for this lack of information. This practice has resulted in wasted water and inefficient use of power.

Evapotranspiration, also called "consumptive use," refers to the rate at which water is lost from the soil by both transpiration and evaporation from the plants, and evaporation from the soil. The rate of evapotranspiration depends on climate, soil-moisture supply, vegetative cover, soil, and land management. The climatic factors that particularly affect consumptive use are precipitation, temperature, humidity, wind movement, and length of growing season. The quantity of water transpired by plants depends upon the amount of water at their disposal, as well as on temperature and dryness of the air, the intensity of sunlight, wind movement, the state of the development of the plant, the amount of its foliage, and the nature of its leaf and root system.

There are several available methods by which consumptive use can be estimated. Chief of these are the Blaney-Criddle, the Thornthwaite, and the van Bavel methods of estimating evapotranspiration.

The Blaney-Criddle (1)* method gives consideration to temperature and daytime hours as the most important factors influencing consumptive use. The Thornthwaite (2) theory of evapotranspiration employs an empirical formula based on latitude and average temperature of the air as the only variables. The van Bavel (3) method utilizes air temperature, sunshine duration, and extraterrestial radiation. Van Bavel and Wilson (4) showed how the values so computed can be utilized in a "bank account" of available soil moisture. Rainfall and irrigation add to the moisture balance, and the daily consumptive

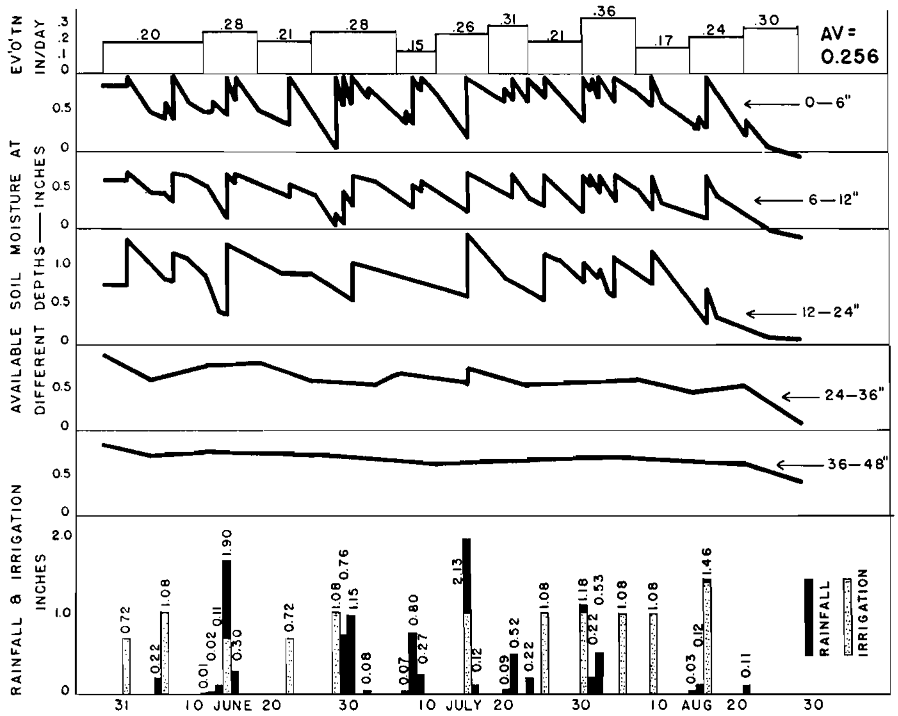

FIG. 1 Cotton irrigated at 60 percent available soil moisture in 1956.

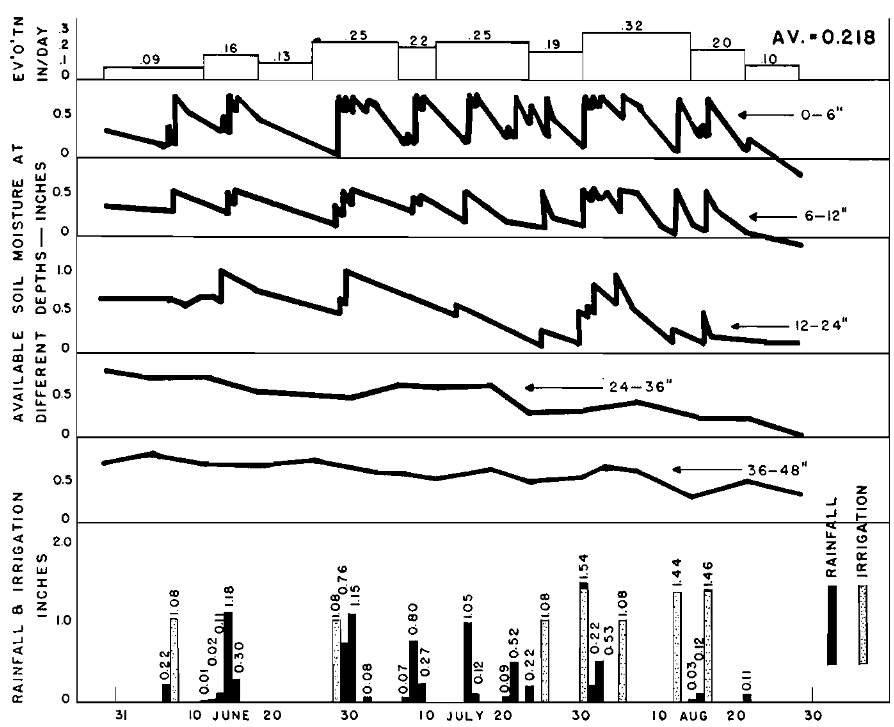

FIG. 2 Cotton irrigated at 30 percent available soil moisture in 1956.

Paper presented at the Winter Meeting of the American Society of Agricultural Engineers at Chicago, Ill., December 1956, on a program arranged by the Soil and Water Division.

The author—JOHN F. THORNTON—agricultural engineer, (SWCRD, ARS) USDA and agricultural experiment station, University of Georgia, Athens.

* Numbers in parentheses refer to the appended references.

This article is reprinted from the TRANSACTIONS of the ASAE (vol. 4, no. 1, pp. 37, 38, 39, 40 and 44, 1961), the Transactions of the American Society of Agricultural Engineers, Saint Joseph, Michigan

use reduces the quantity present. When enough days have elapsed to reduce the balance to near zero, irrigation is needed.

These methods of estimating moisture withdrawal from the soil are valuable tools in the design and operation of irrigation systems. However, whether these estimates are sufficiently accurate for use in designing irrigation systems is debatable. Consequently, daily and periodic maximum rates of evapotranspiration need to be measured in order to provide a more accurate evaluation of their reliability for determining when to irrigate.

It is the purpose of this paper to present evapotranspiration data for cotton as an aid to those who are designing irrigation systems, as well as for those planning irrigation research. Furthermore, these data may help determine the minimum water requirements for optimum yields of cotton.

Plan of Experiment

The irrigation studies which were conducted during the period 1952 to 1956 are shown in Table 2. The magnitude of the study increased steadily during the period.

The irrigation study, reported herein, was conducted during 1956 on an upland field at the Southern Piedmont Conservation Station. The soil was a Cecil sandy loam, which is derived from very old and deeply weathered igneous and metamorphic rock. The crop grown was cotton, Coker's 100 wilt resistant variety, chosen because it represents a crop common to the agriculture of this area. The rooting habit of this crop is a taproot system.

The fertilization for cotton included 500 lb per acre of 0-12-12, broadcast and disked in before planting, with 500 lb per acre of 4-12-12 put in the row at planting. Ammonium nitrate was applied as a side dressing during cultivation at a rate of 300 lb to give 120 lb per acre of nitrogen. Planting, cultivation and other practices were normal and identical on both the irrigated and non-irrigated plots.

The experimental design was randomized block with five replicates, each plot composed of six rows, 42 in. wide and 20.33 ft long.

The irrigation varieties included six levels of soil moisture as follows:

I_5, Irrigated when 40 percent of the available soil moisture was used from the soil (Fig. 1).

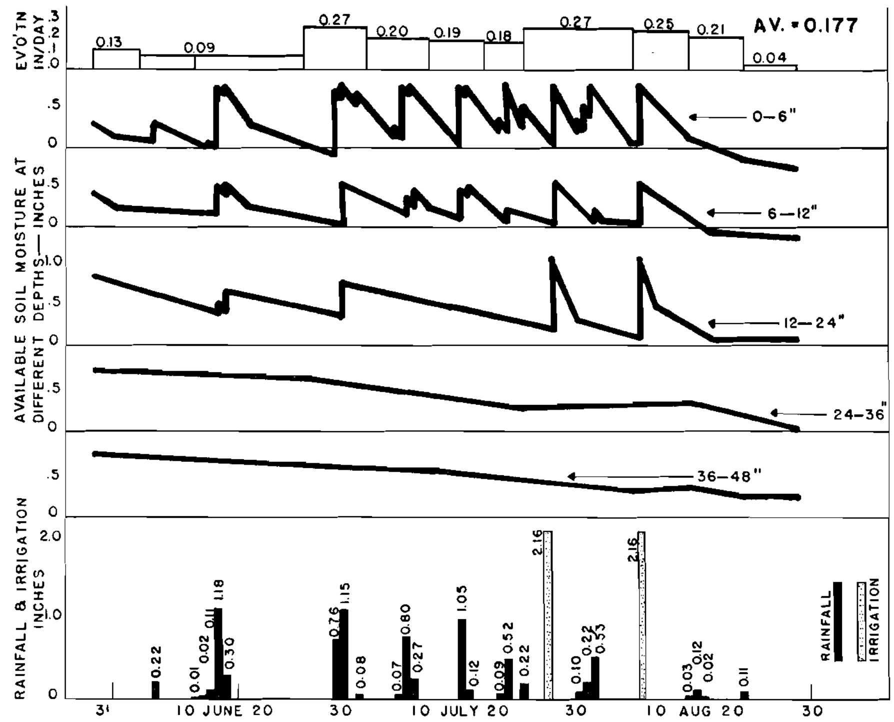

FIG. 3 Cotton irrigated at observed wilting in 1956.

I_4, Irrigated when 70 percent of the available soil moisture was used from the soil (Fig. 2).

I_3, Irrigated when plants showed signs of wilting (Fig. 3).

I_2, Irrigated 5 days after observed wilting (Fig. 4).

I_1, Irrigated when 100 percent available moisture was used from the top 24 inches of the soil (Fig. 5).

I_0, No irrigation (Fig. 6).

Water was applied to the irrigated plots as needed to bring the soil moisture up to field capacity in the top 24 in. of soil at each irrigation.

Irrigation water was applied to plots (21 by 20 ft in size) with two Rainbird No. 25 LA part-circle sprinklers mounted on diagonal corners of each irrigated plot. The average rate of application from these nozzles was 0.72 in. per hour over the plot with both sprinklers running, and 0.36 in. per hour when only one sprinkler was in operation. The distribution was good over the plot.

The rainfall totaled 8.10 in. during the 90-day period covered by this study. Irrigation applications during this period were made at the six levels of soil moisture and were as follows:

Treatment	Irrigations Number	Inches	Rainfall, inches	Total inches
I_0	0	0	8.10	8.10
I_1	2	5.76	8.10	13.86
I_2	2	4.32	8.10	12.42
I_3	2	4.32	8.10	12.42
I_4	7	8.64	8.10	16.74
I_5	11	11.16	8.10	19.26

Surface runoff was measured on small runoff plots to determine the net water entering the soil from rains. The runoff plots were 24.9 in. wide and 42 in. long, or 1/6,000 acre in area. The length extended across the width of one row. A sheet metal trough at the lower edge concentrated the water into a pipe that led downgrade to a measuring can.

Soil moisture records were begun for the cotton on May 28 when the plants were about 4 in. high. At that time the soil contained 3.52 in. of available moisture, which was 75 percent of the 4.70 in. of available water capacity in the soil to a depth of 48 in.

Soil moisture records were obtained from samples taken in each plot at depths of 0-6, 6-12, 12-24, 24-36, and 36-48 in. Samples were taken before each irrigation, two days following each irrigation or rain, and at three or four-day intervals between these readings. The percentage of moisture was determined by weighing and oven drying.

The percent moisture data were converted to inches of available moisture in the soil by the formula:

$$\mathbf{AW} = (\mathbf{SM} - \mathbf{WP}) \times \text{bulk density} \times \mathbf{D}/100$$

in which

AW = inches of available moisture
SM = percent soil moisture in the sample
WP = percent soil moisture at fifteen atmospheres
Bulk density = weight per unit volume in grams per cubic centimeter
D = inches depth of soil sampled

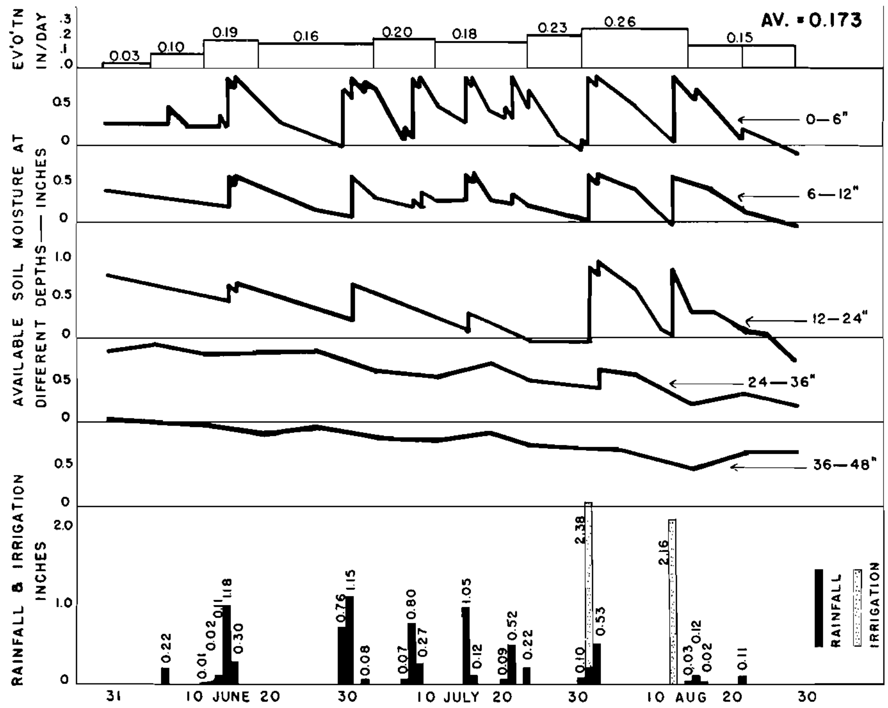

FIG. 4 Cotton irrigated 5 days after observed wilting in 1956.

The rate of evapotranspiration for each period between sampling dates was computed from the formula:

$$E = (M_1 + R + I - RO - M2 - D)/N$$

in which

- E = rate of evapotranspiration in inches per day
- M_1 = inches available soil moisture at beginning of the period
- R = inches rainfall
- I = inches irrigation
- RO = inches runoff
- M2 = inches available soil moisture at end of period
- D = drainage of soil moisture to levels below the root zone
- N = number days in the period

Results

The daily rainfall and irrigation, the available soil moisture, and the rates of evapotranspiration are given in Figs. 1, 2, 3, 4, 5, and 6.

The soil moisture under the non-irrigated cotton declined steadily after August 6. A deficit of 0.60 in. (below wilting point) was recorded August 27 in the 0-24-in. layer; only 0.40 in. of water was available in the 24-48-in. layer. A deficit condition in the 0-24-in. layer began August 6 and continued throughout the study.

The influence of the different soil-moisture treatments on the total use and on the peak use is very pronounced. These data point out the necessity for establishing the soil moisture range under which a crop will be grown before the peak-use and total-use values for the crop in question can be predicted with any degree of precision (Table 1).

Moisture content for the indicated soil depth at the beginning of a period, plus the rain and irrigation during the period, minus the moisture content at the end of the period – all divided by the number of days in the period – gave the value of average daily evapotranspiration shown by these figures. Results showed that non-irrigated cotton consumed moisture from a soil depth of more than 24 in. after July 10 (Fig. 6). There was very little moisture removed below the 24-in. depth in the high irrigated plots.

The rate of moisture use for the different levels of soil moisture by years is given in Table 2. These data show considerable differences in the peak rate and the average daily rate of water use each year. There were variations from one year to the next in both the peak and average rates of moisture used and between different moisture levels within the same year.

The peak rates were determined over short periods of only a few days' duration. It is believed the average rate of 0.20 in. per day during the main growing season more nearly represents the moisture-use requirement of cotton under the conditions of this experiment.

There was no effective rain from June 29 to July 29 in 1952. Irrigation at 5 to 7-day intervals maintained an adequate supply of moisture in the 0-18 soil horizon, while the soil of the non-irrigated cotton approached air-dry condition in that depth. The non-irrigated

TABLE 1. SOURCE AND AMOUNT OF WATER USED BY COTTON IN 1956

Treatments	Rain, in.	Irrigation applied, in.	From soil moisture, in.	Total, in.
I_0	8.10		3.05	11.15
I_1	8.10	5.76	2.46	16.32
I_2	•8.10	4.32	3.19	15.61
I_3	8.10	4.32	3.47	15.89
I_4	8.10	8.64	2.86	19.60
I_5	8.10	11.16	3.74	23.00

TABLE 2. AVERAGE DAILY RATE OF MOISTURE USE BY COTTON DURING THE MAIN GROWING SEASON OF JUNE, JULY AND AUGUST AT WATKINSVILLE, GA.

Year	Moisture level at irrigation in top 2 ft of soil	Rate of evapotranspiration for cotton (inches per day)			
		Irrigated		Not Irrigated	
		Maximum	Average	Maximum	Average
1952	10% AWC*	0.31	0.196		0.113
1953	10% AWC	0.34	0.213		(No record)
1954	30% AWC	0.31	0.216		0.184
1955	60% AWC	0.22	0.175	0.25	0.130
1955	30% AWC	0.30	0.180		......
1956	60% AWC	0.36	0.256		......
1956	30% AWC	0.32	0.218		......
1956	Observed wilting	0.27	0.177		......
1956	Observed w. + 5 day	0.26	0.173		......
1956	0% AWC	0.25	0.181		......
1956	Not irrigated	......	......	0.27	0.124
Average			0.199		0.146

* Available water capacity.

TABLE 3. SOURCE AND AMOUNT OF WATER USED BY COTTON IN 1955 AND 1956

Treatment	Soil		Rainfall		Irrigation		Total	
	1955	1956	1955	1956	1955	1956	1955	1956
Irrigated at:	In.	In.	In.	In.	In.	In.	In.	In.
None	4.34	3.05	6.99	8.10	0	0	11.33	11.15
0% AWC*	..	2.46	..	8.10	..	5.76	..	16.32
Observed wilt + 5 days	..	3.19	..	8.10	..	4.32	..	15.61
Observed wilt	..	3.47	..	8.10	..	4.32	..	15.89
30% AWC	2.24	2.86	6.99	8.10	6.48	8.64	15.71	19.60
60% AWC	2.46	3.74	6.99	8.10	5.76	11.16	15.21	23.00

* Available water capacity.

plants lived on moisture obtained from the soil below 18 in. depth.

In 1956, the rains were well distributed during June and July, but were deficient in August. There was little use of soil moisture below 24 in. depth, even without irrigation, until early August. The available moisture was not completely exhausted in the 36 to 48-in. zone at the end of the study the last of August.

The amount of water used (transpiration and evaporation) from stored soil moisture, rainfall and irrigation are shown in Table 3 for the different treatments in 1955 and 1956. Rainfall during the growing season was 6.99 and 8.10 in. in 1955 and 1956, respectively. Without irrigation, the cotton used 4.34 and 3.05 in. from the soil in 1955 and 1956, for a total use of 11.33 and 11.15 in. those two years. The amount of stored water used from the soil was lessened markedly in 1955 where additional water was applied. However, irrigation treatments had little effect on the amount of water used from the soil in 1956.

The data indicate that 70 percent of the water was used from the top one foot of soil and 90 percent came from the top 2 ft. It was only toward the end of August that water was used extensively from the third foot of soil, regardless of the level of soil moisture. About half the available moisture was left in the 3 to 4-foot layer at the end of the growing season, indicating the plant roots were not active in that layer.

The data in Table 3 cover only a 90-day period from May 28 to August 25, during the main growing season. Evapotranspiration during the periods extending from planting about April 15 to June 1, and from August 26 until harvest is completed about October 15 would require an additional estimated 6 or 8 in. of water. Assuming 7 in., the range of moisture in Table 3 would be 18 to 30 in. for the entire growing season from planting to harvest at Watkinsville, Ga.

The yield of cotton from the different levels of soil moisture in 1955 and 1956 are given in Table 4. Insect control and other production factors were managed for maximum production in these studies.

The yield of cotton increased with moisture to about 18 in. during the three-month growing season. Beyond 18 in. there was a slight decrease in yield.

Conclusions

Cotton needs a good supply of moisture during the boll setting period until three-fourths of the bolls are mature.

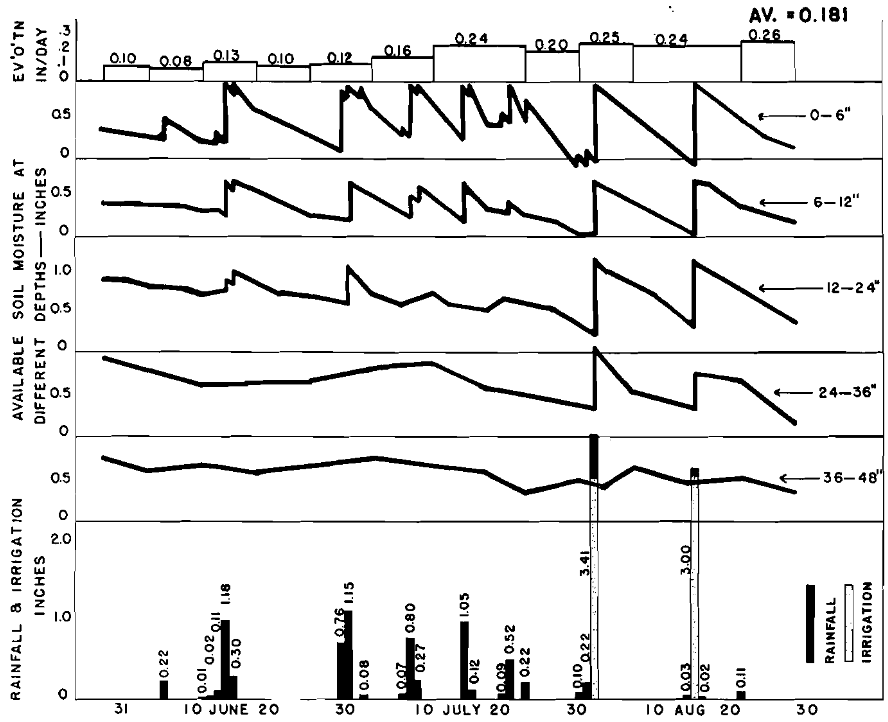

FIG. 5 Cotton irrigated at zero percent available soil moisture in 1956.

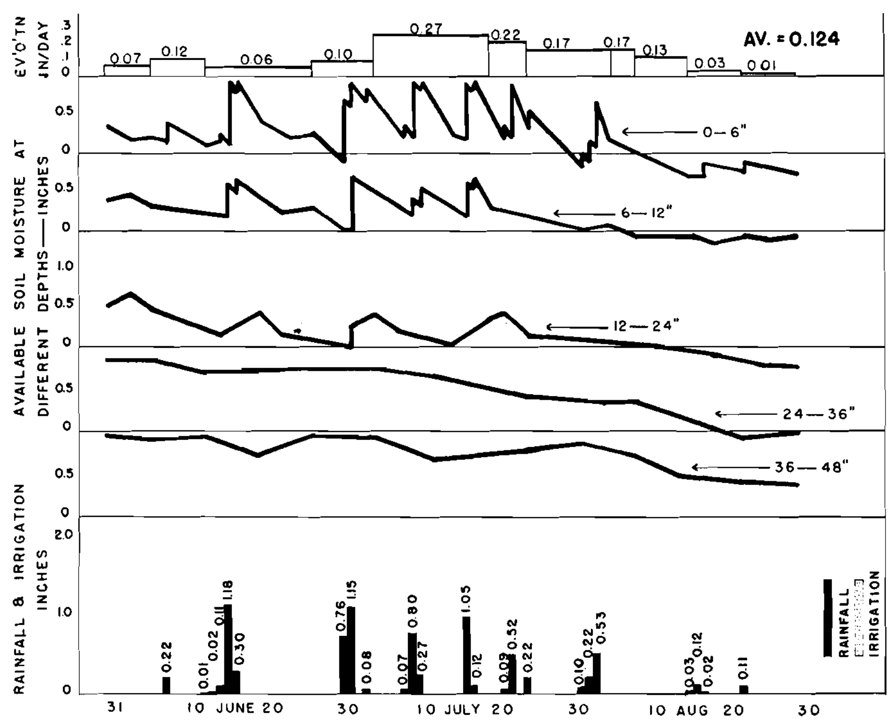

FIG. 6 Cotton not irrigated in 1956.

TABLE 4. YIELD OF SEED COTTON IN RELATION TO AMOUNT OF SOIL MOISTURE USED.

Year	Treatment	Water used in.	Yield, pounds per acre	Yield, pounds per acre per 1 in. of water	Yield with irrigation, pounds per acre	Increase pounds per acre per 1 in. of irrigation
1955	None	11.33	2383	210	....	....
1955	30% AWC*	15.71	3104	198	821	127
1955	60% AWC	15.21	2880	189	497	86
1956	None	11.15	1952	175	....	....
1956	0% AWC	16.32	3621	222	1670	290
1956	Observed w. + 5 day	15.61	3306	212	1354	313
1956	Observed wilt	15.89	2911	183	958	222
1956	30% AWC	19.60	3463	177	1510	175
1956	60% AWC	23.00	3257	142	1305	117

* Available water capacity.

Normally two good irrigations are sufficient to insure good yields. Moderate drought in the early growing period does little harm if cotton gets relief for the development of bolls already set rather than to set new ones. Irrigations as late as at the measured wilting point in the top 24 in. of soil increased the yield 86 percent over non-irrigated, which means 217.10 more pounds per acre in 1956.

The three low levels of irrigation did not affect the plant size and maturity date of cotton. The main effect of the two irrigations applied in these treatments was on development of bolls already set rather than to set new ones.

Soil with lower-moisture treatments showed a more efficient use of moisture available than those with higher-moisture treatments. As soil moisture increased, the efficiency of water use decreased.

The vegetative growth was proportional to moisture use. The height of plants measured 18 to 24, 36 to 42 and more than 60 in., respectively, for the limited, optimum, and excessive quantities of water used.

These data and observations lead to the conclusions that:

(a) Cotton should have an ample but not excessive supply of moisture throughout the growing season.

(b) Yields are proportional to available moisture up to 6 in. per month during June, July and August. Moisture used in excess of that amount will cause some decrease in yield.

References

1 Blaney, Harry F. and Criddle, Wayne D. Determining water requirements in irrigated areas from climatological and irrigation data, Soil Conservation Service Tech. Paper-96, 1950.

2 Thornthwaite, C. W. An approach toward a rational classification of climate, The Geogr. Rev. 38:55-94, 1948.

3 van Bavel, C. H. M. Estimating soil moisture conditions and time for irrigation with the evapotranspiration method, U.S. Department of Agriculture, ARS 41-11, 1956.

4 van Bavel, C. H. M. and Wilson, T. V. Evapotranspiration estimates as criteria for determining time of irrigation, **Agricultural Engineering**, vol. 33, pp. 417-418, 420, July, 1952.