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Application of Rainfall and Temperature Probabilities to Cotton Production

TEXAS HIGH PLAINS

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Summary

Air-temperature and rainfall data from the Texas Agricultural Experiment Station, Lubbock, for the period 1917-62 were analyzed and various probability values calculated. The rainfall and temperature patterns of the area are described; and the use of temperature and rainfall probabilities in long-range planning of cotton production practices is discussed.

During November through March, there is generally less than one rainfall interval per basic period of one-third month. When it does rain, the amounts received average less than 0.45 inch per rainfall interval. On the other hand, almost all of the remaining basic periods have an average of more than one rainfall interval. The peak of rainfall activity comes during the last part of May and the first part of June.

The rainfall probabilities indicate that generally, there will not be sufficient preseason moisture to obviate the need for a preplant irrigation if planting is to be done by May 1. The probabilities also show that one or more summer irrigations will be needed almost every season if the producer is striving for yields of about two bales per acre.

About 50 percent of the time, at least 13.00 inches of rainfall will occur during the cotton growing season, May 1-October 31. About 3 out of 4 years, there should be at least 10.00 inches of rainfall during this period.

During an average calendar year, 17.00 inches or more of rainfall can be expected 50 percent of the time. As much as 22.00 inches can be expected about 1 year in 4.

Air temperatures are the lowest in early January and reach their highest levels in mid-July to early August. The minimum temperature averages are above 60° F. from June 1-September 1; the maximum temperature averages are above 90° F. for a slightly shorter period of time.

About 50 percent of the time, the last cold period of 32° F. or lower will have occurred by April 12. Only in 1 year out of 4 should it occur later than April 20. The first cold period of 32° F. or lower in the fall will have occurred by October 31 at least 50 percent of the time. In 1 year out of 4, this cold period can be expected to occur by October 25.

Fifty percent of the time, there should be at least 202 days between the occurrence of the last 32° temperature or lower in the spring and the first occurrence of a 32° temperature or lower in the fall. There should be at least 192 days between these threshold temperatures 3 out of 4 years.

Thus, it appears that the cotton production season of the High Plains area may be characterized as being rather dry, cool and short for a significant proportion of the time.

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Application of Rainfall and Temperature Probabilities to Cotton Production— TEXAS HIGH PLAINS

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WEATHER IS ONE OF THE MOST IMPORTANT FACTORS in crop production. It may determine completely or in part the species of crops that can be grown, as well as the yield and quality of crops. Weather also has a strong influence on the kinds and frequencies of certain insect pests, the types and severity of crop diseases and the kinds and populations of many weed species. All of these factors contribute directly or indirectly to the cost of crop production.

Weather may be generally defined as the day-to-day status of the atmosphere as it relates to the physical changes on the earth's surface. Among many atmospheric parameters that may be used to describe the state of the atmosphere are temperature, relative humidity, rainfall, solar radiation and air movement. Climate, on the other hand, is a term used to describe the average of any or all atmospheric parameters for a designated period of time.

The weather parameters mentioned above can be, and generally are, measured separately. However, there are certain interrelationships among some of them. For example, relative humidity falls as the air temperature rises, provided there is no change in the moisture content of the air. Fluctuations in humidity at any given temperature may be brought about by the advection of moist or dry air and by moisture supplied by rain.

There are also interactions of solar and terrestrial radiation and air temperatures. Air temperatures during cloudy days (that is, days with lower solar radiation) will be lower than those of a clear day. On the other hand, nighttime air temperatures under a cloudy sky (conditions of lower terrestrial radiation) will not fall to as low a level as they would have reached had the sky been clear.

Therefore, it is evident that there are many highly variable meteorological factors that go together to make up the climate of a given area, and it is the total effect of all of these variables that determines the ecology of the area.

General Cotton Environmental Requirements

The minimum soil temperature for both germination and early seedling growth of Upland cotton varieties averages about 60° F., and the maximum temperature averages about 102° F. The soil temperature at which earliest germination and most rapid

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seedling growth may be expected is about 93° F., Tharp (6). Generally, the cotton plant grows little when air temperatures are 60° F. or lower. Temperatures above 100° F. are detrimental to growth, particularly if they occur several days in succession. The lower the soil moisture content, the more deleterious the effects of high above-ground temperatures.

According to Tharp (6), the water requirement for cotton from emergence to first square is approximately 0.1 inch per day. From first square to first bloom, 0.1 to 0.25 inches of water are required, and from first bloom to peak bloom, the plants use 0.25 to 0.40 inches of water per day. After the peak bloom stage of growth, water use gradually diminishes until plant growth is stopped by either natural or artificial means.

Cotton is a sun-loving plant and, hence, makes its best growth in the absence of cloudy weather. Prolonged periods of overcast skies during the fruiting stages of growth can cause excessive shedding of both squares and young bolls.

Hot, dry winds can greatly retard growth during the seedling stage. Larger plants are also adversely affected by such winds, especially if soil moisture is low.

The length of growing season needed to produce a cotton crop on the High Plains depends primarily on air temperatures and on the yield level being sought. A bale of lint per acre can be produced in approximately 150 to 160 days, if conditions are favorable. But approximately 180 to 190 days of favorable conditions are needed to produce two bales per acre.

General Production Schemes

Yields under dryland (or raingrown) conditions nearly always are limited by lack of moisture. For this reason, the time of planting is less critical than in situations where irrigation is to be applied during the summer growing period. That is, when production factors are favorable, some cotton varieties will have sufficient time to produce a bale of lint per acre even when planted as late as June 10. Cotton that is to be irrigated during the summer, however, should be planted prior to June in order to have more favorable conditions for the additional fruiting and fiber development that are necessary to make the additional yield. The higher the yield sought, the earlier in the season the cotton must be planted. However, in no case should planting begin until the 10-day average minimum soil temperature at the 8-inch depth has reached 60° F.

If water for only a single summer irrigation is available, this irrigation should be applied at the peak-bloom stage of growth. If two summer irrigations are to be used, the first should be applied at the first bloom stage of plant development, and the second should be applied 15 to 20 days later. If three summer irrigations are to be used, the third irrigation should be made about 10 to 15 days after the second one. Each of the above irrigations should be 3 to 4 acre-inches in amount, depending upon soil type, rainfall and other factors.

If a preplant irrigation is to be used, (which is strongly recommended by this station), it should be applied at least 20 to 30 days before the anticipated date of planting. Such a procedure will give the soil temperature a better chance to reach the desired level by the time planting is begun.

The types of cultural practices and equipment used on the High Plains depend to a large extent on soil type and whether or not irrigation is used. Within a given season and on a given farm, however, weather particularly rainfall and temperatures, will primarily govern the timing of a particular cultural practice.

OBJECTIVES OF STUDY

Accurate, long-range forecasts would be of great value in the planning of production practices. Ideally, forecasts would foretell when precipitation was going to occur and in what quantities. They would also delineate the temperature levels that would be reached and their duration and variability.

If such forecasts were possible, the producer could plan his farming operations well in advance. He could select for planting the varieties that would be best adapted to the forthcoming weather conditions. He could also make the most advantageous decisions on such matters as 1) the need for, or the timing of a preplant irrigation; 2) when to plant; 3) when to cultivate; 4) whether or not to use certain pesticides; 5) when to fertilize and how much to apply; 6) when to apply summer irrigations and in what amounts; 7) whether or not to use "lay by" herbicides; 8) if and when to apply harvest-aid chemicals; and 9) when conditions for harvesting would be favorable.

However, because such accurate, long-range forecasts are not yet possible, the farmer has to try to predict what is going to happen in the future largely by his knowledge of what has happened in the past. Long-term weather records provide data on certain aspects and features of the climate in the past. Certain calculations made on such data make it possible to estimate or predict the probability of occurrence (odds) of a given feature in the future. Current, local weather forecasts should, of course, be used as a basis for the planning of operations to be performed in the immediate future.

This study provides cotton producers in the High Plains area of Texas with a guide to the use of rainfall and temperature probabilities for long-range planning and 1) presents rainfall probabilities for certain time-periods; 2) presents probabilities for maximum and minimum temperature levels for basic time-periods during the course of the year; 3) presents probabilities for the dates of occurrence of various threshold temperatures; and 4) presents probabilities for the lengths of time between the spring and fall occurrence of the threshold temperatures.

MATERIALS AND METHODS

The terms used frequently in this paper are defined as follows:

Rainfall. Any form of precipitation (rain, mist, snow, sleet, hail) that measures 0.01 inch or more.

Effective rainfall. Any quantity of precipitation that aids or is subsequently used in plant-growth processes.

Trace. Any quantity of precipitation that is less than 0.01 inch in amount.

Rainfall interval. A day, or an unbroken sequence of days all having 0.01 inch or more of precipitation.

Basic period. That portion of a month obtained by dividing each month into three periods, the first two containing 10 days each and the last one containing the days remaining in the month.

Threshold temperature. Any temperature which normally has a date of last occurrence in the spring, a date of first occurrence in the fall and no occurrence between the spring and fall dates.

Probability. The relative frequency of the occurrence of an event based on the ratio between its occurrence and the total average number of cases necessary to insure its occurrence when such cases are viewed as indefinitely extended. In usual practice the calculated ratio is expressed as *odds,* (that is, 3 out of 5) or as *percentage,* (60 percent).

Source of Data

The daily rainfall and temperature records of the Texas Agricultural Experiment Station, Lubbock, Texas, for the period from 1917-1962 were used in the calculations of the probability values. These probability values are distinctly different from those of forecasts which, on a short-range basis, attempt to provide information on what the weather will actually be.

Rainfall Analyses

The rainfall probabilities were calculated by the incomplete gamma distribution technique. A resume of the procedure follows.

The daily rainfall amounts were totaled over each basic period for the years under study, (for example, Jan. Pl, 1917; Jan. Pl, 1918; . . . Jan. Pl, 1962). These 46 rainfall totals (or less, if there were any basic periods that had no rainfall) were converted to natural logarithms and a "g" value calculated from the formula given by Friedman and Janes (4):

$$g = \frac{1 + \sqrt{1 + 4/3\ (\ln\bar{x} - 1/n\ \Sigma \ln Xi)}}{4\ (\ln\bar{x} - 1/n\ \Sigma \ln Xi)}$$

where $\ln \bar{x}$ = natural logarithm of the mean of the rainfall values; $\Sigma \ln Xi$ = the sum of the natural logarithms of the rainfall amounts; and n = the number of years in which the particular basic period being analyzed had 0.01 or more inches of rainfall. After the g values were calculated, the probabilities for the desired rainfall amounts were taken from enlarged-scale versions of charts prepared by Barger et al. (2). In cases where a chart for the exact desired g value was not available, probabilities were interpolated from charts for lower and higher g values. Also, in cases where there were one or more basic periods with no rainfall, the appropriate adjustments of the probabilities were made.

In addition to the basic-period probabilities, probability values were calculated for each of the 12 whole months and for certain time-periods that corresponded to various seasons that are of importance in cotton production. These probabilities were calculated in the same manner as that given above.

The average number of rainfall intervals per basic period, the average amount of rainfall that occurred during a rainfall interval and the average rainfall per basic period were calculated also.

Maximum and Minimum Temperature Analyses

According to Bingham (3), the distributions of weekly averages of maximum and minimum temperatures usually do not meet the test for normal distributions, but they provide an adequate approximation for most practical applications. In the present study, the frequency distributions of each of the 36 basic-period maximum and minimum temperatures used in the study were tested for normality by Snedecor's method (5); and all but six of the maximum and six of the minimum temperature basic-period frequency distributions were found to be normally distributed. Therefore, in view of these findings as well as those of Bingham's, probability values for all basic periods were calculated on the basis of normal distribution. The procedure used was as follows.

The average maximum temperature for each of the 36 basic periods for all 46 years was computed. Then a mean and standard deviation of the 46 values for each of the 36 basic periods were calculated and used in the following equation:

$t = \bar{X} + sZ$, where:

t = unknown temperature

$\bar{X}$ = mean of the 46 temperature values

s = standard deviation of the 46 temperature values

Z = value from table of the cumulative normal distribution function that corresponded to the desired probability level

The same technique was used to determine the minimum temperature values for the desired probability levels.

Threshold Temperature Analyses

The calendar dates of the last occurrence in the spring and the first occurrence in the fall of 28°, 30°, 32°, 38° and 50° F. were taken from the 1917-1962 daily weather records. These calendar dates were then assigned a coded-date numerical value (for example, March 1 = 1, March 2 = 2, and so forth). A test for normality was run on the frequency distribution of each threshold temperature; and all except the spring threshold temperatures of 38° and 50° F. were found to be normally distributed, Snedecor (5). The mean and standard deviation were then calculated for each of the normally distributed threshold temperatures. These two statistics, the mean and standard deviation, were then used in the manner described in the maximum and minimum temperature analyses section to calculate, for various probability levels, the expected coded-date of the last occurrence in the spring and the first occurrence in the fall of the various temperatures. These values were then decoded, that is, reconverted to calendar dates.

Length of Growing Season Analyses

The procedure of Thom and Shaw (7) was used to calculate the probabilities of having a certain number of days between the last occurrence of a certain temperature in the spring and the first occurrence of the same or a different temperature in the fall. Briefly, the procedure was as follows:

The variances of the coded-dates of a given spring and the same or a different fall threshold temperature (for example, spring 32° F. and fall 50° F.) were added together, and the square root of this sum was extracted. This value (a standard deviation) and the arithmetic difference between the coded-date means for the respective spring and fall threshold temperatures were used, in the manner previously described, to calculate the length-of-growing-season probabilities.

Applicability of the Data

It should be noted that the probabilities reported are no more than estimates. How well they will apply to future weather phenomena depends to a large extent on how adequately the data used represented the true climate of the area. It also should be noted that since the data were taken from a single location, application of the probabilities to locations other than Lubbock will necessitate some adjustments or extrapolation. The following guidelines, which are based upon records for a 31-year period (1) for seven locations on the High Plains, may be used for general adjustments of the data that are subsequently presented.

1. Little or no extrapolation should be attempted beyond the 19-county area, of which the four corner counties are Parmer, Gaines, Borden and Briscoe.

2. Areas to the south and west of a line drawn approximately from the northeast corner of Borden County to the north-central edge of Castro County will generally receive from 0 to 10 percent less rainfall on an annual basis than the Lubbock area. Areas to the north and east of this line will generally receive from 0 to 20 percent more rainfall on an annual basis than the Lubbock area.

3. As air temperatures are related rather closely to elevation and latitude, areas south and east of a line drawn approximately from the southwest corner of Yoakum County to the northeast corner of Floyd County can expect usually to have slightly higher temperatures and up to 15 days more frost-free season than the Lubbock area. Areas to the north and west of this line can expect generally slightly lower temperatures and up to 15 days less frost-free season than the Lubbock area.

4. Deviations from the above general patterns can be expected due to factors such as local topography and movement of weather systems.

RESULTS AND DISCUSSION

Rainfall

Effective Rainfall

As defined earlier, effective rainfall is any quantity of precipitation which aids, or is subsequently used in, plant growth processes. Thus, rainfall that delayed planting, for example, may be untimely rainfall, but if it is subsequently utilized by plants it would also be considered effective rainfall.

Many factors determine the extent to which rainfall is effective. The primary ones are amount, intensity, timeliness and duration of the rain; soil texture and type; physical condition of the soil; moisture content of the soil; type of plant cover; air temperatures; air movement; degree of cloudiness subsequent to the rain; and topography.

With the type of rainfall intervals that are generally characteristic of the High Plains area (see next section), amount of rainfall and topography in the above list are among the most important factors insofar as effective rainfall is concerned. In other words, moisture from small rains of less than 0.25 inch generally is lost as evaporation and will rarely be available for subsequent plant growth. Much of the water from large rains will be lost as run-off if the land has a perceptible amount of slope. The importance of this last factor has been shown in tests at the South Plains Research and Extension Center[1] which showed that yields of lint cotton on land with a 0.2 percent slope were only one-half as large as those obtained from level land. As the slope was increased beyond 0.2 percent, lint yields were correspondingly decreased.

Note that the probabilities to be discussed subsequently are for *total* rainfall, and that the amount of *effective* rainfall will be a lesser amount. There-

[1] "Report of Progress, 1963-64." South Plains Research and Extension Center, Lubbock, Texas.

fore, in order that the subsequent discussions of rainfall probabilities be more realistic, it will be assumed that only approximately 50 percent of the rainfall will be effective. For example, if the amount of soil moisture needed is 3.00 inches, then the probability of getting 6.00 inches of rainfall should be considered.

Rainfall Intervals

The 1917-1962 data show that rainfall was less frequent and the amount of moisture delivered during a rainfall interval was less in the cooler part of the year (November P1 through March P3), than in the warmer part (April P1 through October P3). All basic periods from November P1 (first 10 days of November) through March P3 had an average of less than one rainfall interval per basic period, Figure 1-B. Also, the amount of precipitation that came during a single rainfall interval averaged less than 0.45 inch for all of these basic periods, Figure 1-A. The warmer part of the year, on the other hand, had an average of more than one rainfall interval per basic period except for the April P1, April P2, September P3 and October P2 basic periods. The amount of moisture that came per interval averaged more than 0.45 inch for all basic periods except August P2.

May P3 had the highest average number of rainfall intervals per basic period, 1.8; March P2, April P1 and November P2 had the lowest average number of intervals, 0.6. June P1 had the highest average rainfall per rainfall interval, 0.87 inch; February P1 had the lowest average, 0.18 inch.

The total amount of rainfall per basic period is, of course, the product of the "amount per interval"

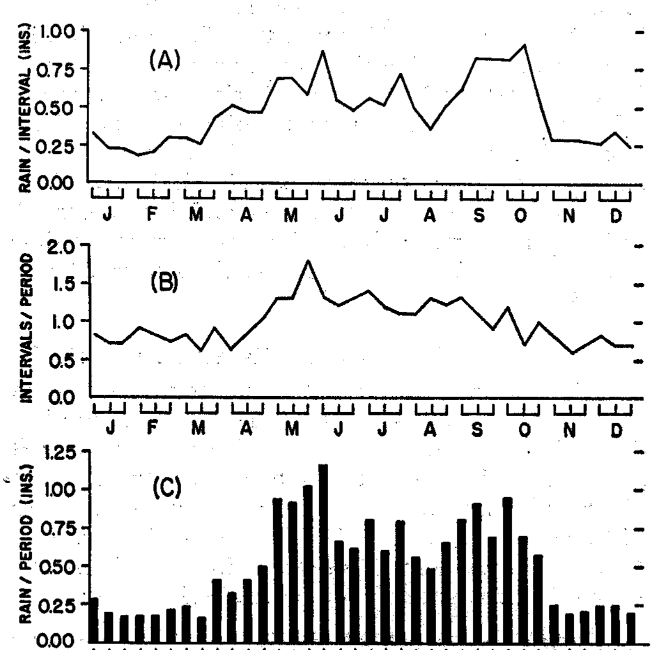

Figure 1. (A) Average rainfall in inches per rainfall interval; (B) Average number of rainfall intervals per basic period; and (C) Average rainfall in inches per basic period.

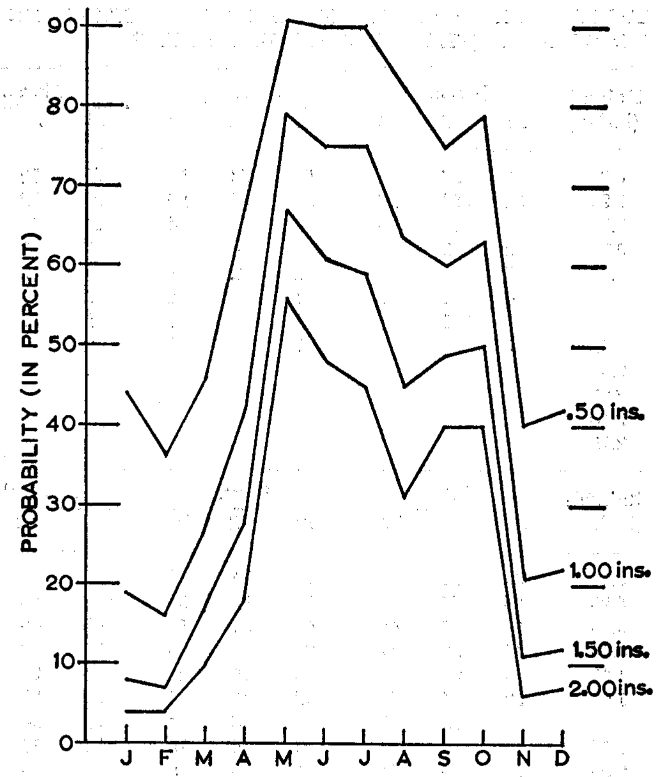

Figure 2. Probability of receiving rainfall during various months that is equal to or greater than the amount stated.

times the "number of intervals per basic period." Except for April P1 and P2, all the basic periods of the warmer part of the year had averages of more than 0.45 inch of total rainfall per basic period, Figure 1-C. On the other hand, the basic periods of the cooler part of the year all had averages of less than 0.30 inch, except March P3. The average for this basic period was 0.39 inch.

The highest average rainfall total for a basic period was the 1.15 inches for June P1. Three basic periods, January P3, February P1 and March P2, all had the lowest average rainfall, 0.15 inch.

Basic Period Rainfall Probabilities

Although probabilities for time periods as short as one-third month are not as reliable as those for longer periods, a need for them is twofold. First, the shorter time-interval probabilities are necessary to show certain sharp changes in the High Plains rainfall pattern during the year; and second, cotton producers should have probability values for short time intervals since many farming operations, for example, land preparation, planting and so forth, are performed during very brief periods through the year.

As an illustration of the first point mentioned above, the probability of getting 0.50 inch or more of rain during a basic period is less than 50 percent from January P1 through April P3, Table 1. The probability of receiving 0.50 inch or more then rises above 50 percent from May P1 through June P1. It

TABLE 1. PROBABILITY (IN PERCENT) OF RECEIVING RAINFALL DURING THE 36 BASIC PERIODS THAT IS EQUAL TO OR MORE THAN THE AMOUNT STATED

Rainfall (inches)	January P1	January P2	January P3	February P1	February P2	February P3	March P1	March P2	March P3	April P1	April P2	April P3	May P1	May P2	May P3	June P1	June P2	June P3
0.01	63[1]	56	59	59	63	52	61	52	70	56	59	78	80	91	91	78	83	85
0.25	34	24	22	21	23	26	27	22	38	35	41	45	68	68	71	66	56	60
0.50	19	11	9	10	10	14	15	10	25	22	28	30	55	52	56	55	41	42
0.75	12	5	3	4	4	7	9	5	18	15	19	22	44	41	45	46	30	30
1.00	7	3	2	2	2	4	6	2	12	10	13	16	35	32	36	39	23	21
1.25	4	1	1	1	1	2	3	1	9	6	9	12	28	25	29	33	17	15
1.50	3	1		1		1	2	1	6	4	6	8	22	20	24	28	13	11
1.75	2			1		1	2		5	3	4	6	17	16	20	24	10	8
2.00	1						1		4	2	3	4	14	13	16	20	7	5
2.25									2	1	2	4	11	10	13	17	6	4
2.50									2	1	1	1	8	8	10	14	4	3
2.75									1	1	1		7	7	9	12	4	2

Rainfall (inches)	July P1	July P2	July P3	August P1	August P2	August P3	September P1	September P2	September P3	October P1	October P2	October P3	November P1	November P2	November P3	December P1	December P2	December P3
0.01	83	74	76	74	74	80	87	72	63	85	52	72	61	46	48	61	52	59
0.25	63	60	61	58	52	56	60	50	43	59	44	48	29	23	25	29	31	23
0.50	48	43	48	41	34	41	46	40	34	46	36	35	16	13	14	16	17	12
0.75	37	30	37	28	22	30	35	32	27	37	30	26	9	7	8	9	9	6
1.00	29	21	29	19	15	23	28	27	22	30	24	20	5	4	4	5	5	4
1.25	22	14	22	12	10	17	22	23	18	25	20	15	3	2	2	3	3	2
1.50	18	10	18	8	6	13	17	20	15	21	16	11	2	2	2	2	2	1
1.75	14	6	14	5	4	10	14	17	13	18	13	9	1	1	1	1	1	1
2.00	11	4	11	4	3	8	11	15	11	15	11	7					1	1
2.25	9	3	8	3	2	6	9	13	9	12	9	5						
2.50	7	1	6			4	7	11	8	10	7	4						
2.75	6		5			4	6	10	6	9	6	3						

[1]Interpretation: Sixty-three percent of the time 0.01 inch or more of total rainfall can be expected to occur during the first 10 days in January.

drops below 50 percent for the remainder of the basic periods. Table 1 also shows that the probability of receiving 0.50 inch during any basic period is less than 20 percent from November P1 through March P2.

The probabilities further indicate that the likelihood of getting sufficient moisture (for example, 0.25 inch) to germinate weed seed is more than 50 percent for all basic periods from May P1 through September P2. Hence, the use of herbicides (preemerge, postemerge or "all-season" types) in cotton production might be quite advantageous in most years.

The high probabilities for rainfall and cool temperatures during the time of planting and subsequent seedling growth (late April through early June) also indicate the use of disease-control chemicals (for example, in-the-furrow fungicides) could be worthwhile, particularly in areas where the incidence of seedling diseases is known to be high.

Monthly Rainfall Probabilities

As noted previously, short-period proabilities are required in many cases. However, monthly rainfall probabilities provide a basis for broader generalization. These probabilities are given in Table 2. The table, as well as Figure 2, again demonstrate the widely fluctuating rainfall pattern of the High Plains area.

The likelihood of receiving rainfall totaling 2.00 inches or more during any one month, for example, is highest for May (56 percent). The probabilities then gradually decline through August and rise again for September and October. During November the values fall sharply and remain quite low until May. Also, it is interesting to note that the probability of having 5.00 inches or more of rainfall is essentially the same for the months of May and September, 15 and 14 percent respectively. Ten percent of the time June and October can be expected to have 5.00 or more inches of total rainfall.

Preseasonal and Early Season Rainfall Probabilities

The preseasonal period (time from harvest to planting) is a very important one in cotton production. The amount of soil moisture accumulated during this time period can determine the amount of preplant irrigation water (if any) that a producer will need to apply. Or in the case of dryland production, the amount of moisture in the soil profile at planting may strongly influence the final crop yield.

Insofar as soil moisture accumulation is concerned, the preseasonal period may differ somewhat from that defined above. For example, heavy rains before harvest can add more moisture to the soil than the plants will use; and if this unused moisture is

TABLE 2. PROBABILITY (IN PERCENT) OF RECEIVING RAINFALL DURING VARIOUS MONTHS THAT IS EQUAL TO OR MORE THAN THE AMOUNT STATED

Rainfall (inches)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.25	65[1]	55	61	82	95	96	96	91	86	88	57	59
0.50	44	36	46	67	91	90	90	82	75	79	40	42
0.75	29	24	35	54	85	83	83	73	66	70	29	30
1.00	19	16	27	43	79	75	75	63	60	63	21	22
1.25	12	11	21	35	73	68	67	53	54	56	15	16
1.50	8	7	17	28	67	61	59	45	49	50	11	12
1.75	5	5	13	23	61	54	51	38	44	45	8	9
2.00	4	4	10	18	56	48	45	31	40	40	6	7
2.25			8	15	51	42	38	26	36	35	4	5
2.50			6	12	46	37	33	21	33	32	3	4
2.75			5	9	41	33	28	17	30	28	2	3
3.00			4	8	37	28	24	14	28	25	2	2
3.25			3	6	33	25	20	12	25	22		
3.50				5	30	22	17	9	23	20		
3.75				4	27	19	15	8	21	18		
4.00				4	24	17	12	6	20	16		
4.25				3	21	15	10	5	18	14		
4.50				2	19	13	8	4	16	13		
4.75				2	17	11	7	3	15	11		
5.00				1	15	10	6	3	14	10		
5.25					14	8	5		12	9		
5.50					12	7	4		12	8		
5.75					11	6	4		10	7		
6.00					10	5	3		10	7		
6.25					9	5			9	6		
6.50					8	4			8	5		
6.75					7	4			7	5		
7.00					6	3			7	4		
7.25					5	3			6	4		
7.50					5	2			6			
7.75					4				5			
8.00									5			

[1]Interpretation: Sixty-five percent of the time, 0.25 inch or more of total rainfall can be expected to occur during January.

stored in the root zone, but below the lowest tillage level, it should be available for plant use the following year. On the other hand, light to moderate rains either before or after harvest may add no moisture below the lowest tillage depth; and, hence, this moisture will either be used by the plants or lost by evaporation during the postharvest tillage operations.

From the foregoing discussion, it is apparent that the length of the preseasonal moisture-accumulation period will vary from year to year and farm to farm. Because of this variation, rainfall probabilities were calculated for nine different time periods in order to allow the producer to choose the one that best approximates his particular production scheme. These probability values are given in the first nine columns of Table 3.

The probability values indicate that the likelihood of getting enough moisture to obviate the use of a preplant irrigation (assuming a total of 6.00 inches or more of rainfall is needed to supply 3.00 inches of soil moisture) is less than 20 percent if planting is done by May 1. This is true regardless of whether the preseason period begins on November 1, December 1 or January 1. However, in cases where early planting is not so necessary, for example, under dryland or very limited irrigation conditions, the producer may plan to delay planting until the latter part of May or the first part of June, if necessary. By so doing, the producer increases his chances of receiving sufficient rainfall for planting. Since the cotton crop will occupy the land for a shorter period of time and will generally begin fruiting sooner, the total water requirement for the crop usually will be less than that of earlier plantings.

If the producer plants around the first of May and has 4 to 5 inches of available moisture in the root zone at that time, he rarely should need to irrigate before "first bloom" stage of plant growth, July 10-15. That is, about 66 percent of the time, or 2 years out of 3, 3.00 or more inches of rainfall will have occurred during the May 1 through June 20 period, Table 3. About 70 percent of the time, or 7 years out of 10, 4.00 or more inches of rainfall will have occurred during the period from May 1 through July 10.

On the other hand, if it is assumed that the cotton crop will have used 6.00 inches of moisture by the time the first bloom growth stage is reached, the odds of not needing an irrigation at this time are quite low. That is, for an irrigation at first bloom not

TABLE 3. PROBABILITY (IN PERCENT) OF RECEIVING RAINFALL DURING VARIOUS TIME PERIODS THAT IS EQUAL TO OR MORE THAN THE AMOUNT STATED

Part 1

Rainfall (inches)	Nov. 1-Mar. 31	Nov. 1-Apr. 30	Nov. 1-May 31	Dec. 1-Mar. 31	Dec. 1-Apr. 30	Dec. 1-May 31	Jan. 1-Mar. 31	Jan. 1-Apr. 30	Jan. 1-May 31	May 1-June 20	May 1-July 10
1.00	91[1]	99	100	82	98	100	69	94	99	94	99
2.00	68	88	100	53	82	97	36	70	94	82	94
3.00	44	69	94	30	58	90	17	44	83	66	83
4.00	26	48	84	16	36	78	8	25	69	50	70
5.00	15	30	72	8	21	64	4	13	55	37	57
6.00	8	18	58	4	11	50		6	42	26	44
7.00	4	10	44	2	5	38		3	31	19	33
8.00		5	33			27			22	13	24
9.00		3	24			19			16	8	18
10.00			17			14			11	6	12
11.00			11			9			7	4	8
12.00			8			6			5	3	6
13.00			5			4			4		4
14.00			4						2		3

Part 2

Rainfall (inches)	July 11-July 31	Aug. 1-Aug. 20	Aug. 21-Sept. 10
0.50	73	68	69
0.75	61	54	59
1.00	51	42	49
1.25	42	32	42
1.50	35	24	35
1.75	29	17	30
2.00	23	13	25
2.25	19	9	21
2.50	16	7	17
2.75	13	5	14
3.00	10	3	12
3.25	8	3	10
3.50	7	2	9
3.75	5		7
4.00	4		7

Part 3

Rainfall (inches)	Sept. 11-Nov. 30	Sept. 11-Dec. 31	Oct. 1-Dec. 31
0.50	98	100	93
1.00	92	95	82
1.50	84	90	71
2.00	76	83	61
2.50	68	76	52
3.00	60	69	44
3.50	52	61	37
4.00	44	54	31
4.50	38	47	26
5.00	32	41	22
5.50	28	35	18
6.00	24	30	15
6.50	20	26	13
7.00	16	22	10
7.50	14	19	9

[1]Interpretation: Ninety-one percent of the time 1.00 inch or more of total rainfall can be expected to occur during the period from November 1-March 31.

to be necessary, a total of approximately 10.00 to 11.00 inches of rainfall (assuming 50 percent of the rainfall to have been "effective") must have occurred during the May 1 through July 10 period. The probability of receiving these amounts are 12 and 8 percent, respectively.

Midseason Rainfall Probabilities

As pointed out above, an irrigation usually will be needed at the first bloom growth stage. The producer who has no irrigation water must, of course, rely solely on rainfall. Once this irrigation has been applied, the next consideration is what are the odds that another irrigation will be needed in 15 to 20 days. Table 3, part 2, shows that the probability of receiving even 3.00 inches of rainfall during the 20 days from July 11 through July 31 is only 10 percent. Hence, the producer can generally count on needing to apply a second summer irrigation around the first of August. The exact time will depend primarily upon how much rainfall was received after the first irrigation was applied and whether or not the producer plans to apply a third irrigation. The probability of receiving 4.00 or more inches of rainfall from August 1 through August 20 is less than 2 percent, Table 3, part 2. Therefore, if the producer has sufficient irrigation water and is seeking relatively high yields of one and one-half to two bales, he probably will need to irrigate a third time about the middle of August in most years. The probability of getting 4.00 or more inches of rainfall during the 20-day period from August 21 through September 10 is only 7 percent. Hence, producers in the sandy soil areas who are seeking higher yields may want to plan for a fourth irrigation around the last of August.

Late Season Rainfall Probabilities

The probability of receiving various amounts of rainfall during the period from first boll opening until harvest are listed in Table 3, part 3.

The first column will generaly be applicable to the boll-opening and harvest period for cotton planted at the usual time and grown under conditions of dryland or one summer irrigation; the second column will apply to cotton planted at the usual time and grown under conditions of two or more summer irrigations; and, the third column will apply to late-planted cotton, which is usually grown with little or no summer irrigation.

The values in the first and second columns indicate that cotton planted at the usual times would be subjected to about 2.00 to 2.50 inches of total rain during the boll-opening period in about 3 out of 4 years, or 76 percent of the time. Late-planted cotton, on the other hand, would not have any open bolls during September and, therefore, would miss some of the heavier rains. Only 52 percent of the time should there be 2.50 inches or more of rainfall during the period of October 1 through December 31.

Growing Season and Annual Rainfall Probabilities

The probabilities of receiving certain amounts of rainfall during the period May 1 through October 31, the period generally called the cotton growing season, and during the entire calendar year are shown in Table 4. About 3 out of 4 years, or 72 percent of the time, 10.00 inches or more of rainfall comes during the growing season, and 50 percent of the time, 13.00 or more inches can be expected to occur. During the calendar year, 17.00 inches or more of rainfall can be expected 50 percent of the time. Thirteen or more inches of total rainfall can be expected about 3 out of 4 years; and 1 year in 4, there should be 22.00 inches or more of rainfall during the year.

TABLE 4. PROBABILITY (IN PERCENT) OF RECEIVING RAINFALL DURING THE "GROWING SEASON" OR DURING THE ENTIRE YEAR THAT IS EQUAL TO OR MORE THAN THE AMOUNT STATED

Rainfall (inches)	Growing season May 1-Oct. 31	Annual Jan. 1-Dec. 31
4.00	100	100
5.00	97[1]	100
6.00	94	100
7.00	91	97
8.00	85	96
9.00	79	93
10.00	72	90
11.00	64	85
12.00	57	80
13.00	50	74
14.00	41	69
15.00	35	63
16.00	29	56
17.00	24	50
18.00	20	44
19.00	16	40
20.00	13	34
21.00	10	29
22.00	8	25
23.00	6	21
24.00	5	18
25.00	4	15
26.00	4	12

[1]Interpretation: Ninety-seven percent of the time 5.00 inches or more of total rainfall can be expected to occur during the period from May 1-October 31.

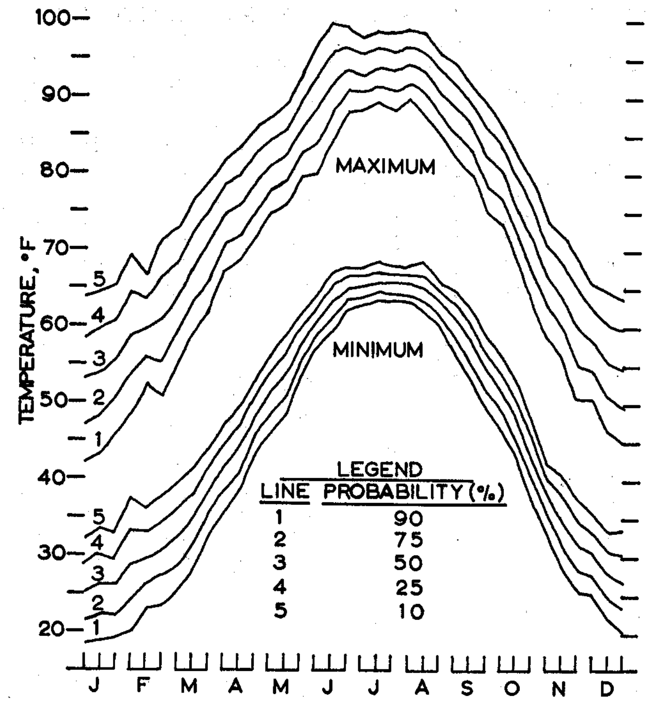

Figure 3. Basic period temperature values for various probability levels. For example, the average maximum or minimum temperature for a given basic period can be expected to be equal to or above the number 1 line 90 percent of the time.

Temperatures

Minimum Temperature Probabilities

The basic-period average minimum temperature values that can be expected at seven probability levels are given in Table 5. Figure 3 illustrates five of these levels. (The values in the figure were plotted to the nearest 0.1 of a degree.)

The temperature value that is given for a certain probability level means that the minimum temperature averaged over a basic period can be expected to be the stated value or higher the indicated percent of the time. For example, a value of 34 for January P1 has a probability of 5 percent. Thus, the average minimum temperature for the first 10 days in January can be expected to be 34° F. or higher 5 percent of the years; conversely, the average minimum temperature for this period of time can be expected to be below 34° F. 95 percent of the time. The average minimum temperature for January P1 can be expected to be 17° F. or above 95 percent of the time, or it can be expected to be below 17° F. only 5 percent of the time.

The variation in minimum temperatures is, as expected, much greater during the colder months than during the warmer months. This can be seen by the range between the temperatures given for the 5 per-

TABLE 5. BASIC PERIOD AVERAGE MINIMUM TEMPERATURE VALUES (° F.) FOR VARIOUS PROBABILITY LEVELS

Probability	January			February			March			April			May			June		
(percent)	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
5	34[1]	36	35	40	38	40	41	43	45	48	51	54	57	59	62	64	68	69
10	32	34	33	38	36	38	39	41	44	47	49	53	56	58	61	63	67	68
25	29	30	30	33	33	34	36	38	41	44	47	50	54	56	60	62	65	66
50	25	26	26	29	30	31	32	35	38	41	44	48	51	55	57	60	63	65
75	22	22	22	24	26	27	29	31	35	38	41	46	48	51	55	59	61	63
90	18	19	19	20	23	24	26	28	33	36	38	44	46	49	54	57	59	62
95	17	17	17	18	22	22	24	26	31	34	37	42	45	48	52	56	58	61

	July			August			September			October			November			December		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
5	68	69	69	69	69	67	66	64	60	58	55	49	43	42	39	37	34	36
10	68	68	68	68	68	66	65	62	59	56	53	48	42	41	37	36	33	34
25	66	67	67	67	67	64	63	60	57	54	51	46	40	38	34	33	30	30
50	65	66	66	65	65	63	61	58	54	52	48	43	38	35	31	30	27	27
75	64	64	64	64	63	62	59	56	52	49	46	40	36	32	28	28	25	23
90	62	63	64	63	62	60	57	54	50	47	43	38	34	29	25	25	22	20
95	62	62	63	62	61	60	56	52	48	46	42	36	33	27	24	24	20	18

[1]Interpretation: The average minimum temperature for this period can be expected to be 34° F. (or higher) 5 percent of the time.

cent and 95 percent probability levels in Table 5. The spread between the 10 and 90 percent lines at the bottom of Figure 3 also illustrates this range in temperature. The widest range in minimum temperatures occurs in February P1. The range narrows generally from February to July. It then begins to widen again in August and continues to widen until February.

Since the normal distribution was assumed in calculating the probabilities, the temperature values at the 50 percent probability levels are the same as the average temperature values.

An examination of the average minimum temperature values shows that the lowest temperatures occur in January P1. They then increase slowly until March P1. From this point until July P1, they increase at the rate of about 3 degrees per basic period. From July P1 through August P2, they remain fairly constant. Subsequent to August P2, they decline approximately 2 to 5 degrees per interval until December P2.

Maximum Temperature Probabilities

The basic period maximum temperature values at seven probabilities are given in Table 6, and five of the probability levels are illustrated in Figure 3.

The variation in maximum temperatures follows the same trend as the minimum temperatures. That

TABLE 6. BASIC PERIOD AVERAGE MAXIMUM TEMPERATURE VALUES (° F.) FOR VARIOUS PROBABILITY LEVELS

Probability	January			February			March			April			May			June		
(percent)	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
5	67[1]	68	68	73	69	74	74	79	81	84	85	88	89	91	94	99	102	101
10	64	64	65	70	67	71	72	76	79	82	83	86	87	89	92	96	99	99
25	59	60	60	64	63	66	68	72	75	78	80	82	84	86	89	93	96	96
50	53	54	55	59	60	61	64	68	70	74	76	79	81	82	86	88	92	93
75	48	48	50	53	56	55	59	63	66	70	72	75	78	79	82	84	88	90
90	43	43	46	48	53	50	55	59	62	67	68	71	75	76	79	80	84	88
95	40	40	43	45	51	47	53	56	59	65	66	69	73	74	78	78	82	86

	July			August			September			October			November			December		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
5	90	100	100	100	100	97	97	93	92	88	84	82	76	74	72	68	67	66
10	98	98	98	98	98	96	95	92	89	87	82	80	74	72	69	66	65	64
25	95	96	96	96	96	93	92	89	86	84	79	76	70	68	65	62	60	59
50	93	94	93	94	93	90	88	86	82	80	76	71	67	64	60	58	55	54
75	90	91	90	92	90	88	85	84	78	77	72	67	63	60	55	54	50	49
90	88	89	88	90	88	85	82	81	75	74	69	63	59	56	50	51	46	45
95	87	88	87	88	86	84	80	79	73	72	67	61	57	54	48	48	43	42

[1]Interpretation: The average maximum temperature for this period can be expected to be 67° F. (or higher) 5 percent of the time.

TABLE 7. CALENDAR DATES FOR VARIOUS PROBABILITY LEVELS, AFTER WHICH THE LAST OCCURRENCE OF VARIOUS TEMPERATURES IN THE SPRING CAN BE EXPECTED

Probability (percent)	32° F.	30° F.	28° F.
1	5-11[1]	5- 6	4-30
5	5- 3	4-27	4-21
10	4-28	4-22	4-16
25	4-20	4-14	4- 8
50	4-12	4- 5	3-30
75	4- 3	3-28	3-21
90	3-27	3-20	3-13
95	3-22	3-15	3- 8
99	3-13	3- 6	2-27

[1]Interpretation: One percent of the time, a spring temperature of 32° F. (or lower) can be expected to occur after May 11.

TABLE 8. CALENDAR DATES FOR VARIOUS PROBABILITY LEVELS, BEFORE WHICH THE FIRST OCCURRENCE OF VARIOUS TEMPERATURES IN THE FALL CAN BE EXPECTED

Probability (percent)	50° F.	38° F.	32° F.	30° F.	28° F.
99	10-10[1]	11- 6	11-22	11-26	12- 4
95	10- 3	10-30	11-16	11-20	11-27
90	9-29	10-27	11-12	11-17	11-23
75	9-23	10-21	11- 7	11-11	11-17
50	9-17	10-14	10-31	11- 5	11-10
25	9-10	10- 7	10-25	10-29	11- 3
10	9- 4	10- 1	10-19	10-24	10-28
5	8-31	9-28	10-16	10-20	10-24
1	8-24	9-21	10-10	10-14	10-17

[1]Interpretation: Ninety-nine percent of the time, a fall temperature of 50° F. (or lower) can be expected to occur before October 10.

is, variation is greatest during the winter months and least during the summer months.

Maximum temperatures are the highest from P3 of June through P2 of August, averaging 93° to 94° F. Subsequently, they drop off rather rapidly until they reach a low the first period of January.

Probabilities for Certain Threshold Temperatures

Some species of plants are damaged or killed when the temperature falls below a certain level. All plants have threshold temperature levels below which they cease to grow. In the case of cotton, plants are generally killed when the temperature falls to 32° F. or below; growth of the plant ceases whenever the temperature gets lower than about 50° F.

The data in Table 7 lists the calendar dates for nine probability levels, after which the last occurrence of various spring temperatures can be expected. For example, if a producer plans to plant cotton only after the probability of the occurrence of a 32° F. temperature is 10 percent or lower, he would delay planting until April 28 or later.

Table 8 gives the dates of first occurrence of various temperatures in the fall at nine probability levels. Fifty percent of the time the first 32° F., or lower, temperature will have occurred by October 31. This means that if a producer plants on May 1, 50 percent of the time he can expect 184 days of growing season, from May 1 through October 31. If

TABLE 9. NUMBER OF DAYS, AT VARIOUS PROBABILITY LEVELS, THAT CAN BE EXPECTED BETWEEN THE LAST OCCURRENCE OF A CERTAIN TEMPERATURE IN THE SPRING AND THE FIRST OCCURRENCE OF A CERTAIN TEMPERATURE IN THE FALL

Probability (percent)	32° F. spring 50° F. fall	32° F. spring 38° F. fall	32° F. spring 32° F. fall	32° F. spring 30° F. fall	32° F. spring 28° F. fall	30° F. spring 50° F. fall	30° F. spring 38° F. fall
1	195[1]	223	239	243	250	202	230
5	184	212	228	233	239	191	219
10	178	206	223	227	233	185	213
25	169	196	213	217	223	175	203
50	158	185	202	207	212	164	192
75	147	174	192	196	201	153	180
90	137	164	182	187	191	143	170
95	131	159	177	181	185	137	164
99	120	148	166	170	174	126	153

Probability (percent)	30° F. spring 32° F. fall	30° F. spring 30° F. fall	30° F. spring 28° F. fall	28° F. spring 50° F. fall	28° F. spring 38° F. fall	28° F. spring 32° F. fall	28° F. spring 30° F. fall
1	246	251	257	209	237	253	257
5	235	240	246	198	225	242	246
10	230	234	240	192	219	236	240
25	220	224	230	182	209	226	230
50	209	213	219	171	198	215	219
75	198	202	208	159	187	204	209
90	188	193	197	149	177	194	199
95	182	187	191	143	171	189	193
99	171	176	180	132	159	177	182

[1]Interpretation: One percent of the time, there will be 195 days between the occurrence of the last 32° F. (or lower) temperature in the spring and the occurrence of the first 50° F. (or lower) temperature in the fall.

planting is done on May 20, then only 164 days of growing season can be expected 50 percent of the time. Furthermore, only 25 percent of the time will a 32° F. temperature not have occurred by November 7. Or in other words, 191 days of growing season can be expected for a May 1 planting only 1 year in 4. Therefore, since 180 to 190 days are required to produce two bales of cotton in an average year, it is apparent that the cotton growing season of the High Plains may often be too short to produce fully mature fiber in such high amounts.

Probabilities for the Number of Days Between Various Spring and Fall Threshold Temperatures

Although the length of the cotton growing season is determined by the planting date and the fall frost date, probabilities of the number of days that can be expected betwen various spring and fall threshold temperatures are often of interest. These probabilities are shown in Table 9.

The length of time between the occurrence of the last 32° F. temperature in the spring and the first occurrence of 32° F. temperature in the fall is generally called the frost-free period, and this would represent the maximum length of growing season. Fifty percent of the time, this period should be at least 202 days in length, and 3 years out of 4, or 75 percent, it should be at least 192 days in length.

REFERENCES

(1) Anonymous, 1965. "Weather data and cotton production." Cotton Economic Research Report No. 75, Univ. of Texas.

(2) Barger, Gerald L., R. H. Shaw, and R. F. Dale, 1959. "Gamma distribution parameters from 2- and 3-week precipitation totals in the North Central region of the United States." Second Report to the North Central Regional Technical Committee on weather information for Agriculture, Agr. and Home Eco. Exp. Sta., Iowa State Univ.

(3) Bingham, Christopher, 1963. "The climate of the Northeast: Probabilities of weekly averages of the daily temperature maximum, minimum, and range." Conn. Agr. Exp. Sta. Bul. 659.

(4) Friedman D. G., and B. E. Janes, 1957. "Estimation of rainfall probabilities." Conn. Agr. Exp. Sta. (Storrs) Bul. 332.

(5) Snedecor, George W., 1957. "Statistical Methods." Iowa State College Press, Ames, Iowa.

(6) Tharp, W. H., 1965. "The cotton plant: How it grows and why its growth varies." Agr. Handbook No. 178, U. S. Dept. of Agr.

(7) Thom, H. C., S., and R. H. Shaw, 1958. "Climatological analysis of freeze data for Iowa." Month. Weath. Rev. 86: 251-257.

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