RESEARCH BULLETIN 836 AUGUST, 1963

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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Incidence of Drouth Conditions in Southeastern Missouri

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(Publication authorized August 26, 1963)

COLUMBIA, MISSOURI

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This bulletin is a report on Department of Agricultural Economics research project 426, Economics of Irrigation.

SUMMARY

The primary purpose of this study was to define, in terms of expected frequencies of occurrence, the weather-related variables which could be associated with the costs and returns of supplemental water application in a four-county area in southeastern Missouri.

A method of evaluating the drouth incidence and the need for supplemental irrigation was used which takes into account the agronomic and climatic conditions which affect the amount of soil moisture available for use by the crop. The method involves computation of the daily available soil-moisture balances in the effective rooting zone of the crop. Daily minimum and maximum temperature values adjusted for the latitude of the geographic area were used to estimate the moisture losses through evapotranspiration from the soil-plant regime.

The climatological data necessary to compute daily soil-moisture balances were obtained from long-term weather records for stations in or adjacent to the study area. The daily soil-moisture balances were computed for a range of available soil-moisture bases adequate to encompass most soil-crop situations in the study area. Days during which soil-moisture was found to be less than a minimum level considered necessary for optimum plant growth were designated as drouth-days. Frequency distributions were prepared of drouth day occurrences and of the number of water applications necessary to prevent their occurrence for selected time periods during the crop season. The drouth hazard of the area is characterized in two primary ways: (1) The expected frequency of occurrence of specified numbers of drouth-days and (2) the expected frequency of need for water application to prevent potential drouth damage. Data dealing with the persistence of drouth periods also are presented.

The data were voluminous and only a summarization of the results was feasible. The results indicate that the occurrence of drouth periods of apparently damaging intensities are quite common for most soil-crop conditions in the Delta during July and August.

Results of this study can be applied to agricultural problems dealing with drouth hazard in several ways. First, the method used to determine the occurrence of periods during which soil-moisture is nonoptimal for plant growth can readily be adopted by farmers as a guide in scheduling water applications. Additional research by soils and crop specialists to establish the relationship between soil-moisture regimes and crop yields and economic analysis of the results will greatly enhance the value of this procedure as a guide to optimum time of irrigation applications.

The results can be used as a basis for a comprehensive evaluation of the economic feasibility of supplemental irrigation. Also, drouth-day information can aid in the interpretation of agronomic tests in which soil moisture is a variable affecting the results. A study of the drouth history of the area would allow the attachment of a probable recurrence value to the observed results. This information will aid in the solution of problems dealing with layout, design, capacity and other engineering aspects of irrigation systems. In short, the drouth-day concept offers a new approach to the study of weather-related problems encountered in agricultural production.

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INTRODUCTION

The importance of supplemental irrigation has increased rapidly in Missouri and other subhumid states in the last 10 years. This increase can be attributed to several factors:

(1) The need for optimum amounts and distribution of water because of improvements in fertilization, genetic capabilities of plants, weed and insect control, and other cultural practices.

(2) Rapid improvements in the equipment and methods used to apply irrigation water.

(3) Increased costs of crop production which tend to make crop failures disastrous.

(4) High levels of farm income which permit investments in equipment to increase output and reduce the risk of crop failure.

Use of supplemental irrigation in crop production serves a dual purpose. First, it provides insurance against severe drouths which could mean total crop failure. Second, if used as a regular farm practice it offers the possibility of an increase in output during most years. The magnitude of the net returns which accrue to irrigation practices during years of severe drouth have prompted many farm operators to invest in irrigation equipment although no thorough economic evaluation of its use is available.

Purpose of the Study

The amount and distribution of rainfall cannot be predicted on a year-to-year basis. For this reason, it is impossible to predict the need for or response to supplemental irrigation during a specific crop season. Severe drouth seasons with total or near complete crop failure will occur. These years will be balanced by seasons of nearly optimum amounts and distribution of rainfall. Between these two extremes will fall years of widely varying degrees of drouth intensity. Consequently, realized costs and returns from irrigation vary widely from year to year due to the influence of the highly variable climatic conditions encountered in subhumid areas.

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Objective economic analyses must consider the effect of these varying intensities of drouth upon net returns from given crops and the associated probabilities of occurrence of these conditions over the useful life of the irrigation equipment. In other words, the owner of irrigation equipment cannot expect an equal return from his investment each year; he must be prepared to recover the cost over time and to take average returns for the period.

Objectives

To make an evaluation of the economic feasibility of supplemental irrigation in subhumid areas it is necessary to have data concerning the occurrence of periods during which the levels of soil moisture are nonoptimal for crop development. The primary purpose of this study was to characterize the drouth hazard of a four-county area in southeastern Missouri for the soil and crop combinations common to the area.

The specific objectives were:

1. To estimate on a probability basis the relative frequency of drouth conditions of various intensities.
2. To determine on a probability basis the frequency of need for supplemental water applications.

Location of the Study Area

The study area included Dunklin, Mississippi, New Madrid, and Pemiscot Counties. These counties were selected for the following reasons:

1. The likelihood of increased use of supplemental irrigation as a regular farm practice is greater for this area than for other parts of the State. The following characteristics support this belief:
   a. The area contains large acreages of productive land which are adapted to crops that have high cash value per acre.
   b. The area has an abundant supply of water suitable for irrigation purposes.
   c. A large proportion of the land is relatively level and is adapted to low-cost methods of water distribution.
2. Previous research has provided detailed information concerning the type of irrigation equipment, methods of water distribution, crops irrigated, costs of application, and other aspects of irrigation.[1]

Source of Data

Daily precipitation and temperature data were obtained from United States Weather Bureau reports for three stations in or adjacent to the study area. The stations and number of years of record available were: Cairo, Ill., 40 years; Sikeston, Mo., 30 years; and Caruthersville, Mo., 36 years. Locations of the study area and weather stations are shown in Figure 1.

[1]Ted L. Jones and Frank Miller, *Irrigation Practices and Costs in Southeastern Missouri—1960,* University of Missouri, Agricultural Experiment Station Research Bulletin 795, Columbia, Missouri, March 1961.

Fig. 1 - Location of the study area and weather stations from which meteorological data were obtained.

QUANTITATIVE MEASUREMENT OF DROUTH

Definition of Agricultural Drouth

A meaningful definition of agricultural drouth is necessary if a useful measure is to be devised. Historically, drouth has referred to a period of inadequate rainfall for optimum plant growth. Although agricultural drouth is closely related to the amount and distribution of rainfall occurring during the growing season, other important factors are involved and should be considered. Plant and soil characteristics can vary the effects of dry periods on crops. A meaningful definition of agricultural drouth must take into account all of the agronomic and climatic conditions which have a significant affect upon the moisture available for use by the crop.

Recognizing the complexity of the relationships that determine drouth conditions, van Bavel and others have developed a procedure for the quantitative measurement of drouth.[2] The unit used is a drouth-day which is defined as follows: "A drouth-day is a 24-hour period in which the soil moisture stress exceeds a limit, which, on the basis of experimental evidence, may be taken as a point at which the productive processes of the crop are being appreciably decreased." The measurement of drouth in this manner allows it to be treated as a continuous variable. The conditioń measured is useful in estimating physical relationships for subsequent economic analysis.

General Procedure for Determining Drouth Hazard

The procedure for determining drouth-days developed by van Bavel utilizes the "bank account" approach of computing daily available soil-moisture balances. Briefly, it consists of selecting a level of soil moisture for a specific soil-crop combination below which the growth and development of the plant is assumed to be detrimentally affected. A drouth-day is considered to occur when the available moisture in the soil falls below this critical level as estimated by moisture-balance computations of daily rainfall and evapotranspiration. A quantitative measure of drouth is obtained by tabulating the number of drouth days which occur during relevant growth periods of the crop. Three basic types of information are needed to quantify drouth hazard by this procedure: (1) The available soil-moisture base for the soil-crop combination, (2) rainfall data, and (3) estimates of daily water loss through the processes of evaporation and transpiration.

Available Soil-Moisture Bases: The soil can be visualized as a reservoir capable of holding water. Not all of the water in this reservoir is available for use by the crop. Three major factors determine soil capacity to hold water for crop use. The first is the amount held in the range between field capacity and the wilting point. Field capacity is defined as the amount of water, expressed as a percentage of the dry weight, which the soil will retain after being thoroughly wetted and allowed to drain for one to three days. The permanent wilting point is reached when the water in the soil is held at a tension at which the plants are unable to extract it at a rate necessary to maintain efficient performance of normal physiological functions. The water-holding capacity generally is expressed as the fraction of an inch of water held per inch of soil depth and varies widely among soil types and horizons within a specific soil type.

A second factor which determines the available soil-moisture capacity is the effective rooting depth of the crop. The rooting depth determines the soil volume from which the crop can extract water. The depth of the rooting zone and the water-holding capacity of the soil jointly determine the maximum quantity of water which is available for plant use. The effective rooting depth will vary with the type of crop and soil and with other environmental factors.

The final factor necessary to determine the available soil-moisture capacity for a given soil-crop combination is the physiological reaction of the plant to

[2] C. H. M. van Bavel, "A Drouth Criterion and Its Application in Evaluating Drouth Incidence and Hazard," *Agronomy Journal,* 45:167-168, April 1953.

soil-moisture stress. As stated earlier, water-holding capacity is the amount of water held by the soil in the range between field capacity and the wilting point.

Although this definition is generally accepted by soil scientists, the point within the range at which productive plant processes are inhibited is quite controversial.[3] One school of thought contends that soil moisture is equally available for plant growth over the entire range from field capacity to the permanent wilting point. Another group of investigators contends that plant growth shows differential response with variations between field capacity and permanent wilting point. This group believes that the relative rate of plant growth decreases at an increasing rate as the water content of the soil decreases from field capacity to permanent wilting point. This controversy need not be resolved for this study to be practical, but an understanding of the concepts involved is useful in making meaningful interpretations of the results.

Until further experimental evidence is presented, the point in the depletion of the water-holding capacity at which drouth damage becomes of economic significance and at which irrigation should be initiated cannot be firmly established for specific soil-crop conditions. In practice, this point must be selected arbitrarily by the farm operator.

The maximum amount of soil moisture available for crop growth is, from the standpoint of drouth-day calculations, a function of three variables: (1) The water holding capacity of the soil, (2) the effective rooting depth of the crop, and (3) the physiological reaction of the crop to soil-moisture stress. If the soil-moisture base is being used as a guide for timing irrigation applications, it may vary some as a result of using these factors. The point of depletion at which irrigation is initiated is substituted for the point of physiological reaction of the crop to soil-moisture stress. The time when irrigation is started should be closely related to the physiological reaction of the crop to soil-moisture stress, but other considerations such as capacity of the equipment, total area to be irrigated, and probability of receiving rainfall also should be included.

For a given soil-crop situation, an available soil-moisture base as used in calculation of drouth-days is usually, but not necessarily, different from an available soil-moisture base used as a guide in the application of water. For purposes of drouth-day calculations the quantity of water held between field capacity and the permanent wilting point is usually used as the base. However, for purposes of timing irrigation applications, the base becomes the amount of water held between field capacity and the soil-moisture level at which the operator decides water applications should be initiated. This idea is illustrated for typically textured soils in Table 1.

Rainfall and Evapotranspiration Data: Once the available soil-moisture base for a given soil-crop combination is determined the additional information

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[3]R. M. Hagan, Y. Vaadia, and M. B. Russell, "Interpretation of Plant Responses to Soil Moisture Regimes," *Advances in Agronomy*, 11:77, New York: Academic Press, 1959.

TABLE I - TYPICAL WATER-HOLDING CHARACTERISTICS OF DIFFERENT-TEXTURED SOILS[a]

Soil Type	Inches of Water Held at Specified Soil Depths													
	Between Field Capacity and the Wilting Point							Between Field Capacity and the Point At Which Irrigation is Desirable						
	12 in.	18 in.	24 in.	30 in.	36 in.	42 in.	48 in.	12 in.	18 in.	24 in.	30 in.	36 in.	42 in.	48 in.
Sands	1.2	1.8	2.4	3.0	3.6	4.2	4.8	.8	1.2	1.6	2.0	2.4	2.8	3.2
Loams	2.0	3.0	4.0	5.0	6.0	7.0	8.0	1.4	2.1	2.8	3.5	4.2	4.9	5.6
Clays	1.9	2.8	3.8	4.8	5.7	6.6	7.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8

[a] Source: United States Department of Agriculture, The Yearbook of Agriculture 1955: Water, p, 120.

needed to compute daily soil-moisture balances can be obtained from climatological records. The needed data, daily rainfall, and daily minimum and maximum temperatures are available at most weather stations.

The minimum and maximum temperatures are used to obtain an estimate of daily evapotranspiration rates. Evapotranspiration is difficult to measure directly, but can be estimated through the use of recorded climatic variables. Researchers have developed several formulae which can be used to obtain estimates of evapotranspiration. In this study the procedures developed by C. W. Thornthwaite are used.[4] His research indicates that there is a close relationship between mean monthly temperature and potential evapotranspiration, if adjustments are made for differences in day length. The method involves fewer calculations than other procedures, and requires the use of climatic variables which are available at most weather recording stations. Although some of the climatic variables influencing evapotranspiration are ignored in Thornthwaite's method, comparisons of the results with those obtained from more elaborate equations reveal no appreciable differences.[5]

Procedure Used to Determine Drouth-Days and Need for Supplemental Irrigation

A simple bookkeeping procedure was used to determine the daily status of soil moisture. It was assumed that the available soil-moisture bases were at their maximum values on the starting date for calculations during each crop season. The starting date was May 31. It is unrealistic to assume that soil moisture will be at a maximum value each year on May 31, but the first rainfall in excess of the existing deficit after this data will correct this error. May 31 was selected because one of the conditions of the formula for calculation of evapotranspiration is that a closed vegetative cover exist. This condition will not be met fully with most crops even at a starting date as late as May 31.

In performing the calculations, the computed amount of evapotranspiration is subtracted each day from the assumed soil-moisture base and rainfall and irrigation applications are added. This procedure gives the available moisture remaining in the soil at the end of each day. If available moisture reaches the zero level for a 24-hour period, this is assumed to result in a drouth-day.

Two restrictions are placed upon this method of computing the daily soil-moisture balances. When the base is completely depleted, evapotranspiration is considered to stop. Also, rainfall in amounts exceeding the existing deficiency are cancelled. The excess moisture is assumed to be lost for use by the crop either through run-off or by percolation through the root zone. It should also

[4] C. W. Thornthwaite, "An Approach Toward A Rational Classification of Climate," *Geog. Rev.*, 38:55-94, 1948.
[5] Wayne L. Decker, "Precision of Estimates of Evapotranspiration in Missouri Climate," *Agronomy Journal*, 54: 529-531, June, 1962; and Howard H. Engelbrecht, "The Application of High Speed Computers in Irrigation Research," *Bulletin of the American Meteorological Society*, 40:569, November 1959.

be noted that the loss of rainfall through run-off is not allowed until the available soil-moisture base is at its maximum value. The implications of the assumptions will be discussed in more detail later.

The need for irrigation was determined by assuming that a water application was made when the irrigation base was completely depleted.[6] For purposes of timing irrigation applications, the irrigation base is the amount of water held between field capacity and the soil moisture level at which the operator decides water applications should be initiated. Generally, irrigation is recommended when the available soil moisture content is 50-75 percent depleted.

Irrigation applications were assumed to be 2 inches when the deficiency was 2 inches or greater. For deficiencies less than 2 inches, the application was assumed to be enough to bring the supply up to field capacity. Irrigation applications in excess of 2 inches were not assumed because engineers who were familiar with the area indicated that this quantity was near the upper limit of feasible application. An illustration of the procedure used to determine the occurrence of drouth-days is presented in Table 2. The procedure used to determine the number of irrigations needed is illustrated in Table 3.

As indicated earlier, some of the assumptions used in the moisture-balance computations need rather careful examination to prevent erroneous interpretation of the results. The method employed assumes that the rate of evapotranspiration is not proportional to the moisture content of the soil. In other words, evapotranspiration is assumed to occur at the maximum rate between field capacity and the wilting point and to terminate completely at the wilting point. Experimental evidence suggests that the evapotranspiration is reduced if the soil surface is dry.[7] This would mean that the available soil moisture is not depleted as rapidly as the procedure indicates after the soil surface is dry.

The selection of a moisture level to use as the point of initial drouth damage should not deviate too far from the permanent wilting point for a given soil-crop situation. As additional experimental evidence becomes available, perhaps differential evapotranspiration rates can be used jointly with accurate determination of the point of initial drouth damage to make accurate drouth-day determinations. Until this degree of accuracy is achieved, it is imperative that the limitations of current procedures be explicitly stated. These limitations are of little consequence in determining the need for water and in scheduling irrigation applications. Since it requires a period of a few days to apply water to a given field, in practice, water applications must be initiated on some portions of the area prior to the occurrence of damaging moisture depletions.

[6]C. H. M. van Bavel and T. V. Wilson, "Evapotranspiration Estimates as Criteria for Determining Time of Irrigation," *Agricultural Engineering,* 33:417-418, July 1952.

[7]Marie Sanderson, "An Experiment to Measure Potential Evapotranspiration," *Canadian Journal of Research,* 26: 445-454, August 1948.

TABLE 2 - PROCEDURE USED IN DETERMINING DROUTH-DAY OCCURRENCES FOR AN AVAILABLE SOIL-MOISTURE BASE OF TWO INCHES[a]

Date	Evapo-transpiration (inches)	Precipi-tation (inches)	Available Soil-Moisture Balance at the End of the Day (inches)
6/20[b]	0.19		1.06
6/21	.20	0.10	.96
6/22	.20	1.10	1.86
6/23	.19		1.67
6/24	.22		1.45
6/25	.22	.15	1.39
6/26	.24		1.14
6/27	.23	.55	1.46
6/28	.23		1.23
6/29	.22		1.01
6/30	.24		.77
7/1	.24		.53
7/2	.25		.28
7/3	.24		.04
7/4	.25		.00
7/5	.23		.00
7/6	.23	.01	.00
7/7	.22	.24	.02
7/8	.22		.00
7/9	.23		.00
7/10	.25	.07	.00
7/11	.23	.78	.55
7/12	.21	.01	.35
7/13	.23		.12
7/14	.20		.00
7/15	.22		.00
7/16	.22	.02	.00
7/17	.19		.00
7/18	.20		.00
7/19	.22	.01	.00
7/20	.22	.24	.02
7/21	.25		.00

[a] Evapotranspiration and precipitation valued for Sikeston, Mo., 1949.

[b] Computations were initiated on May 31 with an available soil-moisture base of two inches.

TABLE 3 - PROCEDURE USED IN DETERMINING NUMBER OF IRRIGATIONS NEEDED FOR AN AVAILABLE SOIL-MOISTURE BASE OF TWO INCHES[a]

Date	Evapo-transpiration	Precipi-tation	Available Soil-Moisture Balance at the End of the Day[b]
	(inches)	(inches)	(inches)
6/20[c]	0.19		1.06
6/21	.20	0.10	.96
6/22	.20	1.10	1.86
6/23	.19		1.67
6/24	.22		1.45
6/25	.22	.15	1.39
6/26	.24		1.14
6/27	.23	.55	1.46
6/28	.23		1.23
6/29	.22		1.01
6/30	.24		.77
7/1	.24		.53
7/2	.25		.28
7/3	.24		.04
7/4	.25		2.00[d]
7/5	.23		1.77
7/6	.23	.01	1.55
7/7	.22	.24	1.57
7/8	.22		1.35
7/9	.23		1.12
7/10	.25	.07	.94
7/11	.23	.78	1.49
7/12	.21	.01	1.29
7/13	.23		1.06
7/14	.20		.86
7/15	.22		.64
7/16	.22	.02	.44
7/17	.19		.25
7/18	.20		.05
7/19	.22	.01	2.00[d]
7/20	.22	.24	2.00
7/21	.25		1.75

[a] Evapotranspiration and precipitation values for Sikeston, Mo., 1949.

[b] The available soil-moisture base for irrigation purposes refers to the quantity of water held between field capacity and the point at which irrrigation is initiated. This point is usually a depletion level less than that of the permanent wilting point.

[c] Computations were initiated on May 31 with an available soil-moisture base of two inches.

[d] An irrigation application sufficient to recharge the available soil-moisture base to a value of two inches was assumed to be applied if the meteorological conditions were such that the available soil-moisture base would have been completely exhausted during the day.

RESULTS

Drouth-Day Occurrence

Daily available soil-moisture balances were determined for each of the three locations in the study area. Available soil-moisture balances were calculated for each year of existing records for the period May 31 to August 31 inclusive. Determinations were made for available soil-moisture bases of 1, 2, 3, 4, 5, and 6 inches. This range is adequate to include most of the soil-crop combinations existing in the Delta and allows for relatively accurate interpolation between bases.

The information gained from an analysis of past weather records can be used to estimate the future occurrence of drouth conditions.[8] To accomplish this objective the occurrence of drouth-days was tabulated by weekly, monthly, and seasonal periods for each year, each soil-moisture base, and each weather station. Frequency distributions of these data were prepared. The hypothesis that there were no significant differences between frequency distributions due to location was tested.[9] The hypothesis was not rejected; consequently, the data from all locations were aggregated to form a single measure of past drouth-day occurrence for the study area.

Cumulative frequency distributions were constructed and the relative frequencies, or probabilities, of occurrence of drouth periods of varying intensities were computed. These empirical probabilities for the seasonal and monthly periods are presented in the Appendix. The probabilities for the weekly periods are presented in Table 4. The figures in the body of the tables refer to the probability of the associated number of drouth days or more occurring, expressed as a percentage of the years. This also can be expressed as the probability of a minimum number of drouth-days.

The probabilities of specified minimum numbers of drouth days are presented for the entire 92-day period, for the individual months, June, July, and August, and for the 11 weekly periods beginning with the climatological weeks June 14 through August 23 for each available soil-moisture base. The results presented in these tables make it possible to determine the estimated drouth hazard for any specified period and for each available soil-moisture base included in the analysis.

If the data in Appendix Table 1 are plotted on probability paper, inferences can be made concerning the occurrence of specified numbers of drouth-days. Graphs of this type indicate the minimum number of drouth-days expected to occur on the abscissa and the associated value for the probability of occurrence, expressed in percent, on the ordinate. It is evident from the graph that the chances for dry periods of damaging lengths are quite high (Figure 2). For instance, the probability is 50 percent that 41 or more drouth-days will occur in a

[8] A. M. Mood, *Introduction to the Theory of Statistics,* New York, McGraw-Hill Book Co., Inc., 1950, p. 273.

[9] H. C. S. Thom, "Three Chapters on Climatological Analysis," United States Weather Bureau Manuscript, United States Department of Commerce, Washington 25, D. C., August 1960, p. 1.

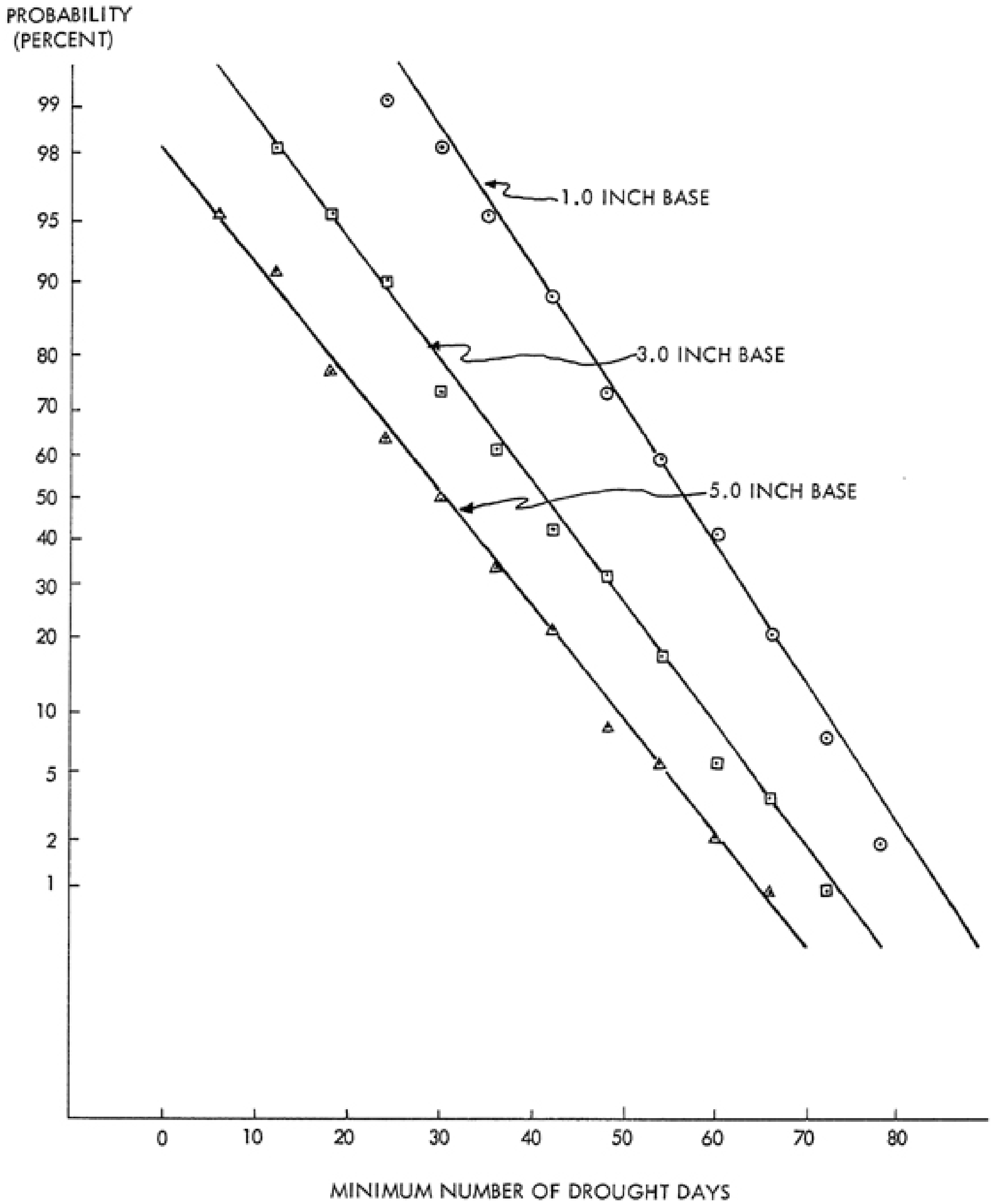

Fig. 2 - Probability for a minimum number of drought days to occur during the period June 1 to August 31 in the Missouri Delta

given year during the 92-day period from June to August 31, if the soil-moisture base is 3 inches. For these same conditions there is a 25 percent chance that5 0 or more drouth days will occur during a given year. Likewise, there is a 75 percent chance that 32 or more drouth days will occur during a given year. One year in ten 59 or more drouth days can be expected to occur during the 92-day period.

TABLE 4 - PROBABILITY FOR A MINIMUM NUMBER OF DROUTH-DAYS TO OCCUR DURING SPECIFIED WEEKLY PERIODS IN THE MISSOURI DELTA

Weekly Period	Available Soil-Moisture Base (inches)	Minimum Number of Drouth-Days							
		0	1	2	3	4	5	6	7
		(Percent)							
June 14-June 20	1.0	100	79	72	59	52	43	32	26
	2.0	100	58	51	44	38	31	23	18
	3.0	100	31	25	18	13	8	4	2
	4.0	100	7	4	1	0	0	0	0
	5.0	100	0	0	0	0	0	0	0
	6.0	100	0	0	0	0	0	0	0
June 21-June 27	1.0	100	88	80	73	64	52	43	33
	2.0	100	70	66	59	53	43	34	27
	3.0	100	51	46	44	38	34	25	17
	4.0	100	34	29	26	17	13	7	6
	5.0	100	11	8	7	3	3	1	1
	6.0	100	2	1	0	0	0	0	0
June 28-July 4	1.0	100	94	88	78	68	61	45	27
	2.0	100	83	76	64	51	47	34	22
	3.0	100	68	64	56	43	38	24	14
	4.0	100	48	45	36	28	27	17	10
	5.0	100	32	26	22	15	13	9	4
	6.0	100	14	11	9	7	5	2	1
July 5-July 11	1.0	100	94	90	81	74	64	48	34
	2.0	100	85	79	74	64	57	40	29
	3.0	100	75	70	58	50	42	30	24
	4.0	100	57	51	47	38	32	22	16
	5.0	100	40	35	32	26	21	13	9
	6.0	100	25	22	20	12	8	6	3
July 12-July 18	1.0	100	95	92	83	71	59	44	34
	2.0	100	86	83	72	61	51	40	30
	3.0	100	79	75	69	59	49	36	27
	4.0	100	72	68	62	53	42	27	19
	5.0	100	57	52	46	42	32	22	16
	6.0	100	42	41	36	27	21	17	12
July 19-July 25	1.0	100	95	93	84	76	67	52	44
	2.0	100	87	82	75	69	62	50	41
	3.0	100	82	77	69	61	54	45	35
	4.0	100	79	72	63	59	54	43	35
	5.0	100	71	65	57	53	48	40	33
	6.0	100	58	52	47	45	37	32	24

TABLE 4 - (CONTINUED)

Weekly Period	Available Soil-Moisture Base (inches)	Minimum Number of Drouth-Days							
		0	1	2	3	4	5	6	7
		(Percent)							
July 26- August 1	1.0	100	98	91	86	75	65	54	42
	2.0	100	89	84	77	69	61	49	37
	3.0	100	87	81	75	66	59	46	34
	4.0	100	85	78	72	61	54	46	32
	5.0	100	76	73	68	59	48	39	31
	6.0	100	65	62	59	49	42	34	27
August 2- August 8	1.0	100	92	86	78	72	61	47	37
	2.0	100	83	79	71	68	59	47	35
	3.0	100	79	76	70	67	59	45	33
	4.0	100	78	76	67	63	58	43	33
	5.0	100	76	70	62	60	52	40	29
	6.0	100	67	61	54	54	45	36	25
August 9- August 15	1.0	100	92	83	74	64	53	47	29
	2.0	100	82	75	72	62	50	44	28
	3.0	100	80	74	70	60	48	42	24
	4.0	100	79	73	69	60	48	42	23
	5.0	100	76	70	66	59	47	41	24
	6.0	100	70	63	59	52	43	39	21
August 16- August 22	1.0	100	89	80	76	66	58	41	25
	2.0	100	74	65	63	56	46	34	21
	3.0	100	70	62	60	55	47	35	21
	4.0	100	70	60	58	52	44	32	21
	5.0	100	67	60	58	53	45	33	21
	6.0	100	65	57	55	52	43	31	20
August 23- August 29	1.0	100	88	79	71	66	56	42	32
	2.0	100	78	71	67	60	49	38	28
	3.0	100	73	66	60	55	44	35	26
	4.0	100	70	63	59	54	43	34	26
	5.0	100	70	63	59	53	42	33	26
	6.0	100	68	60	56	49	40	31	25

It can be contended that a drouth-day is a sterile concept of drouth damage because no measures of yield response or economic values can be attached without additional information. However, it is obvious that the probability of avoiding severe reductions in crop yields and economic returns are rather small if 59 days out of a total of 92 during June, July, and August are determined to be near the wilting point.

Additional insight into the probability of drouth periods during the critical stages of crop development can be gained from an examination of probability distributions for monthly periods (Appendix Table II and Figures 3 and 4). For an available soil-moisture capacity of 3 inches and a probability level of 50 percent, 18 or more drouth-days would be expected during July (Figure 3). One year out of ten 28 drouth-days would be expected in July. Only one year out of five would 11 or fewer drouth days be expected. To preserve clarity, graphs are presented only for selected soil-moisture bases. Other graphs can be prepared from data in the Appendix.

Frequency distributions were also prepared for selected weekly periods during the crop season. This information is in Table 4. Graphs were not prepared, as interpolation between specified numbers of drouth-days is not necessary for effective use of the results.

Relationship of Drouth-Days and Available Soil Moisture Base: The occurrence of drouth days can be expected to diminish as available soil-moisture capacity increases. This relationship is verified by the data. The average number of drouth-days expected for the seasonal and monthly periods was plotted against the associated soil-moisture bases. (Figures 5 and 6).

The graph of the seasonal relationship indicates that the occurrence of drouth-days decreases at a relatively constant rate as the magnitude of the available soil-moisture base increases (Figure 5).

The monthly relationships clearly illustrate that the effectiveness of a large initial soil-moisture base in preventing the occurrence of drouth days diminishes as the season progresses. By August, even a large initial base has been depleted because accumulated potential moisture losses due to evapotranspiration greatly exceed accumulated precipitation during the months of June, July, and August (Figure 7). Therefore, decreases in expected drouth-days as the available soil-moisture base increases are not nearly as great for August as for June and July (Figure 6). The fact that more drouth days are expected in August than in July for bases exceeding 3 inches is not due to the deficit between potential evapotranspiration and precipitation, which is smaller in August than in July. Rather, it is due to differences in the degree of depletion of the initial available soil-moisture base on the first days of August compared to the first day of July.

Persistence of Drouth: The total effect of drouth periods is not determined solely by the number of drouth-days. A simple total does not take into account the sequence or order in which the drouth-days occur. A given number of drouth-days occurring in an unbroken sequence would in all probability have a more

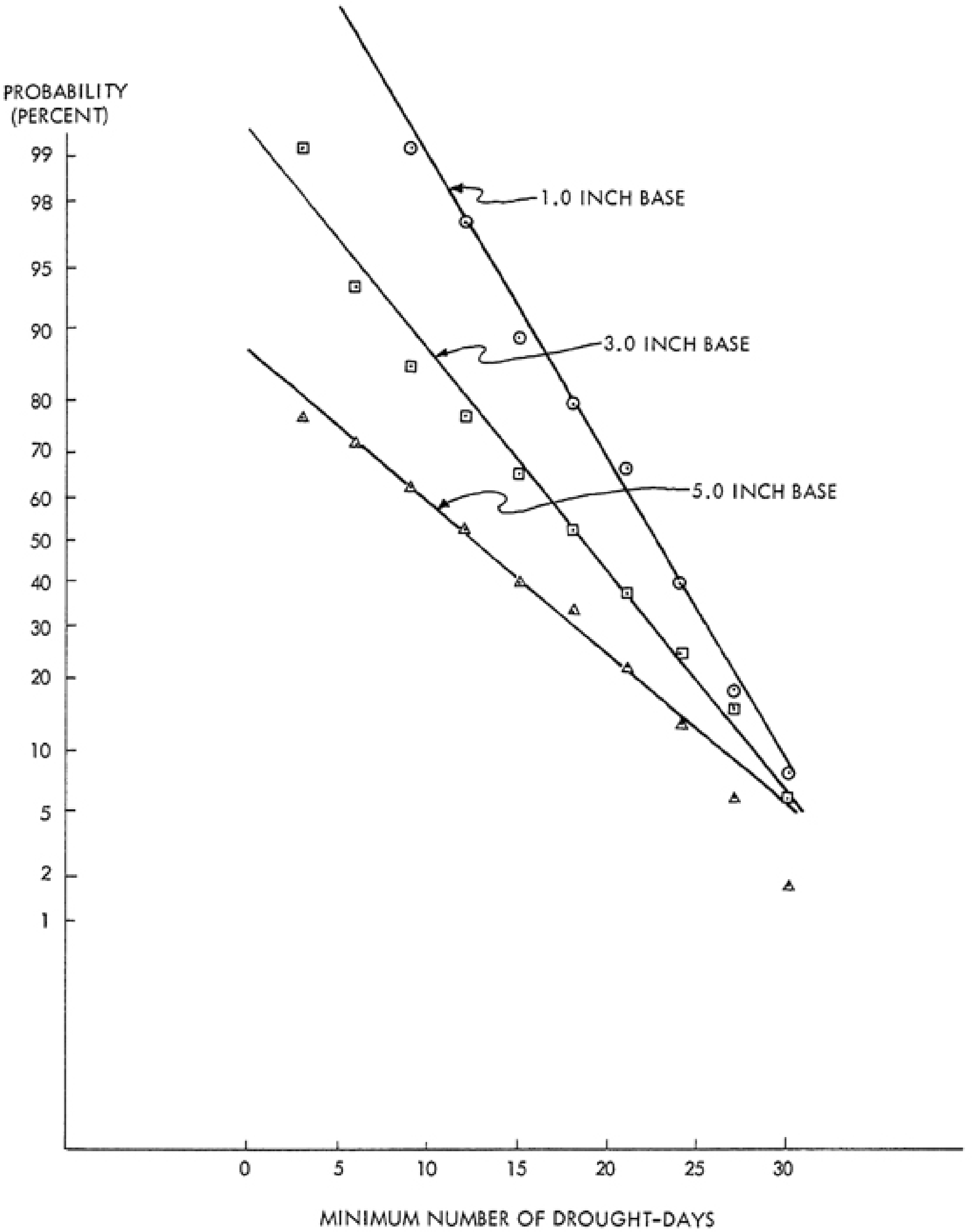

Fig. 3 - Probability for a minimum number of drought-days to occur during July in the Missouri Delta.

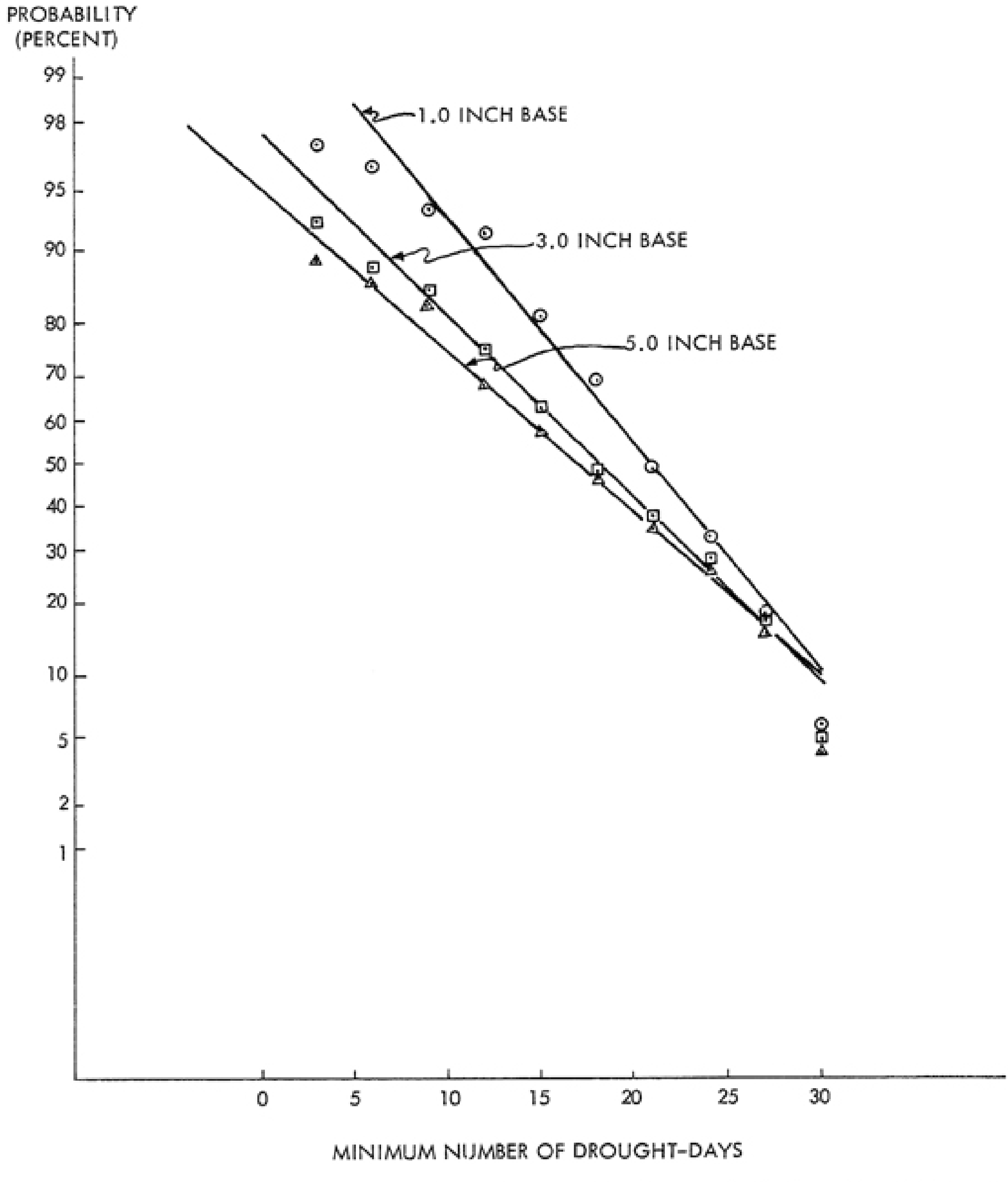

Fig. 4 - Probability for a minimum number of drought-days to occur during August in the Missouri Delta.

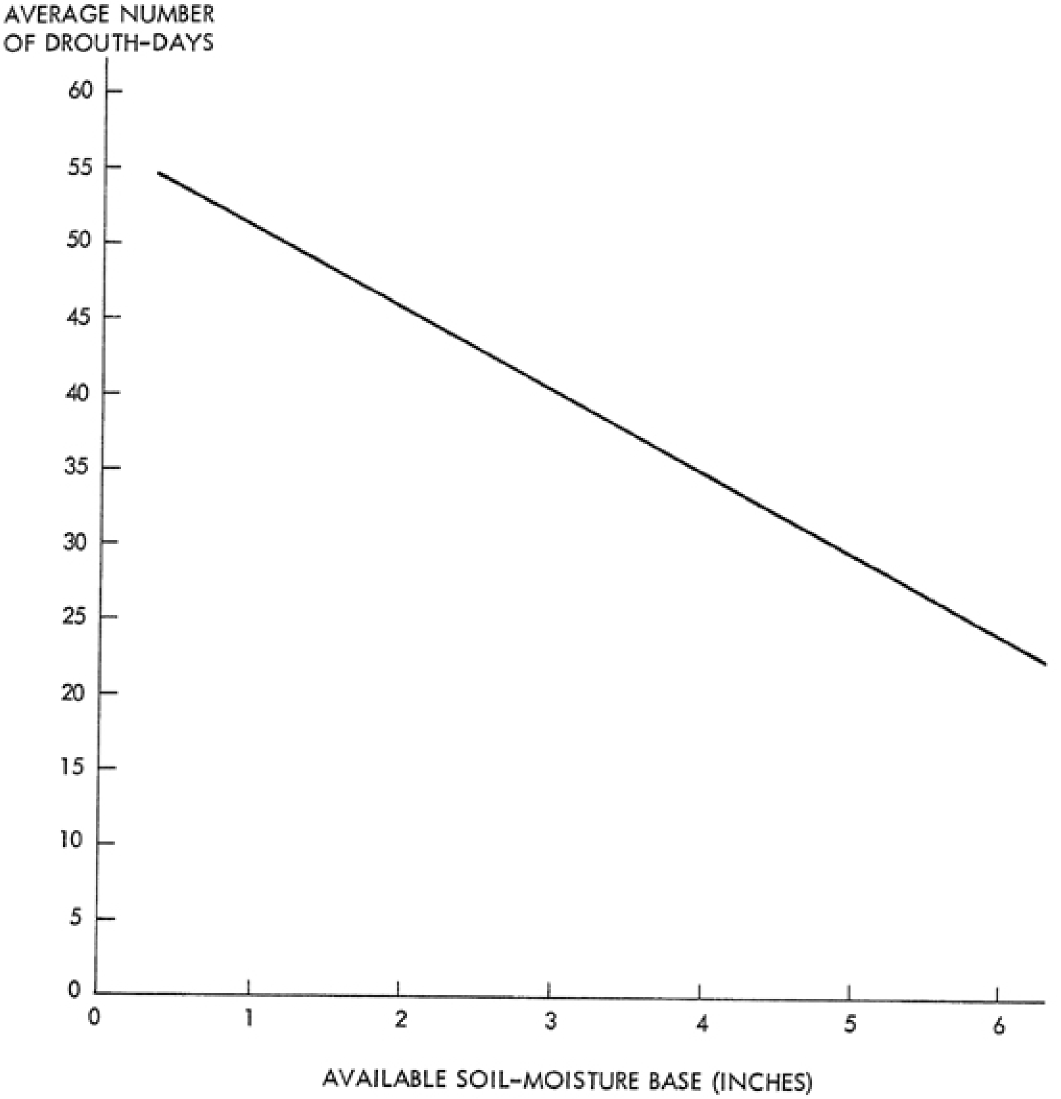

Fig. 5 - Relationship of average number of drouth-days and available soil-moisture base for the period June 1 to August 31 in the Missouri Delta.

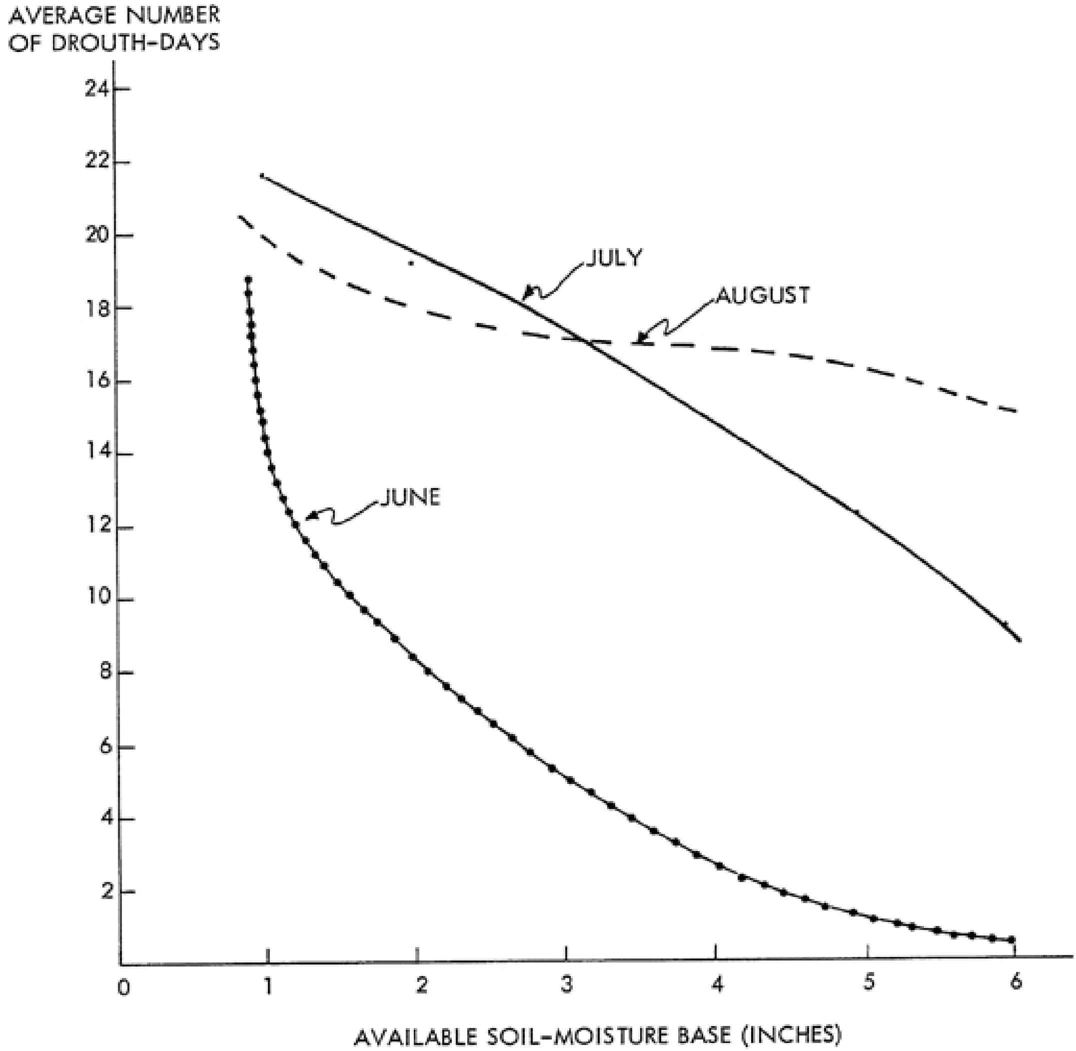

Fig. 6 - Relationship of average number of drouth-days per month and available soil-moisture base for June, July, and August in the Missouri Delta.

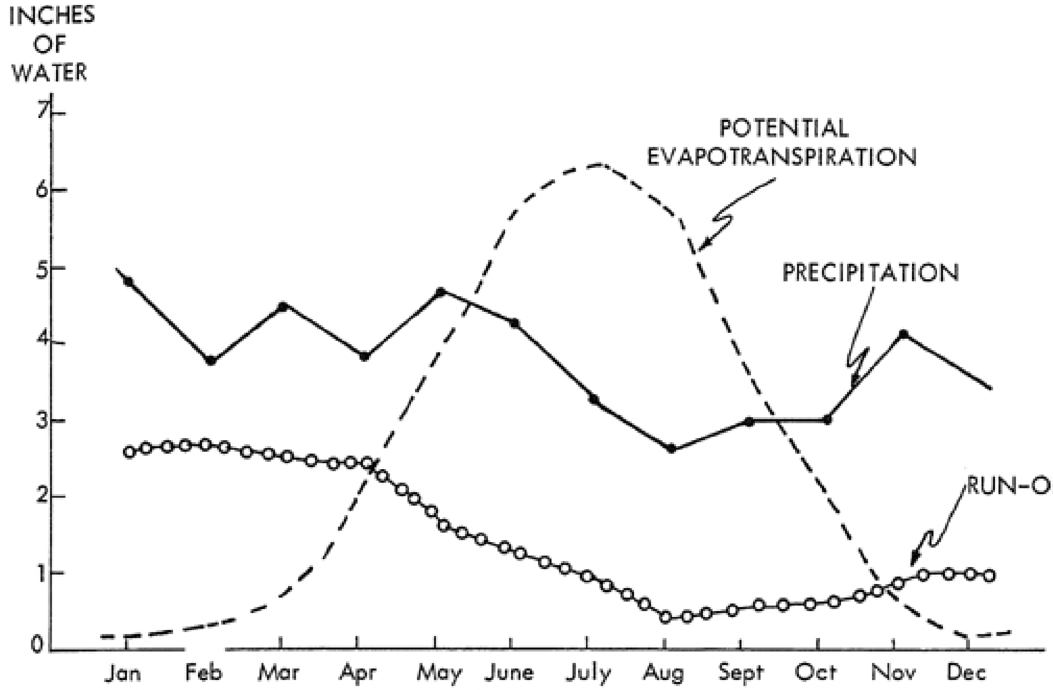

Fig. 7 - Average monthly precepitation, run-off, and potential evapotranspiration for the southeast Missouri lowlands, 1947-1959 (J.O. McQuigg and W.L. Darker, The Hgdrologic Balance of the Lowlands of Southeast Missouri, unpublished note, 1962).

depressing effect on crop yields than an equal number occurring in several short sequences. An estimate of the probability of drouth-day sequences of specified lengths was obtained by the following procedure.

Frequency distributions of drouth-day sequences by length were prepared for all sequences that occurred during July. This month was selected because it is most critical to the growth and development of the crops usually grown in the Delta. When cumulative distributions were prepared, it was possible to determine the probability that any drouth sequence beginning in July would equal or exceed any specified length of time. If the available soil-moisture base is 2 inches there is 50 percent probability that a drouth-day sequence, once begun in July, will equal or exceed eight days in length (Figure 8). Likewise, there is 10 percent probability that the sequence will equal or exceed 24 days in length. The probabilities for a larger base are very similar in magnitude and are not presented. There is, of course, less chance for the sequence to begin if the initial base is larger, but once begun, the probable duration is very nearly the same as that of a 2-inch base. The slight difference which does exist must arise from the shifting of the period of first occurrence of drouth into time periods of different rainfall patterns.

This analysis provides a conservative measure of the number of continuous days to be expected without sufficient rainfall to offset daily evapotranspiration

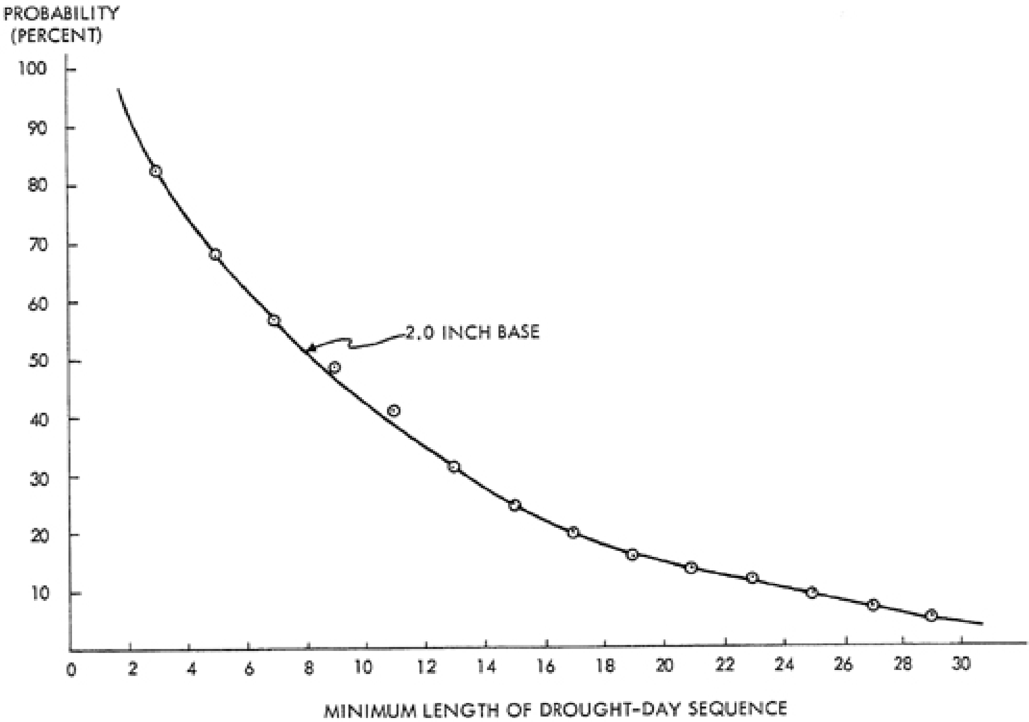

Fig. 8 – Probability that any drought-day sequence which begins during July in the Missouri Delta will attain a minimum specified length.

after the original base has been depleted. Reference to Table 2 will indicate the conservative nature of this measure. If July 7, with an available moisture belance at the end of the day of 0.02 inches is ignored, the length of the sequence becomes seven days rather than two sequences of three days each. Similarly, on July 20 a drouth-day sequence is interrupted by a single day with a very small available soil-moisture balance.

The probability of a consecutive number of drouth-days is a more impressive measure of incidence than a simple total of drouth-days. Therefore, the sequential arrangement was examined in another way. Frequency distributions were prepared of the longest drouth-day sequence occurring during each July in the period of years studied for each available soil-moisture base. Cumulative probability distributions prepared from this information indicate the probability that the longest drouth-day sequence occurring in July will attain a minimum specified length.

The graphs in Figure 9 indicate that in 50 percent of the years a drouth sequence of 12 days or more in length will occur in July if the available soil-moisture base is 3 inches. Under these same conditions, a drouth sequence of 21 days or more could be expected to occur 13 percent of the time. Information for other available soil-moisture bases is presented in Figure 8 and Appendix Table III.

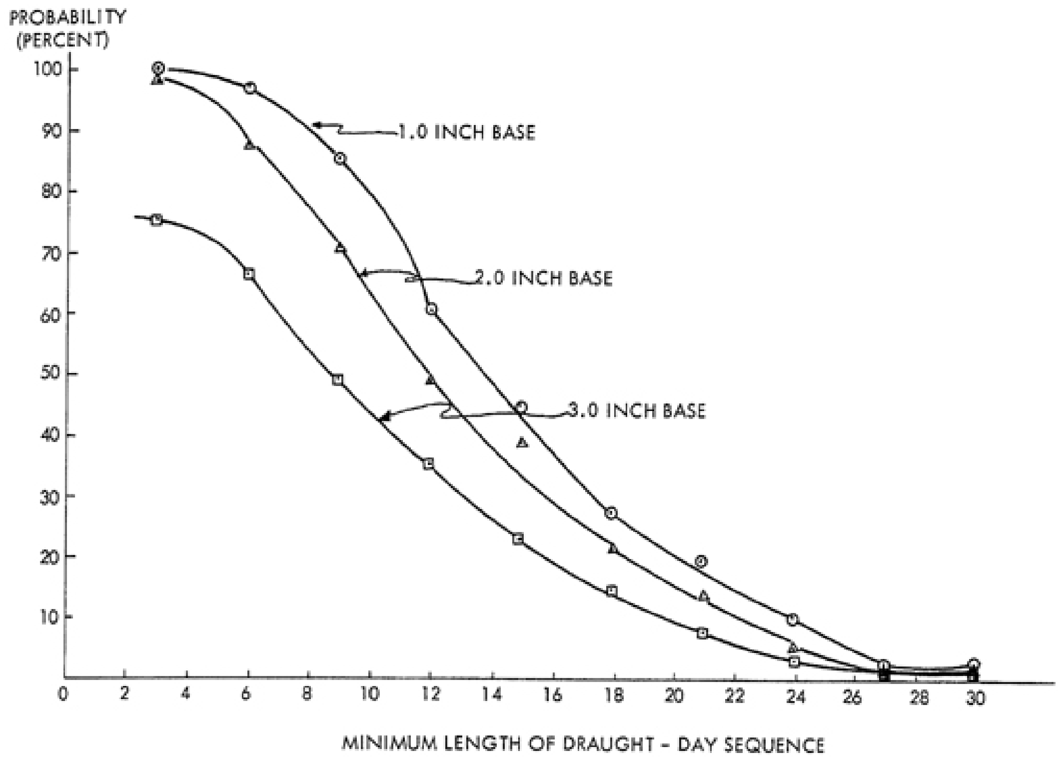

Fig. 9 - Probability that the longest draught-day sequence occurring during July in the Missouri Delta will attain a minimum specified length.

This drouth measure has the same conservative characteristics as that concerned with the probable duration of any sequence beginning in July in that one day with a very small available soil-moisture balance can partition the sequences. In addition, the sequences presented in this latter measure are confined strictly to the month of July. Though the drouth-day sequence may have originated in June and terminated in August, only the days in the sequence which occurred in July were counted.

Need for Irrigation Applications

The probable need for supplemental irrigation applications was determined in the same manner as the probable occurrence of drouth-days. The need for irrigation applications was tabulated bi-weekly, monthly, and seasonally for each year, for each available soil-moisture base, and for each location. Frequency distributions of these data were prepared for each available soil-moisture base and location. The hypothesis that there were no significant differences between the frequency distributions due to location was tested. The hypothesis was not rejected; consequently, the data from all locations were aggregated to form a single measure of probable need for irrigation.

It should be restated at this point that an available soil-moisture base for the purpose of timing irrigation applications is different from an available soil-moisture base as used in the calculation of drouth-days. For instance, assume a farmer has a soil-crop combination in which the maximum amount of water which could be held in the root-zone between field capacity and the permanent wilting point amounted to 3 inches. However, this farmer wishes to maintain through the use of irrigation a soil-moisture level of not less than one-third of this maximum capacity. The moisture base for purposes of timing water applications then becomes two-thirds of 3 inches, or 2 inches. When this amount of water is depleted from the root zone, irrigation will be initiated.

Cumulative frequency distributions were constructed. The relative frequencies, or probabilities, of specified numbers of irrigation applications for different time periods throughout the season are presented in Appendix Tables IV and V and Table 5. The data refer to the probable number of irrigation applications needed for the entire 92-day period, for individual months, June, July, and August and for five bi-weekly periods beginning with the two weeks starting June 21 and terminating August 23. Probability distributions for each soil-moisture base are presented for each of the periods. Graphs are presented for the seasonal period and for the monthly periods of June and July for 1-, 2-, 3-, and 4-inch available soil-moisture bases.

Figure 10 indicates that in 50 percent of the years six irrigation applications or more would be needed, if water applications were scheduled to prevent the soil-moisture base from being depleted more than 2 inches from maximum capacity. Eighty percent of the years five or more irrigations would be needed, and 20 percent of the years seven or more irrigations would be required.

The great disparity between frequency of need for irrigations between the 1-inch available soil-moisture base compared to all others is explained by the fact that only 1 inch would be applied, whereas, on the others the application amounted to 2 inches.

The frequency of need for irrigation during June and July is presented in Figures 11 and 12. If an available soil-moisture base of 3 inches is applicable, in 73 percent of the years two or more irrigations would be required in July. Under the same conditions the need for three irrigations would occur only 30 percent of the time. Graphs are not included for the bi-weekly periods; the probabilities of occurrence are presented in Table 5.

Relationship of Irrigation Needs and Soil-Moisture Base: The need for water applications decreases as the available soil-moisture base increases. This relationship for the seasonal period is illustrated in Figure 13. The average number of applications needed is plotted against the range of available soil-moisture bases. As noted earlier, the average number of irrigation applications needed decreases quite rapidly between the 1- and the 2-inch bases. The decrease in needed applications in relation to increases in the available soil-moisture base are very slight over the remaining range.

TABLE 5 - PROBABILITY OF THE NEED FOR A MINIMUM NUMBER OF IRRIGATIONS TO OCCUR DURING SPECIFIED BI-WEEKLY PERIODS IN THE MISSOURI DELTA

Periods	Soil Moisture Base	Minimum Number of Irrigations			
		0	1	2	3
		(Percent)			
June 21- July 4	1.0	100	94	74	20
	2.0	100	83	10	0
	3.0	100	65	10	0
	4.0	100	47	7	0
	5.0	100	33	3	0
	6.0	100	14	0	0
July 5- July 18	1.0	100	98	76	27
	2.0	100	80	13	0
	3.0	100	65	10	0
	4.0	100	69	13	0
	5.0	100	50	8	0
	6.0	100	41	7	0
July 19- August 1	1.0	100	99	84	29
	2.0	100	89	22	0
	3.0	100	87	17	0
	4.0	100	72	11	0
	5.0	100	72	14	0
	6.0	100	55	10	0
August 2- August 15	1.0	100	96	67	25
	2.0	100	80	11	0
	3.0	100	68	11	0
	4.0	100	73	9	0
	5.0	100	65	13	0
	6.0	100	68	11	0
August 16- August 29	1.0	100	89	64	14
	2.0	100	75	85	0
	3.0	100	60	85	0
	4.0	100	52	85	0
	5.0	100	57	6	0
	6.0	100	49	8	0

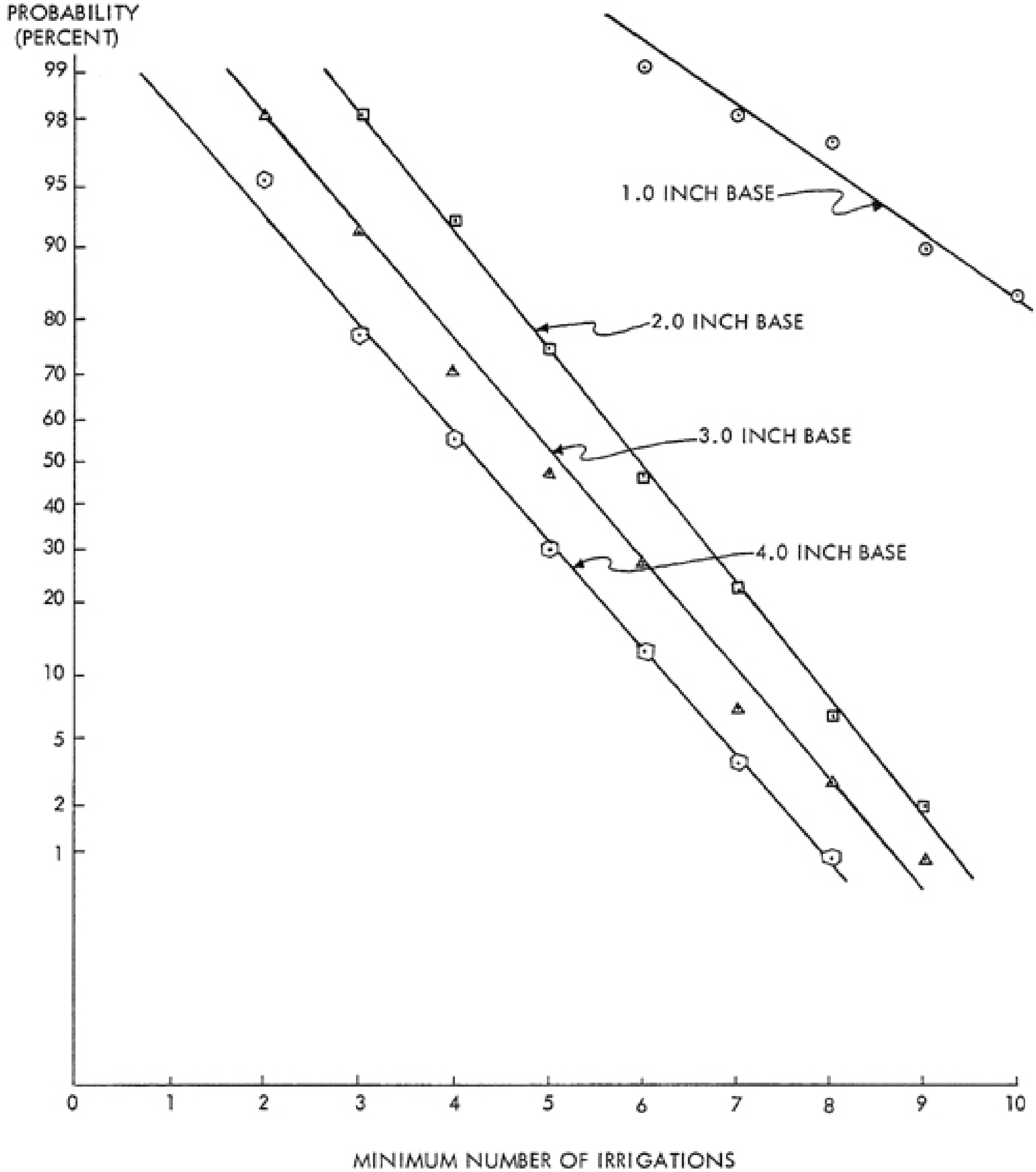

Fig. 10 - Probability of the need for a minimum number of irrigations during the period June 1 to August 31 in the Missouri Delta.

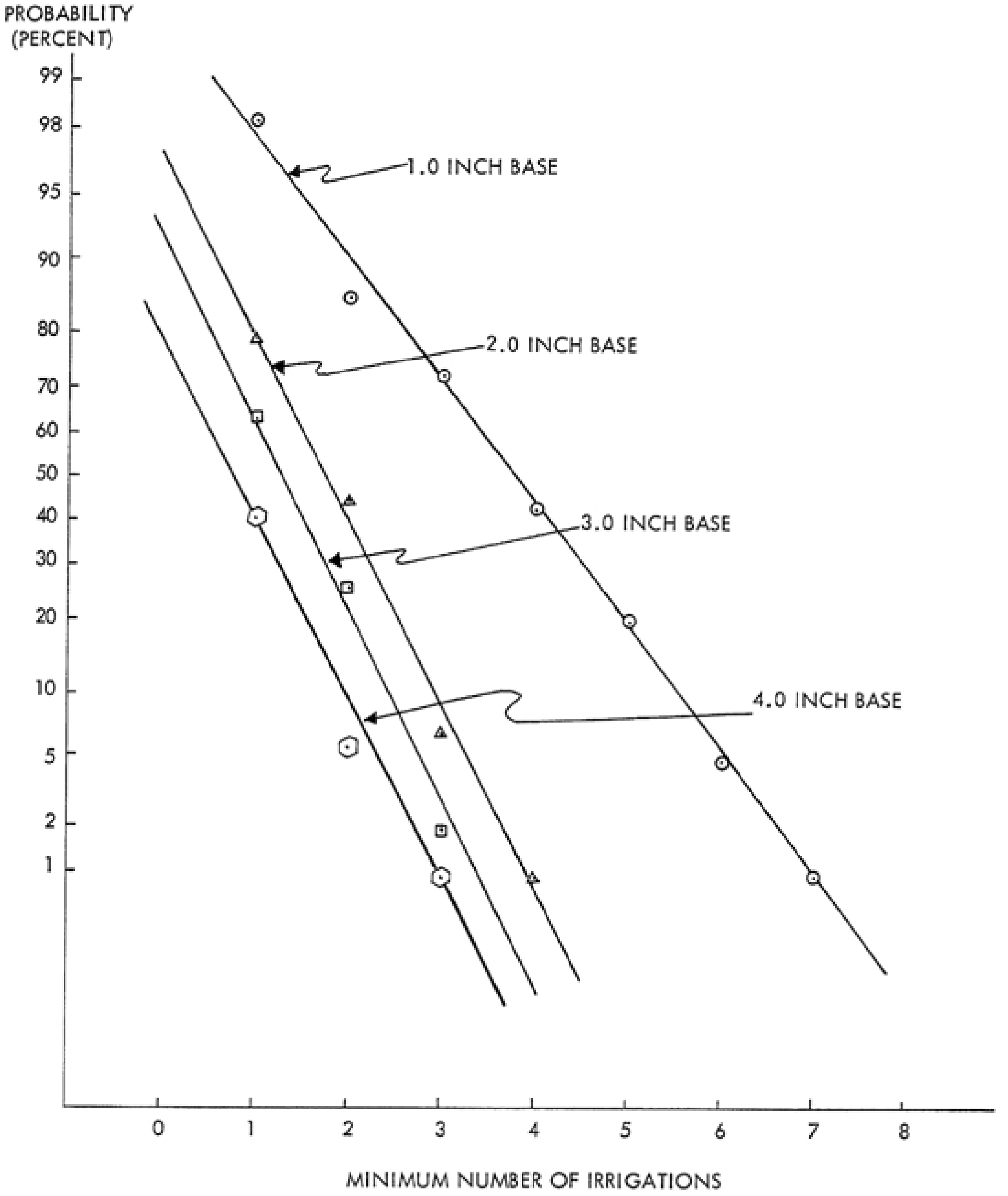

Fig. 11 - Probability of the need for a minimum number of irrigations during June in the Missouri Delta

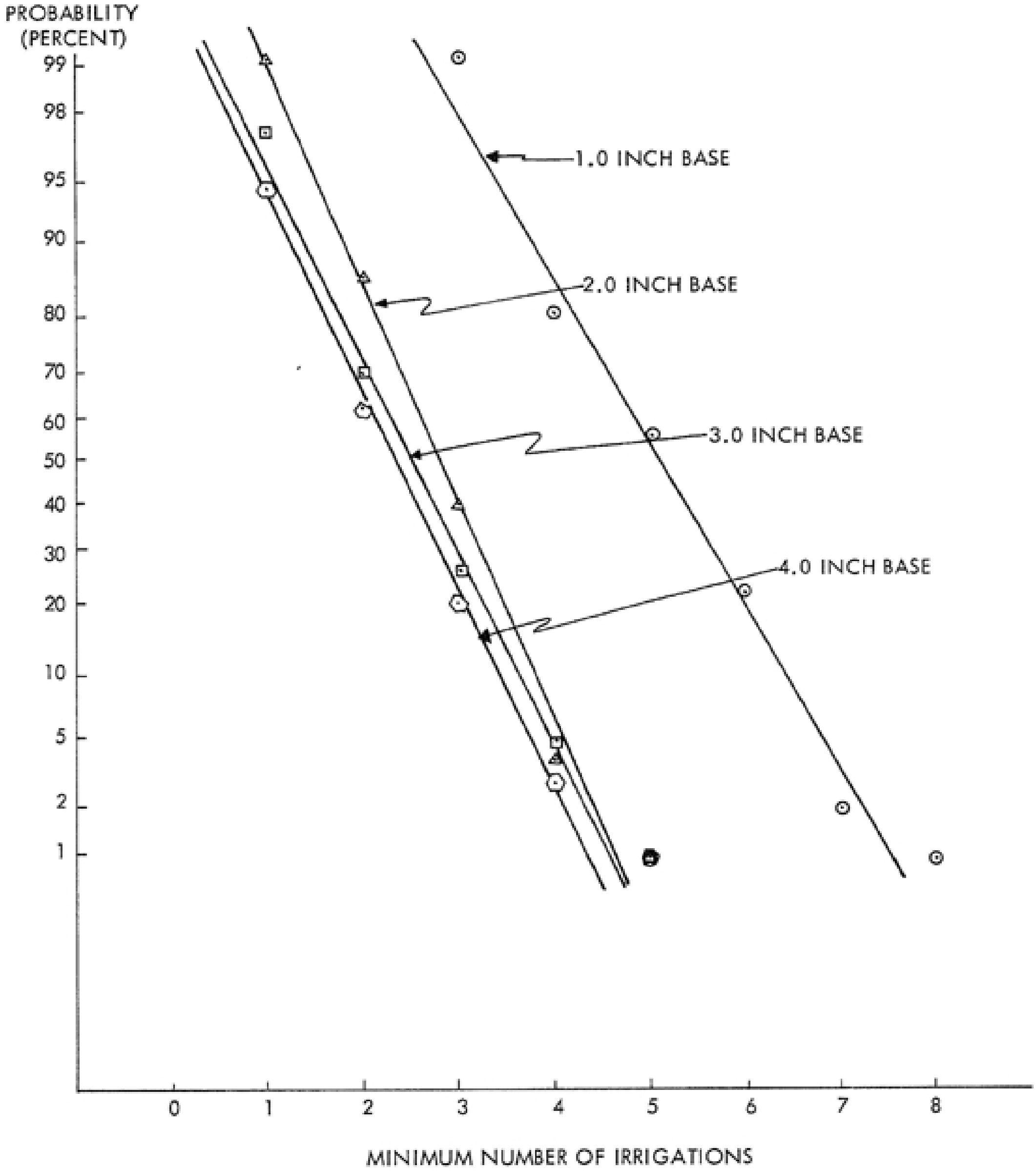

Fig. 12 - Probability of the need for a minimum number of irrigations during July in the Missouri Delta.

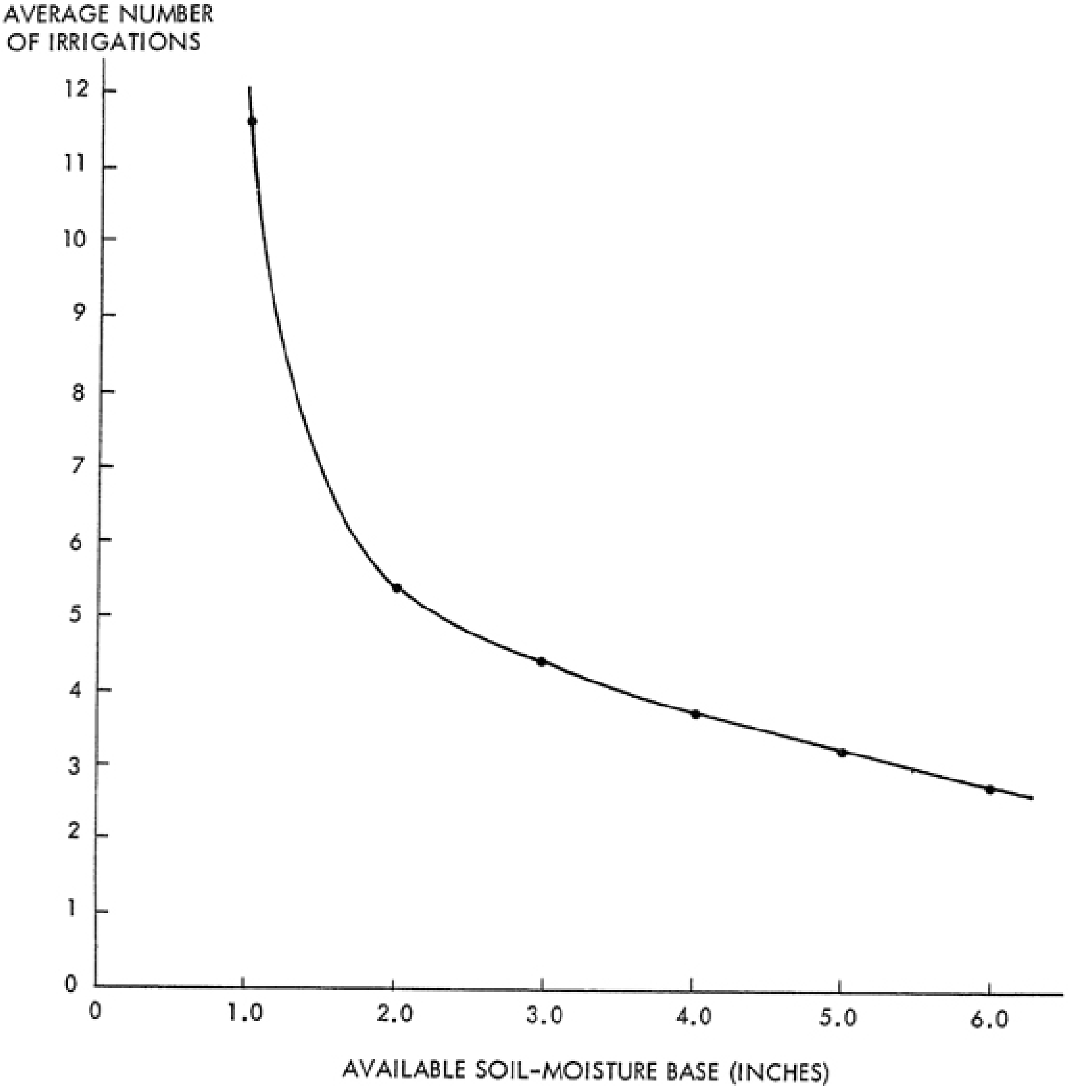

Fig. 13 - Relationship of average number of irrigations needed and available soil-moisture base for the period June 1 to August 31 in the Missouri Delta.

Once the initial base has been depleted only small differences in need for water can be expected. This fact is illustrated in Figure 14 which shows the relationship of irrigations needed to available soil-moisture base for June, July, and August. During August the large initial soil-moisture base has been depleted most years. Consequently, little difference is noted in the probable need for irrigation applications between soil-moisture bases. By the same token, the lower probability of need for irrigation applications in July compared to August is due to the effect of the large initial soil-moisture bases.

APPLICATION OF FINDINGS

The results of this study can be applied to agricultural problems dealing with the drouth hazard in several ways. First, the nature of the soil-crop-climate complex which determines the occurrence of drouth conditions is made clear. Consequently, relatively simple calculations can give farmers a more reliable

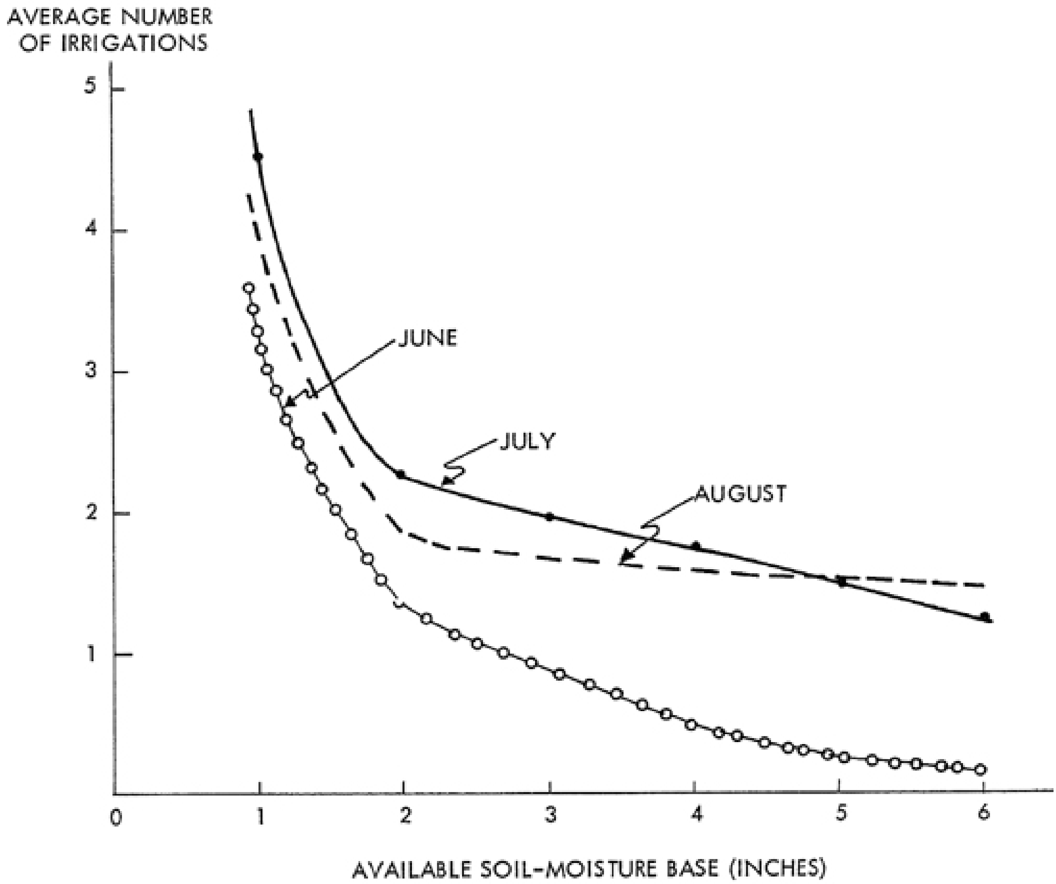

Fig. 14 - Relationship of average number of irrigations needed per month and available soil moisture base for June, July, and August in the Missouri Delta.

estimate of drouth conditions than is possible from rainfall data alone. Daily soil moisture balances can be calculated and made available to farmers in relatively large areas. Further research based on these findings will reveal when water should be applied to keep lack of moisture from being a limiting factor in the guest for optimum yields.

Although further refinement will greatly enhance the value of drouth-day information, it can be put to good use in its present form. The probability distributions of weather-related events such as drouth-days and need for supplemental irrigation can be used as the basis for a comprehensive evaluation of the economic feasibility of supplemental irrigation in subhumid areas. The expected influences on costs and returns can be calculated for long periods and the expected net return over the useful life of irrigation equipment can be determined.

Several studies which utilize the drouth-day approach to attack problems related to soil moisture have been completed. Knetsch and Parks have analyzed the response of corn and Starr millet to irrigation and nitrogen using drouth days as an independent variable influencing yield.[10] Optimum rates of nitrogen application were determined for expected drouth conditions and for an irrigation program.

Ehlers, using experimental plot data, determined the relationships between drouth-days in specified growth periods and corn yields.[11] Multiple correlation techniques were used to estimate the functional relationships. Probabilities of occurrence of varying yield reductions due to drouth were used in conjunction with estimated costs of irrigation to determine the feasibility of irrigating corn. Citations of other relevant studies are included in the Bibliography.

The information dealing with duration or persistence is particularly useful in emphasizing the probable occurrence of drouth periods of damaging lengths. It can be stated with a high degree of confidence that a sequence of 15 consecutive drouth days during July, a month critical for the growth of crops such as corn and cotton, will result in yield reductions and economic losses.

Drouth-day information can play an important part in the interpretation of agronomic tests in which soil moisture is a variable affecting the outcome of the experiment. For instance, in an extremely dry year a substantial yield increase would be expected for an irrigation treatment over the check or unwatered plot, but a record of the drouth-days that occurred during the experiment when compared with a probability distribution for the specific soil-crop combination might reveal that such severe drouth conditions could be expected to occur only once every 10 to 12 years. This probable recurrence value could be included in the report of the experimental results.

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[10] Jack L. Knetsch, "Moisture Uncertainties and Fertility Response Studies," *Journal of Farm Economics*, 41:70-76, February 1959; and J. L. Knetsch and W. L. Parks. *Interpreting Results of Experiments—A Progress Report*, Tennessee Valley Authority Report No. T59-1AE, Knoxville, Tennessee, August 1958.

[11] Wayne F. Ehlers, "Economic Implications of Drouth Probabilities for Humid Area Irrigation," *Journal of Farm Economics*, 42:1518-1519, December 1960.

Data on the drouth hazard of an area will provide valuable information for designing irrigation systems. The information presented here provides a guide as to the frequency of need for irrigation. It can also be used as a guide in choosing the size of irrigation systems required to cover a given number of acres within a specified time interval. An estimate of annual water requirements for irrigation can also be derived from the data.

For example, suppose an operator has 60 acres of corn which he desires to irrigate. From a knowledge of the specific soil conditions on his farm he decides that the data for an available soil-moisture base of 3 inches are appropriate for his farm. He also determines that the growth period during which moisture deficiencies are most critical occurs during July and that he wishes to design his irrigation system to provide full protection against drouth damage in this period at least nine years out of 10. From Figure 11 it can be seen that to provide protection at this level the operator would need to be prepared to apply water at least four times during the month. This would mean that he would need to have ample equipment to cover the 60 acres in approximately eight days or at a rate of seven and one-half acres per day. Assuming a net application of 2 inches per acre and an efficiency of 75 percent, the irrigator would need capacity to supply 20 acre-inches of water per day. Assuming a 12-hour irrigating day this amounts to 1.67 acre-inches of water per hour or 759 gallons per minute.

The design of the distribution system would depend on other considerations, also, such as infiltration rate of the soil, labor involved in applying water and others. Maximum expected water requirements for irrigation in July could be computed by the number of applications, four, times the gross application per acre, 2.67 inches, times the number of acres, 60. The resulting 640 acre-inches would be the maximum amount of water required in July nine years out of 10.

In short, the drouth-day concept offers a new approach to the study of problems encountered in the use of irrigation in agricultural production.

BIBLIOGRAPHY

Beringer, Christoph, *An Economic Model for Determining the Production Function for Water in Agriculture,* California Agricultural Experiment Station, Giannini Foundation Research Report No. 240, 1961.

Decker, Wayne L., "Precision of Estimates of Evapotranspiration in Missouri Climate," *Agronomy Journal,* 54:529-531, June, 1962.

Ehlers, Wayne F., "Economic Implications of Drouth Probabilities for Humid Area Irrigation," *Journal of Farm Economics,* 42: 1518-1519, December, 1960.

Engelbrecht, Howard H., "The Application of High Speed Computers in Irrigation Research," *Bulletin of the American Meteorological Society,* 40:569, November, 1959.

Hagan, R. M., Y Vaadia, and M. B. Russell, "Interpretation of Plant Responses to Soil Moisture Regimes," *Advances in Agronomy,* 11:77-98, New York: Academic Press, 1959.

Holcombe, J. L., and Fred H. Wiegmann, *Drouth Intensity and Irrigation Needs for Cotton in the St. Joseph Area.* Department of Agricultural Economics Circular 185, Louisiana State University, Agricultural Experiment Station, December, 1955.

Knetsch, J. L. "Moisture Uncertainties and Fertility Response Studies," *Journal of Farm Economics.* 41:70-76, February, 1959.

Knetsch, J. L., and W. L. Parks, *Interpreting Results of Irrigation Experiments—A Progress Report,* Tennessee Valley Authority Report No. T59-1AE, Knoxville, Tennessee, August, 1958.

Knetsch, J. L., and G. Smallshaw, "The Occurrence of Drouth in the Tennessee Valley," Tennessee Valley Authority Report T58-2AE, 1958.

Kroth, E. M., V. C. Jamison, and H. E. Grogger, *Soil Moisture Survey of Some Representative Missouri Soil Types,* United States Department of Agriculture, Agriculture Research Service, ARS-41-34, April, 1960.

Jones, Ted L., and Frank Miller, *Irrigation Practices and Costs in Southeastern Missouri—1960,* University of Missouri, Agricultural Experiment Station Research Bulletin 795, Columbia, Missouri, March, 1961.

McQuigg, J. D., and Wayne L. Decker, "The Hydrologic Balance of the Lowlands of Southeast Missouri," Unpublished note, Columbia, Missouri, 1962.

Mood, A. M., Introduction to the Theory of Statistics, New York, McGraw-Hill Book Company, Inc., 1950.

Moore, Charles V., "A General Analytical Framework for Estimating the Production Function of Crops Using Irrigation Water," *Journal of Farm Economics.* 43:876-888, November, 1961.

Reutlinger, Shlomo and James A. Seagraves, "A Method of Apprasing Irrigation Returns," *Journal of Farm Economics,* 44:837-850, August, 1962.

Sanderson, Marie, "An Experiment to Measure Potential Evapotranspiration," *Canadian Journal of Research.* 26:445-454, August, 1948.

Thom, H. C. S., "Three Chapters on Climatological Analysis," United States Weather Bureau Manuscript, United States Department of Commerce, Washington 25, D. C., August, 1960.

Thornthwaite, C. W., "An Approach Toward A Rational Classification of Climate," *Geog. Rev.,* 38:55-94, 1948.

van Bavel, C. H. M., "A Drouth Criterion and Its Application in Evaluating Drouth Incidence and Hazard," *Agronomy Journal,* 45:167-168, April, 1953.

van Bavel, C. H. M., *Drouth and Water Surplus in Agricultural Soils of the Lower Mississippi Valley Area,* Technical Bulletin 1209, United States Department of Agriculture, Agricultural Research Service, Washington, D. C., December, 1959.

van Bavel, C. H. M., and F. J. Verlinden, *Agricultural Drouth in North Carolina.* North Carolina Agricultural Experiment Station Technical Bulletin 122, Raleigh, North Carolina, June, 1956.

van Bavel, C. H. M., and T. V. Wilson, "Evapotranspiration Estimates as Criteria for Determining Time of Irrigation," *Agricultural Engineering,* 33:417-418, July, 1952.

APPENDIX TABLE I - PROBABILITY FOR A MINIMUM NUMBER OF DROUTH-DAYS TO OCCUR DURING THE PERIOD JUNE 1 TO AUGUST 31 IN THE MISSOURI DELTA

Available Soil-Moisture Base (inches)	Minimum Number of Drouth-Days													
	0	6	12	18	24	30	36	42	48	54	60	66	72	78
	(Percent)													
1.0	100	100	100	100	99	98	95	88	73	59	41	21	8	2
2.0	100	100	100	97	96	94	77	60	47	29	16	6	2	1
3.0	100	100	98	95	90	73	61	44	32	17	6	4	1	0
4.0	100	97	95	90	75	61	47	34	20	7	5	2	1	0
5.0	100	95	91	77	64	49	34	22	8	6	2	1	0	0
6.0	100	91	81	66	53	36	25	10	6	2	1	0	0	0

APPENDIX TABLE II - PROBABILITY FOR A MINIMUM NUMBER OF DROUTH-DAYS TO OCCUR DURING SPECIFIED MONTHLY PERIODS IN THE MISSOURI DELTA

Monthly Period	Available Soil-Moisture Base (inches)	Minimum Number of Drouth-Days										
		0	3	6	9	12	15	18	21	24	27	30
		(Percent)										
June	1.0	100	95	83	79	67	46	38	21	4	0	0
	2.0	100	76	64	49	38	25	9	2	0	0	0
	3.0	100	52	41	31	14	3	1	0	0	0	0
	4.0	100	36	23	8	3	0	0	0	0	0	0
	5.0	100	12	6	1	0	0	0	0	0	0	0
	6.0	100	3	0	0	0	0	0	0	0	0	0
July	1.0	100	100	100	99	97	89	79	63	39	18	8
	2.0	100	100	99	94	88	78	68	49	35	17	8
	3.0	100	99	93	85	74	65	51	37	24	15	6
	4.0	100	89	84	73	63	53	42	27	22	10	5
	5.0	100	76	71	61	52	40	33	22	13	6	2
	6.0	100	65	59	46	40	29	21	11	6	2	1
August	1.0	100	97	96	94	92	80	69	48	32	18	6
	2.0	100	97	94	91	82	70	58	42	29	18	5
	3.0	100	93	88	85	76	62	48	37	28	18	5
	4.0	100	90	86	84	70	59	47	37	28	18	5
	5.0	100	89	86	83	68	58	46	35	26	15	4
	6.0	100	87	81	75	64	54	41	30	21	12	4

APPENDIX TABLE III - PROBABILITY THAT THE LONGEST DROUTH-DAY SEQUENCE OCCURRING DURING JULY IN THE MISSOURI DELTA WILL ATTAIN A MINIMUM SPECIFIED LENGTH

Available Soil-Moisture Base	Minimum Length of Drouth-Day Sequence										
	0	3	6	9	12	15	18	21	24	27	30
	(Percent)										
1.0	100	100	97	85	60	45	27	20	10	3	3
2.0	100	99	94	76	56	41	25	16	9	3	2
3.0	100	98	88	71	49	39	22	14	6	2	2
4.0	100	88	76	59	43	31	19	10	6	2	2
5.0	100	76	66	49	36	24	15	9	4	2	1
6.0	100	63	54	39	29	17	8	5	1	1	1

APPENDIX TABLE IV - PROBABILITY OF THE NEED FOR A MINIMUM NUMBER OF IRRIGATIONS TO OCCUR DURING THE PERIOD JUNE 1 TO AUGUST 31 IN THE MISSOURI DELTA

Soil Moist Base	Minimum Number of Irrigations																			
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	(Percent)																			
1.0	100	100	100	100	100	100	99	98	97	90	84	67	51	38	23	11	6	2	2	1
2.0	100	100	100	98	93	76	47	22	7	2	1	0	0	0	0	0	0	0	0	0
3.0	100	100	98	92	71	48	28	8	3	1	0	0	0	0	0	0	0	0	0	0
4.0	100	100	95	78	55	30	13	4	1	0	0	0	0	0	0	0	0	0	0	0
5.0	100	97	90	64	47	24	6	3	1	0	0	0	0	0	0	0	0	0	0	0
6.0	100	95	76	55	32	14	4	1	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX TABLE V - PROBABILITY OF THE NEED FOR A MINIMUM NUMBER OF IRRIGATIONS TO OCCUR DURING SPECIFIED MONTHLY PERIODS IN THE MISSOURI DELTA

Periods	Soil Moisture Base	Minimum Number of Irrigations								
		0	1	2	3	4	5	6	7	8
						(Percent)				
June	1.0	100	98	85	72	42	20	5	1	0
	2.0	100	79	44	7	1	0	0	0	0
	3.0	100	63	24	2	1	0	0	0	0
	4.0	100	40	6	1	0	0	0	0	0
	5.0	100	26	2	1	0	0	0	0	0
	6.0	100	7	1	0	0	0	0	0	0
July	1.0	100	100	100	99	80	55	21	2	1
	2.0	100	99	86	39	4	1	0	0	0
	3.0	100	97	69	25	5	1	0	0	0
	4.0	100	94	62	20	3	1	0	0	0
	5.0	100	82	51	19	2	1	0	0	0
	6.0	100	70	40	9	2	1	0	0	0
August	1.0	100	98	96	89	65	38	8	1	0
	2.0	100	94	67	18	3	1	0	0	0
	3.0	100	89	58	17	1	0	0	0	0
	4.0	100	89	49	15	1	0	0	0	0
	5.0	100	85	50	15	2	1	0	0	0
	6.0	100	84	50	14	1	0	0	0	0