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Correlation of Drouth Indices with Corn Yields

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Roy L. Ewalt, John P. Doll, and Wayne L. Decker

INTRODUCTION

The General Problem

Climatic variables are important inputs in agricultural production processes. Few businessmen are more dependent upon the weather than the farmer. Yet weather inputs have often been overlooked by agricultural research workers. This neglect has hindered the application of research results to practical farming situations.

For example, consider fertilizer use research. While a constant amount of fertilizer may be used on a particular soil and crop over a period of several years, the crop yields in these years may vary considerably. These variations are, in large part, due to variations in weather inputs such as rainfall, temperature, or hail. Clearly, adequate practical recommendations on fertilizer use cannot be made unless climatic variations are considered.

There has been a tremendous increase in research in climatology and meteorology in the last twenty years. Significant advances have been made in these fields. Methods and data now available, however, need to be studied further in order to determine their usefulness to practical farming situations and farm management research. In particular, there is a significant need to identify and measure climatic inputs of significance in agricultural production processes. Once measured, the impact of climatic inputs on farm businesses can be determined using methods of analysis now developed.[1]

The Specific Problem

The specific problem considered in this study was the occurrence and variability of drouth and the effects of drouth on corn yields. The main objectives were:

1. To study methods of measuring the climatic factors affecting corn yields, herein called drouth, and to compute indices of these drouth measures.
2. To evaluate the usefulness of these drouth indices as measures of the climatic factors affecting corn yields by determining their correlation with corn yield data.

LITERATURE REVIEW

Methods of estimating water loss from the soil due to evaporation from the soil and transpiration from plants, collectively called evapotranspiration, have recently been developed. These methods can be used to compute water balances

[1]This bulletin is the second report of an investigation of the effects of the weather on farm businesses. The problem mentioned here is discussed in detail in the first report, which also discusses possible methods of analysis. See J. D. McQuigg and J. P. Doll, "Weather Variability and Economic Analysis," Missouri Agricultural Experiment Station Research Bulletin 771, June, 1961.

and crop indices which in turn can be used to relate weather to crop yields. Two methods of estimating evapotranspiration, Penman's (22) and Thornthwaite's (27), are used in this study. Both estimates were developed after World War II and published by 1948. A third method has been presented by Blaney and Criddle (5).

Many attempts have been made to characterize drouth and to evaluate the effects of drouth on corn yields. The work of Barger and Thom (2) (3) represents a method of evaluation based on county yield statistics and rainfall totals. However, attempts to relate corn yields to drouth as defined by evapotranspiration estimates have not been recorded in the literature.

Gerber and Decker (12) compared the methods of Penman, Thornthwaite, and Blaney to determine which most nearly approached measured evapotranspiration. They found that Penman's method most nearly approached measured evapotranspiration. Also, Penman's method was the most sensitive to weather changes and yielded higher estimates of evapotranspiration than the other methods.

In more recent work, Decker (6) found estimated evapotranspiration, using either Penman's or Thornthwaite's method, to be in close agreement with measured evapotranspiration when the soil surface was wet. Evapotranspiration, as estimated from environmental conditions, was greater than measured evapotranspiration when the soil surface was dry. He suggests that both methods could be improved through a simple adjustment for the bias introduced by overestimation when the soil surface is dry.

Knetsch and Smallshaw (16) used Penman's method of estimating evapotranspiration to compute drouth indices for 28 weather stations in the Tennessee Valley using 1, 2, 3, 4, and 6 inch levels of soil moisture capacity. Using these drouth indices, they estimated the probability of occurrence of various intensities of drouth for the Tennesssee Valley.

Parks and Knetsch (21) studied the influence of nitrogen levels and drouth intensity on corn yields. After they had calculated the number of drouth days from estimates of evapotranspiration, they correlated the number of drouth days with corn yields. The production function derived from the drouth data accounted for the time of occurrence and the intensity of drouth. They presented estimates of corn yields for various applications of nitrogen and differing intensities of drouth.

Knetsch and Parks (15) developed an equation describing the relationship between millet yield and nitrogen and drouth levels. The length of drouth was varied from seven to 46 days by the use of irrigation. Drouth was estimated by a method developed by van Bavel. Although only one year of data was used, the use of irrigation as a research tool provided data corresponding to many years of drouth data. Their equation, fitted by the least squares regression method, is

$$Y = 3.07 + 0.1506\,N + 0.0010\,D - 0.0023\,N^2 - 0.0007\,D^2 - 0.0005\,ND$$

where Y is the estimated yield of forage in tons, N is nitrogen expressed in tens of pounds, and D is the number of drouth days occurring in the June-September crop season. This equation accounted for 91 percent of the variation among treatment means.

Van Bavel (33) discusses a method of computing drouth indexes for different crops using estimated evapotranspiration data. He computed a drouth index for a tobacco crop using Thornthwaite's method of estimating evapotranspiration. Cumulative frequency curves and histograms were computed to show the probability of occurrence of various intensities of drouth. He computed the probability of shortages of from one to 10 inches water during the growing season. No attempt was made to show how this water shortage or drouth condition affected the yield of the tobacco crop.

Robins and Domingo (25) studied the effects of severe moisture deficits at specific growth stages of the corn plant. They concluded that soil moisture depletion to the wilting percentage at certain physiological growth stages markedly reduced grain yields of field corn. Such deficits for periods of one to two days during the tasseling or pollination period reduced yield by 22 percent and periods of six to eight days reduced yield by 50 percent. After fertilization, yield reduction due to lack of water appeared to be related to the maturity of the grain crop. Following maturity, lack of water had no reducing effect on yield.

Orazem and Herring (20) studied the effects of soil moisture at planting time, rainfall during the growing season, and nitrogen on yield of grain sorghums in the sandy lands of southwest Kansas. Statistical tests indicated the best positive relationship existed between yield of sorghum and soil moisture at planting time. Rainfall during the growing season and nitrogen also had effects on yield; however, these effects depended upon soil moisture at planting time. The greater the soil moisture at seeding time the greater the effects of rainfall and nitrogen during the growing season. They concluded that soil moisture at seeding time could be used to provide a relatively good estimate of crop yield and could be of great assistance in deciding the amount of fertilizer to be applied to grain sorghum.

Denmead and Shaw (8) studied the ratio of measured evapotranspiration to open pan evaporation for different periods during the growing season for corn. They found that prior to silking the ratio increased in a sigmoid manner from a value of 0.36 at the planting date to 0.81 at silking. The value of 0.81 remained constant for 16 days after silking and then declined. They suggest that the changing ratio was due to the increasing leaf area until silking and to declining physiological activity of the crop after the commencement of ear growth. They conclude that the corn crop approaches the condition of a green crop, actively growing and completely shading the ground for a period of only 2 to 3 weeks during the growing season. Since the requirements of active growth and complete shading of the ground are necessary requirements for the use of current estimates of evapotranspiration, it was concluded that such procedures would be applicable to corn only during this short period.

Fisher (10) studied the influence of rainfall on the yield of wheat in Rothamsted, England. He divided yearly rainfall into 61 periods of 6 days each. Each set of 61 values was then analyzed by calculating coefficients using fifth degree orthogonal polynomials. The amount and distribution of rainfall was represented by a series of six polynomial coefficients. These coefficients were considered as independent variables in solving multiple regression problems with wheat yields as the dependent variable. Fisher's method gives a regression curve which shows the effects on yield of a unit change in a given meteorological element at any time during the growing season.

METHODS OF ESTIMATING EVAPOTRANSPIRATION

Soil water is an important agriculture resource. Depletion of the supply of this resource occurs as a result of transpiration by plants and evaporation from soil surfaces. By definition, drouth conditions exist when the water available for plant growth in the soil reservoir is exhausted and yield reduction or death of the plant results.

The amount of water lost by evapotranspiration is not constant. The rate of evapotranspiration depends on the weather, on plant conditions, and on the availability of water in the soil. Relevant concepts dealing with soil moisture, the moisture budget, and evapotranspiration measures used in this study are discussed below.

Soil Moisture

The range of moisture conditions in the soil are discussed by Baver (4). The soil is said to be at the saturation point when all soil pores are filled with water. This amount of water is undesirable for efficient plant growth because a certain amount of air is required by plant roots and soil microorganisms. Water held in the soil from field capacity to saturation is called gravitational water because it drains from the soil pores under the force of gravity; it is normally in the soil only for short periods of time. A soil is at field capacity, then, after the gravitiational water drains out.

When the soil contains water at levels below field capacity the proportions of air and water are conducive to plant growth. This water is held in the soil pores against the pull of gravity but may be readily removed by plants until the wilting point has been reached. As the soil's moisture content approaches the wilting point, the soil still appears somewhat moist but the water is held so tightly to the soil particles that plants cannot take up water fast enough to balance the loss by transpiration and the plant wilts.

Soil with a moisture content below the wilting point still contains water but this water is not available for plant growth. Dry soil cannot support plant growth; plants will permanently wilt and die in dry soil.

The amount of water between field capacity and the wilting point is the available water for plant growth. Water available for plant growth is the water of economic importance to the farmer. In this study, a drouth day is defined as any day during the growing season when the soil has dried to the wilting point.

Moisture Budget

Soil, plant and meteorological conditions all play an important role in the process of evapotranspiration. If water in the soil is freely available for evapotranspiration, which is the case at or above field capacity, Holmes and Robertson (14) indicate the rate of water loss will be largely dependent on meteorological factors. The amount of water loss under these conditions is called potential evapotranspiration. When soil moisture is above or near field capacity, potential evapotranspiration is equal to actual evapotranspiration. As the soil dries, the available moisture decreases and is held more tightly to the soil particles by hydraulic tension. As a result, the transport of water to the soil surface decreases and less water is available for evaporation than when the soil was at field capacity, assuming constant meteorological conditions. As the soil becomes drier, actual evapotranspiration decreases and is less than potential evapotranspiration. Thornthwaite and Halsted (29) suggest that actual evapotranspiration is in ratio to the soil moisture in storage. That is, when the soil moisture is one-half the total storage possible, actual evapotranspiration is one-half of potential evapotranspiration. However, experimental evidence of this is lacking.

The method used to compute soil moisture budgets used in this study was to subtract potential evapotranspiration and add rainfall to the available moisture in the soil assuming that soil moisture will not exceed field capacity or go below the wilting point. This method will overestimate actual evapotranspiration when the available moisture in the soil is low due to the small amount of water available for evaporation and transpiration. On the other hand, the assumption that soil moisture will not exceed field capacity or go below wilting point may tend to prevent the method from overestimating the drouth situation.

Methods of Estimating Evapotranspiration

Several investigators have attempted to estimate the ratio between precipitation and potential evapotranspiration. The early estimates of Transeau (32), Meyer (19), and Thornthwaite (28) were based on assumed relationships between temperature and evaporation. More refined estimates have been developed in recent years by Penman (22) (23) (24), Thornthwaite (27) (30), Blaney and Criddle (5), McCloud (18) and Albrecht (1). The methods of estimating evapotranspiration developed by Penman and Thornthwaite have been the most widely accepted.

Penman's method is based on the fact that the net heat received by a surface through radiation must be used for evaporation, heating the air and soil, and as energy for photosynthesis and chemical processes. The application of this idea to the problem of estimating evapotranspiration results in partitioning the amount of energy received by a surface and determining that used for evapotranspiration. For a description of the development of the method the reader is referred to Penman's papers and to the review of Gerber and Decker (12). Penman's relationship estimates the amount of evaporation from a free water surface. However, Penman contends that the ratio between evaporation from a free water surface, Eo, and potential evapotranspiration, Et, is nearly a constant which varies with the season from 0.6 to 0.8. In this way, Et can be derived from Eo.

Thornthwaite's method estimates potential evapotranspiration by using an exponential relationship between mean monthly temperature and potential evaporation. This relationship is relatively easy to evaluate and has been described by Thornthwaite and other workers.

RESULTS OF THE STUDY

The objective of this study was to analyze the effects of drouth on corn yields. In order to do so, it was necessary to compute the seasonal drouth days occurring for a particular soil and crop. After the drouth days were computed, they were correlated with crop yields.

The corn yield data from Plot 18, Sanborn Field, University of Missouri were used in this study. The plot has been in continuous corn since 1889 with six tons of manure per acre applied annually. Most of the variations in yields are believed due to weather factors.

The time period considered in this analysis was 1905 through 1959. The years 1906, 1908, 1909, 1910, 1927, 1935, and 1945 were not included in the study. Corn yield in these years was believed to be influenced by factors other than drouth, such as weeds or severe insect infestation. The analysis included 48 years of weather and corn yield data. Within a season, drouth days were computed for the period of March 29 through September 5.

The soil on Sanborn Field is classified as Putnam silt loam, although it is slightly more rolling in topography and has a deeper and somewhat darker surface than typical Putnam. The water holding capacity of this soil is rather low. Based on measurements made by Thornton et al. (31) on a similar soil, the top 6 feet of soil, the rooting depth of corn reported by Hayward (13), contains 6 inches of available water for plant growth when the soil is at field capacity. It was assumed that the soil would be at field capacity on March 29, the beginning of the growing season.

The weather data needed to compute the rate of evapotranspiration and the water balance in the soil was obtained from the United States Weather Bureau, Columbia, Mo. The data were readily available for the time period considered in this study.

Three methods were used to measure the intensity of drouth: (1) rainfall as a direct measure of drouth, (2) a soil water budget based on Penman's method of estimating evapotranspiration, and (3) a soil water budget based on Thornthwaite's method of estimating evapotranspiration. The two latter methods were used to estimate daily evapotranspiration. These evapotranspiration estimates were used along wih rainfall to compute the amount of available water in the soil for each day during the growing season. When the available water in the soil reached the zero level for any particular day, the day was called a drouth day. The drouth days were then tabulated and correlated with corn yields. For brevity, the soil water budgets based on evapotranspiration estimated by Penman's technique and Thornthwaite's technique will be referred to hereafter as "Penman's method" and "Thornthwaite's method." A discussion and comparison of the results of the three methods of measuring drouth follows.

A Comparison of Penman's and Thornthwaite's Methods

Drouth days computed by Penman's method are presented in Appendix Tables 1, 2, and 3. As recommended by Penman, a ratio of 0.7 between E_t and E_o was used. Drouth days computed by Thornthwaite's method are presented in Tables 4, 5, and 6 of the Appendix.

A comparison of drouth days computed by the two methods is presented in Table 1. The mean number of drouth days per season is 21.8 for Penman and 21.1 for Thornthwaite. During May, June, and July, Penman's method estimated more drouth days than did Thornthwaite's. In August, Thornthwaite's method estimated considerably more drouth days than Penman's method. Thus, the difference between the two methods is not in the total number of drouth days estimated but rather is in the time during the growing season when estimated drouth days occur. Thornthwaite's method depends upon temperature; the high August temperatures cause it to estimate more drouth days in August. Penman's method depends upon a radiative balance and more drouth days are estimated early in the summer when radiation is higher.

The correlation between corn yields and the number of drouth days is a measure of the dependence of corn yields upon moisture occurrence. The regression statistics for equations of linear regression computed for each method of estimating drouth are presented in Table 2, where corn yields represent the dependent variable and drouth days estimated per season the independent variable. The equations were estimated from the data in Appendix Tables 3 and 6, omitting years when drouth days did not occur.

Although the two methods estimate approximately the same average number of drouth days per season, the regression equations in Table 2 differ somewhat. Both regression equations are significant at the 0.01 probability level; however, Penman's method yielded the highest r^2, 45 percent, indicating that variations among yearly drouth days predicted by the Penman method vary more closely with corn yields than do those predicted by Thornthwaite's method. The estimated effect of a seasonal drouth day upon yields does not differ appreciably. For Thornthwaite's method, a drouth day reduces yields about 0.6 of a bushel while, for Penman, each drouth day reduced yield by about 0.7 of a bushel.

The effects of drouth or its opposite, rainfall, upon corn yield depends not only upon total amount but also on distribution. Thus, a breakdown of total

TABLE 1-DROUTH DAYS COMPUTED BY PENMAN'S METHOD MINUS THOSE COMPUTED BY THORNTHWAITE'S METHOD.

Year	May	June	July	August	Check Sum
1905	0	2	0	0	2
1907	0	0	0	0	0
1911	0	4	-4	-2	-2
1912	0	0	4	-2	2
1913	0	11	0	-1	10
1914	0	4	-2	-1	1
1915	0	0	0	0	0
1916	0	0	0	-2	-2
1917	0	0	6	-1	5
1918	0	0	-4	0	-4
1919	0	0	0	-9	-9
1920	0	0	3	-1	2
1921	0	0	0	0	0
1922	0	0	-3	-5	-8
1923	0	0	0	0	0
1924	0	0	0	0	0
1925	0	0	0	0	0
1926	0	2	7	2	11
1928	0	0	0	0	0
1929	0	0	0	-31	-31
1930	0	6	8	-4	10
1931	0	0	0	-1	-1
1932	0	0	11	0	11
1933	0	0	1	-4	-3
1934	7	7	-1	0	13
1936	0	13	0	-4	9
1937	0	0	-4	-4	-8
1938	0	0	0	-8	-8
1939	0	0	-7	-4	-11
1940	0	0	2	1	3
1941	0	0	0	-10	-10
1942	0	0	0	0	0
1943	0	0	0	-8	-8
1944	0	5	0	-5	0
1946	0	0	4	0	4
1947	0	0	0	3	3
1948	0	8	0	0	8
1949	0	0	0	0	0
1950	0	0	5	2	7
1951	0	0	0	0	0
1952	0	0	5	-1	4
1953	0	9	1	1	10
1954	0	0	1	0	1
1955	0	0	0	-6	-6
1956	0	0	0	0	0
1957	0	0	5	-5	0
1958	0	0	0	0	0
1959	0	14	-2	-3	9
Total	7	84	36	-113	14

TABLE 2-THE REGRESSIONS FOR DROUTH DAYS PER SEASON AND CORN YIELDS FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Regression Equation	Drouth Estimated by Penman's Method	Drouth Estimated by Thornthwaite's Method
n	36	37
a	53.5	48.3
b	-0.667	-0.568
r^2	45%	33%
t value for b	-5.31**	-4.17**

**Significant at the 0.01 probability level.

drouth days during the season into periods of shorter length should result in a closer correlation between drouth and yields. For corn, the periods selected should coincide with important stages of growth. Three important periods for corn growth are: (1) the vegetative growth period prior to silking, (2) the silking and tasseling period, and (3) ear filling after silking. A complete discussion of the biological considerations for yield prediction for corn is presented by Shaw and Loomis (26). Unfortunately, phenological data were not available for Plot 18 on Sanborn Field; the growing period was therefore arbitrarily divided into periods first by months and then by weeks.

The regression statistics of the equations for the monthly drouth days estimated by the two methods are given in Table 3, where corn yields represent the

TABLE 3-THE REGRESSION EQUATIONS FOR DROUTH DAYS PER MONTH AND CORN YIELDS FOR PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI. t VALUES FOR REGRESSION COEFFICIENTS ARE IN PARENTHESES.

Regression Equation	Drouth Estimated by Penman's Equation	Drouth Estimated by Thornthwaite's Equation
n	36	37
a	53.6	48.9
May coefficient	-2.027 (-0.88)	(No estimated drouth days)
June coefficient	+0.012 (0.03)	-0.140 (-0.24)
July coefficient	-1.110 (-3.73**)	-0.869 (-3.31**)
August coefficient	-0.552 (-1.42)	-0.495 (-1.72)
R^2	46%	38%

**Significant at the 0.01 probability level.

dependent variable and drouth days per month the independent variables. The equations were computed from the data in Appendix Tables 2 and 5, omitting years when drouth days did not occur.

Dividing the growing period into monthly periods did not greatly increase the fit of the equations, but does indicate the relative importance of drouth days occurring during each month. For both methods, July alone produced a regression coefficient that was statistically significant. For the Penman method, the May coefficient was large and negative. This may indicate that drouth in May reduces yields drastically, approximately two bushels per drouth day. However, the regression coefficient is not significantly different from zero and the probability of drouth in May is very low. Drouth in May was estimated only once during the 48 year period of study by Penman's method and never occurred with Thornthwaite's method. The June coefficient for the Penman method is positive and very small, with a *t* value that would not be significant at the 0.9 level of probability. All other coefficients are negative, indicating that the occurrence of drouth days reduces corn yields.

The effects of drouth days upon corn yields vary considerably for the two methods. The largest difference occurs in July, when a drouth day based on Penman's method is estimated to reduce yield by 1.1 bushels and a drouth day based on Thornthwaite's method reduces estimated yield by 0.9 of a bushel.

Correlation coefficients for drouth days per month and corn yields are presented in Table 4. These coefficients show the simple correlation of drouth days

TABLE 4-CORRELATION COEFFICIENTS (R) FOR DROUTH DAYS PER MONTH AND CORN YIELDS FOR PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI. THORNTHWAITE'S METHOD ESTIMATED NO DROUTH DAYS IN MAY.

		May	June	July	August	Corn Yield
May	Thornthwaite	—	—	—	—	—
	Penman	1	0.21	0.28	0.10	-0.30
June	Thornthwaite		1	0.46	0.33	-0.35
	Penman		1	0.42	0.50	-0.37
July	Thornthwaite			1	0.10	-0.55
	Penman			1	0.16	-0.63
August	Thornthwaite				1	-0.31
	Penman				1	-0.32

per month with corn yields and of drouth days per month with each other. All correlation coefficients between monthly drouth days and corn yields are negative, with the largest coefficients occurring for July. The Thornthwaite method estimated no drouth days in May, so these correlation coefficients are not in Table 4. For both methods, the correlation between number of drouth days in

June and July is about 0.4. While July and August drouth days are not highly correlated, the correlation for June and August drouth days is 0.5 for Penman's method. None of the correlation coefficients among monthly drouth days are extremely high, indicating that monthly weather statistics are extremely variable

Regression statistics for equations relating drouth days per week and corn yields are presented in Table 5. They were computed from data included in

TABLE 5-THE REGRESSION EQUATIONS FOR DROUTH DAYS PER WEEK AND CORN YIELDS FOR PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI. t VALUES FOR COEFFICIENTS ARE IN PARENTHESES, NONE ARE STATISTICALLY SIGNIFICANT AT THE 0.05 PROBABILITY LEVEL.

Regression Equation	Drouth Estimated by Penman's Equation	Drouth Estimated by Thornthwaite's Equation
n	36	37
a	60.1	51.4
Coefficient for Week Beginning:		
May 31	-1.060 (-0.34)	(no drouth days estimated)
June 7	3.374 (1.53)	23.506 (1.08)
June 14	-1.740 (-0.60)	0.884 (0.37)
June 21	0.250 (0.10)	-2.222 (-0.86)
June 28	-0.124 (-0.06)	0.295 (0.12)
July 5	-2.304 (-1.12)	-1.597 (-0.77)
July 12	-0.538 (-0.38)	0.658 (0.45)
July 19	-0.811 (-0.58)	-1.917 (-1.22)
July 26	-1.417 (-0.89)	-0.737 (-0.59)
August 2	-2.588 (-1.49)	-2.502 (-2.01)
August 9	-1.185 (-0.84)	0.273 (0.18)
August 16	-0.693 (-0.37)	-0.324 (-0.18)
August 23	-1.348 (-0.71)	0.692 (0.45)
August 30	1.233 (0.59)	-1.512 (-0.98)
R^2	68%	52%

Tables 1 and 4 in the Appendix, omitting years of zero drouth days. The equation fit to the weekly drouth days generated by the Penman method explained 68 percent of the variation in corn yields; 52 percent of the variation was explained by the equation based on Thornthwaite's method. In addition, the signs of the regression coefficients based on Penman's method appear to be more reasonable, because none of the regression coefficients have positive signs during the apparent critical period from the last part of June to the first part of August. The June 7 coefficient for the Thornthwaite method is large, positive, and misleading. The probability of a drouth day occurring during the week of June 7 is low; only one was estimated by the method of Thornthwaite. Thus, this coefficent has no effect on predicted yield most years. None of the coefficients are significant at the 0.05 probability level, probably because the effects of weather are being divided among an increased number of independent variables.

Correlation coefficients for drouth days per week and corn yields are presented in Table 6. With the exception of the June 7 coefficient for the Thornthwaite method, all correlation coefficients between drouth days per week and corn yields are negative. This is not consistent with the data of Table 5 where some of the partial regression coefficients were positive, possibly because of the high correlations existing among some of the independent variables. In general, the correlation coefficients of drouth days per week with yield are the smallest for the last four weeks in August. For the Penman method, weather in May and June does appear to have an important effect on yields. With the exception of the week of June 7, weather in June does have an important effect on yield when drouth days are computed by Thornthwaite's method. For both methods, the drouth days in any given week are highly correlated with those in the weeks closest to it; the correlation between weeks decreases as the time span between weeks increases. Finally, as before and perhaps due to random effects in the data, drouth days computed for August correlate more closely with drouth days for June than for July.

Figure 1 presents the actual corn yields for Plot 18, Sanborn Field and the yields predicted by the regression equation fit to weekly drouth days computed by Penman's method; Figure 2 presents the same information for the regression equation fit to drouth days computed using Thornthwaite's method. By comparing the figures, it can be seen that the equation based on the Penman method does a better job of fitting the extreme values. The equation based upon Thornthwaite's method never predicts a yield above approximately 52 bushels or below approximately seven bushels.

Comparison of Penman's and Thornthwaite's Methods with Rainfall Totals

It is of interest to compare drouth days as a measure of drouth to rainfall as a measure of drouth. Using the data presented in Table 7 of the Appendix, a regression equation was estimated using corn yield as the dependent variable and weekly rainfall for the independent variables. The regression statistics for the equation are presented in Table 7. It explains 75 percent of the variation in corn yields. In general, rainfall has an increasing effect on corn yield, but the equation in Table 7 indicates that rainfall in four of the weeks, those beginning on April 26, June 7, June 14, and August 30, has a decreasing effect on yield. Reasons for this may be (1) rainfall in the week beginning April 26 will delay corn planting which would in turn decrease yields, (2) rainfall during the weeks of June 7 and June 14 could delay or eliminate the cultivation of corn, causing weediness and reduced yields.

The coefficients of correlation between corn yields and inches of rain in each week during the time interval of April 26 through August 5 are given in Table 8. The coefficients of correlation between rainfall in each week and rainfall in each of the other weeks are also listed in this table. These coefficients show that rainfall in some weeks is negatively correlated with corn yields while

TABLE 6-CORRELATION COEFFICIENTS (R) FOR DROUTH DAYS PER WEEK AND CORN YIELDS FOR PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI. THE THORNTHWAITE METHOD ESTIMATED NO DROUTH DAYS IN MAY.

Penman's Method

Week	May	June				July				August					Corn
Beginning:	31	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
May 31	1	0.69	0.57	0.32	0.42	0.25	0.09	0.28	0.38	0.45	0.37	0.16	0.19	0.09	-0.41
June 7		1	0.71	0.38	0.34	0.09	-0.07	0.09	0.22	0.20	0.24	0.26	0.21	0.09	-0.73
June 14			1	0.78	0.65	0.22	0.15	0.21	0.30	0.11	0.36	0.48	0.36	0.29	-0.33
June 21				1	0.79	0.39	0.34	0.32	0.21	0.04	0.24	0.35	0.17	0.17	-0.36
June 28					1	0.57	0.31	0.35	0.30	0.23	0.29	0.14	0.10	0.14	-0.50
July 5						1	0.73	0.56	0.27	-0.13	0.06	-0.06	0.05	0.11	-0.50
July 12							1	0.46	0.23	-0.20	-0.16	-0.09	0.09	0.09	-0.38
July 19								1	0.62	0.10	0.00	-0.19	-0.11	-0.08	-0.52
July 26									1	0.51	-0.02	-0.07	0.01	0.00	-0.58
August 2										1	0.35	-0.11	-0.02	0.04	-0.44
August 9											1	0.44	0.37	0.48	-0.34
August 16												1	0.66	0.55	-0.11
August 23													1	0.85	-0.20
August 30														1	-0.22

Thornthwaite's Method

Week	June				July				August					Corn
Beginning:	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
June 7	1	0.47	0.41	0.05	-0.12	0.04	0.24	0.20	0.22	0.03	0.04	-0.15	-0.16	0.01
June 14		1	0.69	0.62	0.21	0.05	0.27	0.36	0.36	0.39	0.28	0.09	0.05	-0.29
June 21			1	0.76	0.32	0.29	0.35	0.30	0.17	0.20	0.32	0.02	-0.14	-0.32
June 28				1	0.62	0.38	0.36	0.28	0.16	0.35	0.31	0.06	-0.02	-0.40
July 5					1	0.73	0.60	0.38	0.03	0.19	0.04	-0.11	-0.07	-0.46
July 12						1	0.70	0.41	-0.05	0.01	-0.06	-0.10	-0.04	-0.35
July 19							1	0.59	0.08	0.14	-0.05	-0.16	-0.14	-0.47
July 26								1	0.39	0.09	-0.07	0.04	0.03	-0.52
August 2									1	0.33	-0.10	-0.03	-0.06	-0.44
August 9										1	0.51	0.31	0.41	-0.30
August 16											1	0.65	0.40	-0.03
August 23												1	0.71	-0.01
August 30													1	-0.07

Figure 1 - PENMAN'S METHOD

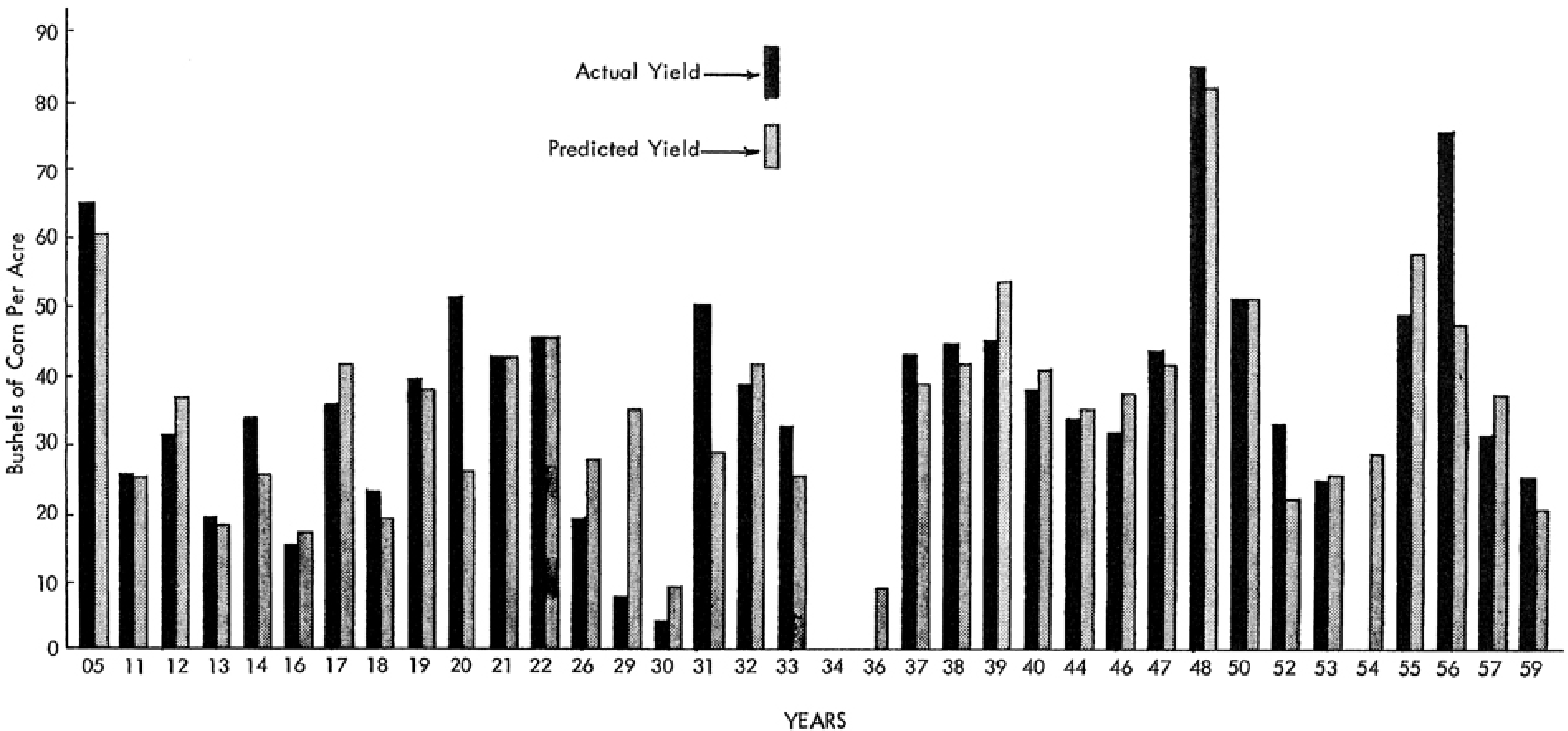

Figure 2 - THORNTHWAITE'S METHOD

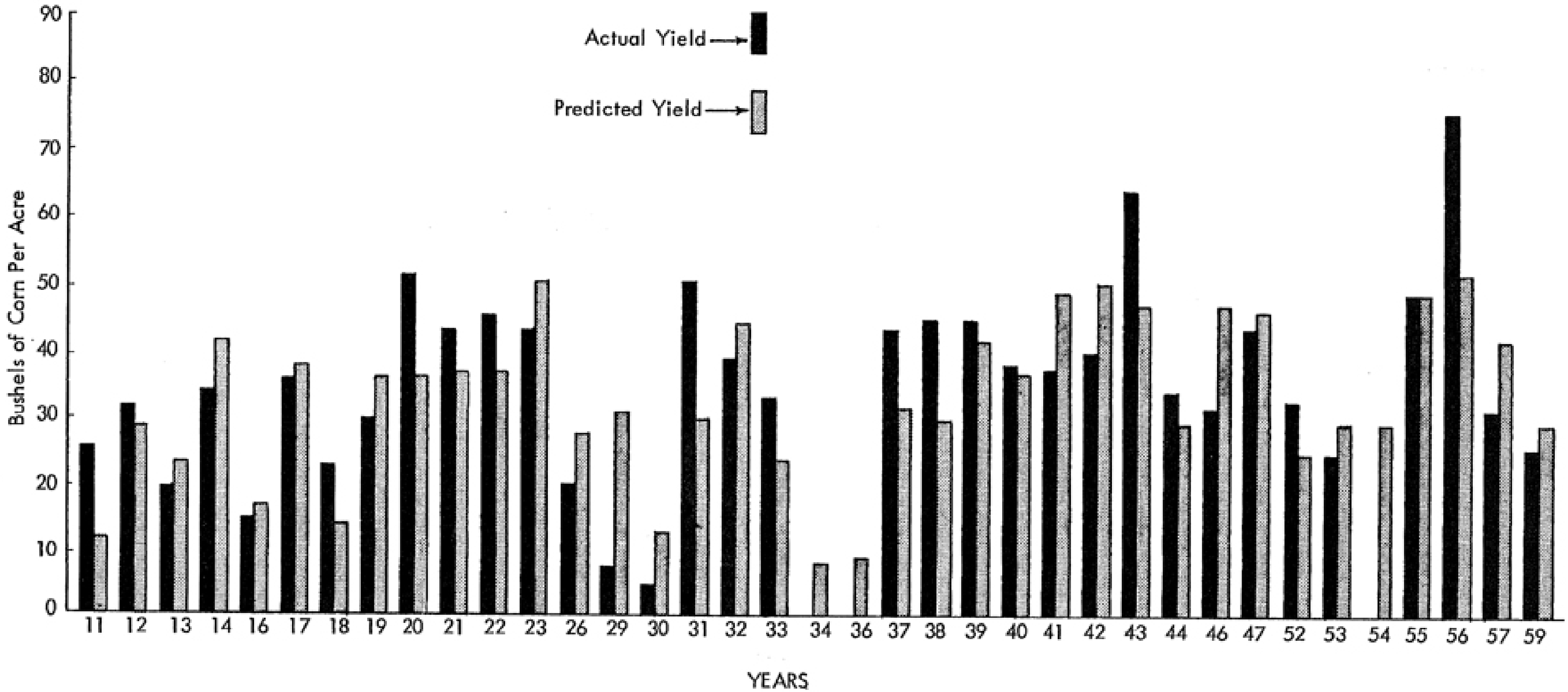

TABLE 7–THE REGRESSION EQUATION FOR WEEKLY RAINFALL AND CORN YIELDS FOR PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI. t VALUES FOR COEFFICIENTS ARE IN PARENTHESES.

Regression Equation	
n	48
a	-1.1
Coefficient for Week Beginning:	
April 26	-0.892 (-0.39)
May 3	4.644 (1.44)
May 10	1.666 (0.73)
May 17	2.293 (1.02)
May 24	3.414 (1.27)
May 31	1.309 (0.53)
June 7	-2.941 (-1.03)
June 14	-1.587 (-0.79)
June 21	2.694 (1.10)
June 28	9.740 (4.37**)
July 5	0.006 (0.00)
July 12	7.151 (2.75*)
July 19	8.699 (2.51*)
July 26	1.025 (0.48)
Aug. 2	1.774 (0.72)
Aug. 9	0.856 (0.47)
Aug. 16	2.670 (1.20)
Aug. 23	3.508 (1.55)
Aug. 30	-1.232 (-0.86)
R^2	75%

*Significant at the 0.05 level of probability.
**Significant at the 0.01 level of probability.

in other weeks the correlation is positive. This negative relationship may be due to excessive rainfall in these particular weeks. With exception of the week of May 3, the coefficients of correlation indicate that rainfall in June and July has the greatest positive effect on yield. This is consistent with previous results; drouth in June and July has the most detrimental effects on yield.

Rainfall in any one week is not highly correlated with rainfall in any of the other weeks (Table 8). On the other hand, the drouth days computed above indicated drouth in one week is highly correlated with drouth in the next week.

TABLE 8-CORRELATION COEFFICIENTS (R) BETWEEN CORN YIELDS AND INCHES OF RAINFALL PER WEEK FOR PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI

	Apr.	May					June				July				August					Corn
	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
April 26	1	-.22	-.06	.03	.10	.03	-.09	-.20	-.15	-.16	-.13	-.00	.02	-.10	.03	-.19	-.09	.07	-.14	-.12
May 3		1	.29	.29	-.08	.20	.32	.00	.05	.05	.07	.36	.22	.35	.00	.06	-.10	-.18	-.02	.49
May 10			1	.06	-.18	.02	.17	.07	-.01	.01	-.05	-.13	-.08	.13	.09	-.23	-.05	-.12	-.15	.03
May 17				1	-.06	.31	.38	-.17	.02	-.36	-.12	.08	.10	.13	-.10	.07	-.18	-.01	.32	.01
May 24					1	.27	.06	.01	-.07	-.03	-.09	.08	-.22	-.14	.09	.12	-.18	-.07	-.08	-.01
May 31						1	.28	.00	.05	-.23	.06	.14	-.23	-.01	.05	.04	-.38	-.04	-.18	-.02
June 7							1	.37	.14	-.03	-.09	.40	-.02	.16	.07	-.13	-.15	-.10	-.07	.12
June 14								1	.17	.39	-.12	.21	.11	.20	-.05	.03	.07	-.01	-.18	.22
June 21									1	-.07	.44	.13	.28	-.09	.14	-.05	-.20	.17	-.12	.24
June 28										1	.08	.08	-.02	.05	.03	-.02	.03	.07	-.06	.48
July 5											1	-.21	-.12	-.09	-.01	-.18	.00	.15	-.03	.03
July 12												1	.06	.11	-.08	-.13	-.11	-.19	-.10	.44
July 19													1	.16	-.04	.07	-.12	.30	-.05	.45
July 26														1	-.15	-.07	-.10	-.16	-.18	.17
August 2															1	.01	-.19	.01	-.04	.05
August 9																1	.16	.03	.31	.05
August 16																	1	-.07	.11	-.08
August 23																		1	.14	.19
August 30																			1	-.13

SUMMARY AND CONCLUSIONS

This study presents the results of an analysis of methods of measuring drouth and the correlation of these measures with corn yields. Drouth indices were computed for the corn crop grown on Plot Number 18, Sanborn Field, University of Missouri, using three different measures of drouth:

1. H. L. Penman's method of estimating evapotranspiration.
2. C. W. Thornthwaite's method of estimating evapotranspiration.
3. Rainfall.

Penman's and Thornthwaite's methods of evapotranspiration were used to compute soil moisture budgets and estimate drouth days. When comparing the two methods, it was found that Penman's method estimated more drouth in the first part of the growing season while Thornthwaite's method estimated more drouth in the last part of the season. There was little difference in the total or mean number of drouth days estimated by the two methods for the 48 years considered in the study, but there was a considerable difference in their estimate of when drouth occurs during the growing season.

The data obtained from the three drouth measures were used to compute regression equations for corn yields using least squares regression procedures. The purpose of the regression analysis was not to forecast corn yields but to determine which index correlated best with existing yield data. The regression equations expressed corn yields as a function of weekly, monthly, and seasonal drouth days; rainfall was divided only by weeks.

Correlating corn yields with the total number of drouth days per growing season resulted in low coefficients of determination, 0.33 for Thornthwaite's method and 0.45 for Penman's method. This method ignores the effects of the distribution of drouth throughout the growing season.

The results were not significantly improved when corn yields were correlated with the number of drouth days per month during the growing season. Thornthwaite's method resulted in an R^2 of 0.38 as compared to a R^2 of 0.46 for Penman's method. Drouth in July was found to have the most significant effect on corn yields with August next in importance.

The results were improved when corn yields were correlated with the number of drouth days per week; the R^2 for Thornthwaite's method was 0.52 as compared to an R^2 of 0.68 for Penman's method. When weekly rainfall was correlated with corn yields, and R^2 of 0.75 was obtained. Weekly rainfall explained more variation in corn yields than either of the other two more sophisticated methods, while Penman's method explained more than did Thornthwaite's method.

Thus, if all that is desired in a method of indexing drouth, weekly rainfall seems the simplest and also the most effective measure. Of the two methods of computing evapotranspiration and drouth days, Penman's method appears to be the more desirable. Penman's method depends upon a variety of climatic measures, including rainfall, windspeed, humidity, percent sunshine, and radiation measures, and is more difficult to compute. Many times, the necessary data needed for Penman's method may not be available. When the data are available, the added realism of Penman's method would appear to be worth the extra effort. The comments above, of course, are based only on this single analysis. More work should be done before generalizations are made.

The results show that drouth in July and the first part of August has the greatest negative effect on corn yield, with drouth occurring around July 20th being the most serious. Drouth prior to July and after August 15 did not greatly reduce corn yields. Drouth in one week is highly correlated with drouth in the next week, but drouth in any month is not highly correlated with drouth in the next month.

The analysis of weekly rainfall suggested that rainfall during the last week in June, beginning June 28, and during the early weeks of July has the greatest effect upon corn yield. Also, the analysis indicated that, although weekly drouth data are highly correlated, weekly rainfall amounts are not.

The correlation analysis used here suggests the difficulty of forecasting crop yields. Weather conditions from the last part of June to the first part of August have a significant effect upon yield of corn; until these weather variables can be accurately forecast, there is little hope of an accurate forecast of corn yields. Thus, economic analyses concerning corn production and weather variation must rely heavily upon historical climatological data. Also, the correlation analysis can be misleading. Drouth in May and June might have an important effect on corn yields. The results of the analysis indicate it does not, but this is because drouth usually does not occur in May and June and the analysis is therefore unable to assess its effects accurately should it occur.

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APPENDIX

TABLE 1-DROUTH DAYS PER WEEK, COMPUTED WITH PENMAN'S EQUATION WHERE Et = .7Eo AND CORN YIELDS FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Year	Week beginning: May	June				July				August					Corn
	31	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
1905	0	0	0	1	1	0	0	0	0	0	0	0	0	0	64.3
1907	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33.4
1911	0	3	7	7	7	4	0	5	3	3	7	4	0	2	25.1
1912	0	0	0	0	0	0	0	3	7	4	1	0	0	1	30.8
1913	5	7	7	0	3	2	1	4	7	7	7	3	7	7	19.2
1914	3	4	4	6	2	0	2	7	7	7	2	3	0	0	33.9
1915	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45.7
1916	0	0	0	0	0	0	2	6	7	7	5	0	4	2	14.6
1917	0	0	0	0	0	0	1	7	7	1	0	0	0	0	35.6
1918	0	0	0	0	0	2	7	6	7	7	0	0	0	0	22.4
1919	0	0	0	0	0	0	0	1	6	5	0	0	0	0	39.1
1920	0	0	0	0	0	5	6	7	3	0	6	3	0	0	50.8
1921	0	0	0	0	0	3	4	7	2	0	0	0	0	0	42.8
1922	0	0	0	0	0	0	0	0	3	2	2	5	0	0	45.0
1923	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42.6
1924	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37.8
1925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34.0
1926	0	0	0	0	6	1	0	2	4	7	3	0	0	0	19.8
1928	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35.6
1929	0	0	0	0	0	0	0	0	0	4	7	6	7	5	7.8
1930	0	0	0	4	6	7	7	6	7	7	3	0	2	6	4.0
1931	0	0	0	0	2	4	7	1	5	4	0	0	0	0	50.0
1932	0	0	0	0	0	0	2	7	3	3	0	0	0	0	38.3
1933	0	0	0	0	1	5	6	6	7	0	0	4	7	6	32.4
1934	5	2	2	3	7	7	6	7	6	7	6	0	0	0	0.0
1936	4	7	7	7	7	7	6	5	7	4	4	6	7	2	0.0
1937	0	0	0	0	0	0	1	0	2	4	7	4	2	5	42.7
1938	0	0	0	0	0	0	0	0	0	3	7	1	4	3	44.8

TABLE 1-CONTINUED

Year	May	June				July				August					Corn
	31	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
1939	0	0	0	0	0	0	5	0	0	1	1	0	0	0	44.3
1940	0	0	0	0	0	0	0	0	3	6	0	0	0	0	37.9
1941	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37.0
1942	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39.6
1943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63.6
1944	0	0	2	6	7	6	7	6	0	0	0	0	0	0	33.6
1946	0	0	0	0	0	7	7	2	1	0	0	0	0	0	31.4
1947	0	0	0	0	0	0	0	0	0	3	4	6	7	6	43.0
1948	0	7	1	0	0	0	0	0	0	0	0	0	0	0	84.8
1949	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32.0
1950	0	0	0	0	0	0	4	0	1	2	0	0	0	0	51.2
1951	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40.6
1952	0	0	0	0	4	6	1	7	7	3	0	0	0	0	32.3
1953	0	2	7	6	5	1	7	3	7	1	0	6	7	4	24.7
1954	0	0	0	0	0	6	7	7	6	0	0	0	0	0	0.0
1955	0	0	0	0	0	0	0	0	0	0	0	4	0	0	48.3
1956	0	0	0	0	0	0	0	0	0	2	1	3	7	4	75.2
1957	0	0	0	0	0	5	7	4	1	0	1	2	7	7	30.9
1958	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91.1
1959	0	0	5	7	6	5	7	4	3	0	6	4	6	7	25.2

TABLE 2-DROUTH DAYS PER MONTH, COMPUTED WITH PENMAN'S EQUATION WHERE Et = .7Eo., AND CORN YIELDS FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Year	May	June	July	August	Corn Yield
1905	0	2	0	0	64.3
1907	0	0	0	0	33.4
1911	0	20	15	14	25.1
1912	0	0	9	5	30.8
1913	0	19	16	27	19.2
1914	0	19	15	13	33.9
1915	0	0	0	0	45.7
1916	0	0	14	19	14.6
1917	0	0	14	2	35.6
1918	0	0	20	8	23.4
1919	0	0	7	3	39.1
1920	0	0	22	9	50.8
1921	0	0	16	0	42.8
1922	0	0	3	9	45.0
1923	0	0	0	0	42.6
1924	0	0	0	0	37.8
1925	0	0	0	0	34.0
1926	0	2	7	11	19.8
1928	0	0	0	0	35.6
1929	0	0	0	26	7.8
1930	0	6	30	14	4.0
1931	0	0	20	5	50.0
1932	0	0	11	3	38.3
1933	0	0	24	14	32.4
1934	7	14	29	14	0.0
1936	0	28	28	23	0.0
1937	0	0	2	20	42.7
1938	0	0	0	16	44.8
1939	0	0	4	2	44.3
1940	0	0	2	7	37.9
1941	0	0	0	0	37.0
1942	0	0	0	0	39.6
1943	0	0	0	0	63.6
1944	0	11	23	0	33.6
1946	0	0	17	0	31.4
1947	0	0	0	22	43.0
1948	0	8	0	0	84.8
1949	0	0	0	0	32.0
1950	0	0	5	2	51.2
1951	0	0	0	0	40.6
1952	0	0	24	4	32.3
1953	0	17	20	17	24.7
1954	0	0	26	0	0.0
1955	0	0	0	9	48.3
1956	0	0	0	11	75.2
1957	0	0	17	9	30.9
1958	0	0	0	0	91.1
1959	0	15	22	18	25.2

TABLE 3-TOTAL NUMBER OF DROUTH DAYS PER GROWING SEASON, COMPUTED WITH PENMAN'S EQUATION, Et = .7Eo., AND CORN YIELD FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Year	Drouth Days Per Season	Corn Yield
1905	2	64.3
1907	0	33.4
1911	52	25.1
1912	16	30.8
1913	67	19.2
1914	47	33.9
1915	0	45.7
1916	33	14.6
1917	16	35.6
1918	29	23.4
1919	15	39.1
1920	30	50.8
1921	16	42.8
1922	12	45.0
1923	0	42.6
1924	0	37.8
1925	0	34.0
1926	23	19.8
1928	0	35.6
1929	29	7.8
1930	55	4.0
1931	23	50.0
1932	15	38.3
1933	42	32.4
1934	64	0.0
1936	80	0.0
1937	25	42.7
1938	18	44.8
1939	7	44.3
1940	9	37.9
1941	0	37.0
1942	0	39.6
1943	0	63.6
1944	34	33.6
1946	17	31.4
1947	26	43.0
1948	8	84.8
1949	0	32.0
1950	7	51.2
1951	0	40.6
1952	28	32.3
1953	56	24.7
1954	26	0.0
1955	10	48.3
1956	17	75.2
1957	34	30.9
1958	0	91.1
1959	60	25.2

TABLE 4-DROUTH DAYS PER WEEK, COMPUTED WITH THORNTHWAITE'S EQUATION AND CORN YIELDS FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Year	Week beginning: June				July				August					Corn
	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
1905	0	0	0	0	0	0	0	0	0	0	0	0	0	64.3
1907	0	0	0	0	0	0	0	0	0	0	0	0	0	33.4
1911	0	6	7	7	4	3	5	4	5	7	4	0	2	25.1
1912	0	0	0	0	0	0	0	6	4	1	0	0	6	30.8
1913	0	7	0	5	2	1	3	7	7	7	4	7	7	19.2
1914	1	6	6	2	0	4	7	7	7	3	3	0	0	33.9
1915	0	0	0	0	0	0	0	0	0	0	0	0	0	45.7
1916	0	0	0	0	0	1	7	7	7	5	2	4	2	14.6
1917	0	0	0	0	0	0	2	7	2	0	0	0	0	35.6
1918	0	0	0	0	5	7	6	7	7	0	0	0	0	22.4
1919	0	0	0	0	0	0	1	7	5	1	0	5	0	29.1
1920	0	0	0	0	3	6	7	3	0	7	3	0	0	50.8
1921	0	0	0	0	2	5	7	2	0	0	0	0	0	43.8
1922	0	0	0	0	0	0	2	4	2	3	6	3	3	45.0
1923	0	0	0	0	0	0	0	0	0	0	0	0	1	42.6
1924	0	0	0	0	0	0	0	0	0	0	0	0	0	37.8
1925	0	0	0	0	0	0	0	0	0	0	0	0	0	34.0
1926	0	0	0	0	0	0	0	0	6	3	0	0	0	19.8
1928	0	0	0	0	0	0	0	0	0	0	0	0	0	25.6
1929	0	0	0	0	0	0	0	1	7	7	7	7	5	7.8
1930	0	0	0	0	3	7	6	7	7	3	0	5	6	4.0
1931	0	0	0	2	5	7	1	6	5	0	0	0	0	50.0
1932	0	0	0	0	0	0	0	0	3	0	0	0	0	38.3
1933	0	0	0	0	5	6	6	7	0	3	5	7	6	32.4
1934	0	1	3	7	7	7	7	6	7	6	0	0	0	0.0
1936	0	5	7	7	7	6	5	7	5	5	7	7	2	0.0
1937	0	0	0	0	0	4	0	3	6	7	4	4	6	42.7
1938	0	0	0	0	0	0	0	0	7	7	3	5	6	44.8
1939	0	0	0	0	1	6	2	2	5	1	0	0	0	44.3
1940	0	0	0	0	0	0	0	0	6	0	0	0	0	37.9
1941	0	0	0	0	0	0	0	0	0	5	4	1	2	37.0
1942	0	0	0	0	0	0	0	0	0	0	0	0	1	39.6
1943	0	0	0	0	0	0	0	0	0	0	0	6	6	63.6
1944	0	0	3	7	6	7	6	0	0	1	4	0	0	33.6
1946	0	0	0	0	3	7	2	1	0	0	0	0	0	31.4
1947	0	0	0	0	0	0	0	0	0	3	7	7	6	43.0
1948	0	0	0	0	0	0	0	0	0	0	0	0	0	84.8
1949	0	0	0	0	0	0	0	0	0	0	0	0	0	32.0
1950	0	0	0	0	0	0	0	0	0	0	0	0	0	51.2
1951	0	0	0	0	0	0	0	0	0	0	0	0	0	40.6
1952	0	0	0	0	1	5	7	7	4	0	0	0	0	32.3
1953	0	1	6	5	0	7	3	7	1	0	5	7	4	24.7
1954	0	0	0	0	5	7	7	6	0	0	0	0	4	0.0
1955	0	0	0	0	0	0	0	0	2	0	7	6	0	48.3
1956	0	0	0	0	0	0	0	0	0	1	3	7	4	75.2
1957	0	0	0	0	0	7	4	1	0	2	3	7	7	30.9
1958	0	0	0	0	0	0	0	0	0	0	0	0	0	91.1
1959	0	0	0	4	6	7	4	4	1	7	5	6	7	25.2

TABLE 5-DROUTH DAYS PER MONTH, COMPUTED WITH THORNTHWAITE'S EQUATION AND CORN YIELDS FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Year	June	July	August	Corn Yield
1905	0	0	0	64.3
1907	0	0	0	33.4
1911	16	19	16	25.1
1912	0	5	7	30.8
1913	8	16	28	19.2
1914	15	17	14	33.9
1915	0	0	0	45.7
1916	0	14	21	14.6
1917	0	8	3	35.6
1918	0	24	8	22.4
1919	0	7	12	39.1
1920	0	19	10	50.8
1921	0	16	0	42.8
1922	0	6	14	45.0
1923	0	0	0	42.6
1924	0	0	0	37.8
1925	0	0	0	34.0
1926	0	0	9	19.8
1928	0	0	0	35.6
1929	0	0	31	7.8
1930	0	22	18	4.0
1931	0	20	6	50.0
1932	0	0	3	38.3
1933	0	23	18	32.4
1934	7	30	14	0.0
1936	15	28	27	0.0
1937	0	6	24	42.7
1938	0	0	24	44.8
1939	0	11	6	44.3
1940	0	0	6	37.9
1941	0	0	10	37.0
1942	0	0	0	39.6
1943	0	0	8	63.6
1944	6	23	5	33.6
1946	0	13	0	31.4
1947	0	0	19	43.0
1948	0	0	0	84.8
1949	0	0	0	32.0
1950	0	0	0	51.2
1951	0	0	0	40.6
1952	0	19	5	32.3
1953	9	19	16	24.7
1954	0	25	0	0.0
1955	0	0	15	48.3
1956	0	0	11	75.2
1957	0	12	14	30.9
1958	0	0	0	91.1
1959	1	24	21	25.2

TABLE 6-TOTAL NUMBER OF DROUTH DAYS PER GROWING SEASON, COMPUTED WITH THORNTHWAITE'S EQUATION AND CORN YIELD FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Year	Drouth Days Per Season	Corn Yield *
1905	0	64.3
1907	0	33.4
1911	54	25.1
1912	17	30.8
1913	57	19.2
1914	46	33.9
1915	0	45.7
1916	35	14.6
1917	11	35.6
1918	32	23.4
1919	19	39.1
1920	29	50.8
1921	16	42.8
1922	23	45.0
1923	1	42.6
1924	0	37.8
1925	0	34.0
1926	9	19.8
1928	0	35.6
1929	34	7.8
1930	44	4.0
1931	26	50.0
1932	3	38.3
1933	45	32.4
1934	51	0.0
1936	70	0.0
1937	34	42.7
1938	28	44.8
1939	17	44.3
1940	6	37.9
1941	12	37.0
1942	1	39.6
1943	12	63.6
1944	34	33.6
1946	13	31.4
1947	23	43.0
1948	0	84.8
1949	0	32.0
1950	0	51.2
1951	0	40.6
1952	24	32.3
1953	46	24.7
1954	29	0.0
1955	15	75.2
1957	31	30.9
1958	0	91.1
1959	51	25.2

TABLE 7-WEEKLY RAINFALL IN INCHES AND CORN YIELDS FROM PLOT 18, SANBORN FIELD, COLUMBIA, MISSOURI.

Year	Date at Beginning of Each Week																			
	April	May					June				July				August					Corn
	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
1905	1.04	1.22	3.03	0.00	0.28	0.00	0.10	1.18	0.06	4.15	1.96	0.00	0.23	0.20	2.11	1.02	3.72	0.06	0.12	64.3
1907	1.79	1.33	2.23	0.41	0.05	0.06	1.34	1.84	1.66	0.40	0.09	3.16	0.06	2.23	0.85	0.14	1.94	0.27	0.09	33.4
1911	2.42	0.00	0.21	0.31	0.17	0.66	0.15	0.20	0.11	0.05	1.54	0.07	0.37	1.05	0.05	0.00	1.28	0.53	0.60	25.1
1912	2.74	0.06	1.05	0.00	2.09	0.90	0.47	2.05	0.00	1.48	0.00	0.15	0.29	0.04	0.90	2.35	1.24	0.42	0.06	30.8
1913	0.00	0.27	0.63	0.50	0.03	0.13	0.03	0.00	2.18	0.09	2.50	0.00	0.77	0.08	0.00	0.08	0.69	0.00	0.00	19.2
1914	0.42	0.04	0.99	0.00	0.34	0.01	0.86	0.08	0.35	2.07	0.66	0.56	0.25	0.00	0.07	0.78	1.75	4.47	0.86	33.9
1915	0.70	0.67	0.00	2.36	2.63	0.98	2.18	3.29	1.73	1.01	0.50	1.89	0.09	0.99	0.65	0.93	1.99	0.72	0.00	45.7
1916	1.24	0.24	1.24	0.34	2.74	2.56	0.09	0.34	0.66	0.01	0.00	0.55	0.00	0.11	0.03	1.54	0.01	0.46	1.04	14.6
1917	2.63	0.19	0.08	2.93	1.61	0.62	0.72	0.00	1.30	0.02	0.31	0.50	0.12	0.00	2.05	1.88	0.84	0.50	0.40	35.6
1918	0.81	0.74	0.49	2.63	0.09	0.10	0.00	0.82	0.80	0.96	0.08	0.26	0.26	0.13	0.00	4.01	2.28	1.34	8.71	23.4
1919	1.43	1.67	1.43	1.40	0.48	3.54	0.43	0.37	0.73	0.00	2.25	0.22	0.00	0.19	1.45	1.22	0.22	2.34	0.00	39.1
1920	1.73	0.63	1.63	1.04	0.29	0.03	0.10	0.02	0.48	0.89	0.44	0.34	0.00	1.80	0.06	0.08	2.16	0.70	0.50	50.8
1921	1.53	0.96	1.41	0.00	0.88	0.14	1.57	0.00	1.48	0.84	0.00	0.60	0.01	1.25	2.28	1.94	1.16	0.44	3.73	42.8
1922	0.37	1.28	0.79	0.87	1.00	0.40	0.17	0.02	0.71	1.29	1.11	0.53	0.59	1.16	1.14	0.07	1.08	0.29	0.92	45.0
1923	0.18	0.11	0.36	0.99	0.51	2.52	1.65	0.49	1.63	1.27	0.09	1.98	0.00	0.39	1.59	1.74	0.44	0.15	0.39	42.6
1924	0.71	1.44	0.09	2.33	1.20	0.89	3.37	1.90	1.61	0.01	0.36	3.51	1.14	0.98	1.91	0.33	0.00	0.50	2.59	37.8
1925	0.50	0.62	2.35	0.14	0.45	0.47	0.75	3.11	2.29	0.45	0.18	0.01	1.27	0.55	0.76	1.66	2.69	0.00	0.00	34.0
1926	0.14	0.49	0.16	0.99	0.86	0.74	0.28	0.75	1.41	0.00	3.25	0.00	0.12	0.78	0.00	0.82	2.69	1.01	4.28	19.8
1928	0.00	0.00	0.76	0.52	0.42	0.68	2.63	7.15	0.71	3.73	0.40	0.00	0.47	2.85	1.23	0.57	0.50	0.88	0.05	35.6
1929	1.83	0.86	4.37	3.16	1.07	2.67	2.70	1.61	1.37	0.39	0.67	0.47	0.00	0.04	0.21	0.08	0.10	0.01	1.54	7.8
1930	1.82	0.16	0.70	0.58	0.23	0.66	0.93	0.57	0.59	0.35	0.02	0.00	0.48	0.00	0.03	1.17	0.96	0.02	0.31	4.0
1931	0.00	0.98	0.27	4.79	0.41	0.24	1.03	0.03	0.00	0.89	0.04	0.04	1.56	0.00	0.58	3.75	0.90	1.99	5.93	50.0
1932	0.15	0.28	0.63	0.00	0.70	2.58	0.47	2.23	1.06	1.70	0.43	0.00	0.11	1.16	0.80	3.54	0.87	1.01	0.21	38.3
1933	0.63	0.66	3.76	1.19	1.20	0.00	1.57	0.00	0.20	0.41	0.34	0.37	0.27	0.04	1.88	0.31	0.46	0.21	0.18	32.4
1934	0.60	0.35	0.96	0.00	0.04	0.39	0.97	1.93	0.07	0.20	0.03	0.26	0.10	0.28	0.00	0.46	4.48	0.00	0.62	0.0
1936	0.63	0.25	0.54	1.07	0.63	0.21	0.00	0.00	0.00	0.00	0.00	0.32	0.48	0.17	1.05	0.01	0.21	0.07	1.68	0.0
1937	2.89	0.84	0.21	1.65	0.28	1.92	1.97	0.10	0.00	0.15	0.00	1.88	0.91	0.03	0.58	0.01	1.36	0.00	0.30	42.7
1938	0.75	1.81	1.72	2.96	0.03	2.77	2.36	2.93	1.02	0.00	0.05	2.41	0.00	0.64	0.22	0.00	1.05	0.48	0.41	44.8

TABLE 7-CONTINUED

Year	April	May					June				July				August					Corn
	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	Yield
1939	0.04	2.77	0.31	0.18	1.74	0.00	1.32	1.71	0.06	0.06	0.00	0.66	1.38	0.48	0.65	5.00	2.84	0.00	0.00	44.3
1940	0.83	0.17	0.00	2.90	0.25	1.35	1.56	0.02	2.97	0.01	0.00	0.57	1.49	0.00	0.40	3.28	1.71	0.89	0.36	37.9
1941	1.28	1.27	0.02	0.07	2.29	1.73	2.07	0.00	0.73	2.48	2.33	0.00	0.19	0.13	0.66	0.29	0.71	1.64	0.81	37.0
1942	1.25	1.14	1.32	0.38	0.95	0.51	1.00	1.11	4.57	0.86	2.43	0.31	0.85	0.18	2.34	0.47	0.12	0.80	0.27	39.6
1943	0.07	5.09	3.26	4.66	0.23	3.24	3.18	0.45	1.25	0.00	0.68	0.61	1.52	3.61	0.80	0.29	0.12	0.15	0.68	63.6
1944	3.81	0.11	0.00	1.82	0.40	0.11	0.47	0.04	0.32	0.00	0.24	0.01	2.01	1.35	1.11	0.06	3.19	1.87	0.93	33.6
1946	1.18	1.76	2.08	1.55	0.29	1.28	0.00	0.76	0.08	0.29	0.11	0.00	1.20	3.48	0.82	3.78	0.29	0.83	0.05	31.4
1947	0.41	0.00	0.05	1.63	1.15	2.12	0.70	1.03	1.62	1.55	1.08	0.25	0.10	0.60	0.42	0.73	0.00	0.05	0.21	43.0
1948	1.66	0.64	1.29	0.13	0.00	0.01	0.07	2.89	3.33	1.57	0.00	0.70	4.20	0.29	0.99	0.14	0.01	3.44	0.03	84.8
1949	1.98	1.75	0.03	2.87	0.44	2.11	0.50	0.38	3.00	0.60	2.24	1.83	0.94	1.40	0.00	0.78	1.03	0.50	0.00	32.0
1950	1.57	0.64	0.05	1.16	3.50	3.02	0.55	1.16	0.00	0.45	0.00	1.62	1.06	0.90	0.91	1.49	0.11	1.15	1.26	51.2
1951	0.45	1.13	0.20	0.83	0.06	0.61	1.21	1.50	3.36	1.15	2.79	0.13	1.25	0.97	0.94	3.30	0.81	1.00	1.47	40.6
1952	0.01	1.01	0.20	0.68	1.40	2.88	0.05	0.46	1.10	0.00	0.36	1.00	0.02	0.02	2.65	2.72	1.66	0.00	0.90	32.3
1953	0.24	1.31	0.84	0.50	0.00	0.35	0.01	0.00	0.48	1.80	0.08	0.16	0.86	0.01	2.73	0.09	0.00	0.00	2.45	24.7
1954	2.54	0.12	0.19	1.68	0.92	2.06	1.12	0.13	0.16	0.19	0.01	0.00	0.20	1.18	2.31	1.28	0.32	1.16	0.00	0.0
1955	0.09	0.85	1.73	0.83	0.64	1.40	0.93	0.92	3.76	0.13	1.82	0.37	0.58	0.00	1.82	0.00	0.18	2.60	0.00	48.3
1956	1.52	2.52	0.63	0.64	1.10	0.31	0.11	1.24	0.63	3.76	0.13	2.44	0.25	0.28	0.00	0.85	0.79	0.00	0.59	75.2
1957	0.36	0.51	1.03	1.73	0.77	0.33	0.58	0.22	0.67	0.55	0.14	0.08	0.69	3.86	0.00	0.00	0.85	0.00	0.12	30.9
1958	0.09	2.44	0.36	0.04	0.42	0.85	1.62	2.36	1.43	2.75	0.55	4.25	1.72	2.26	0.01	1.52	0.68	0.05	0.03	91.1
1959	0.03	0.86	1.39	1.15	0.95	0.00	0.06	0.04	0.00	0.56	0.12	0.39	1.13	1.79	0.15	0.53	0.18	0.24	0.01	25.2