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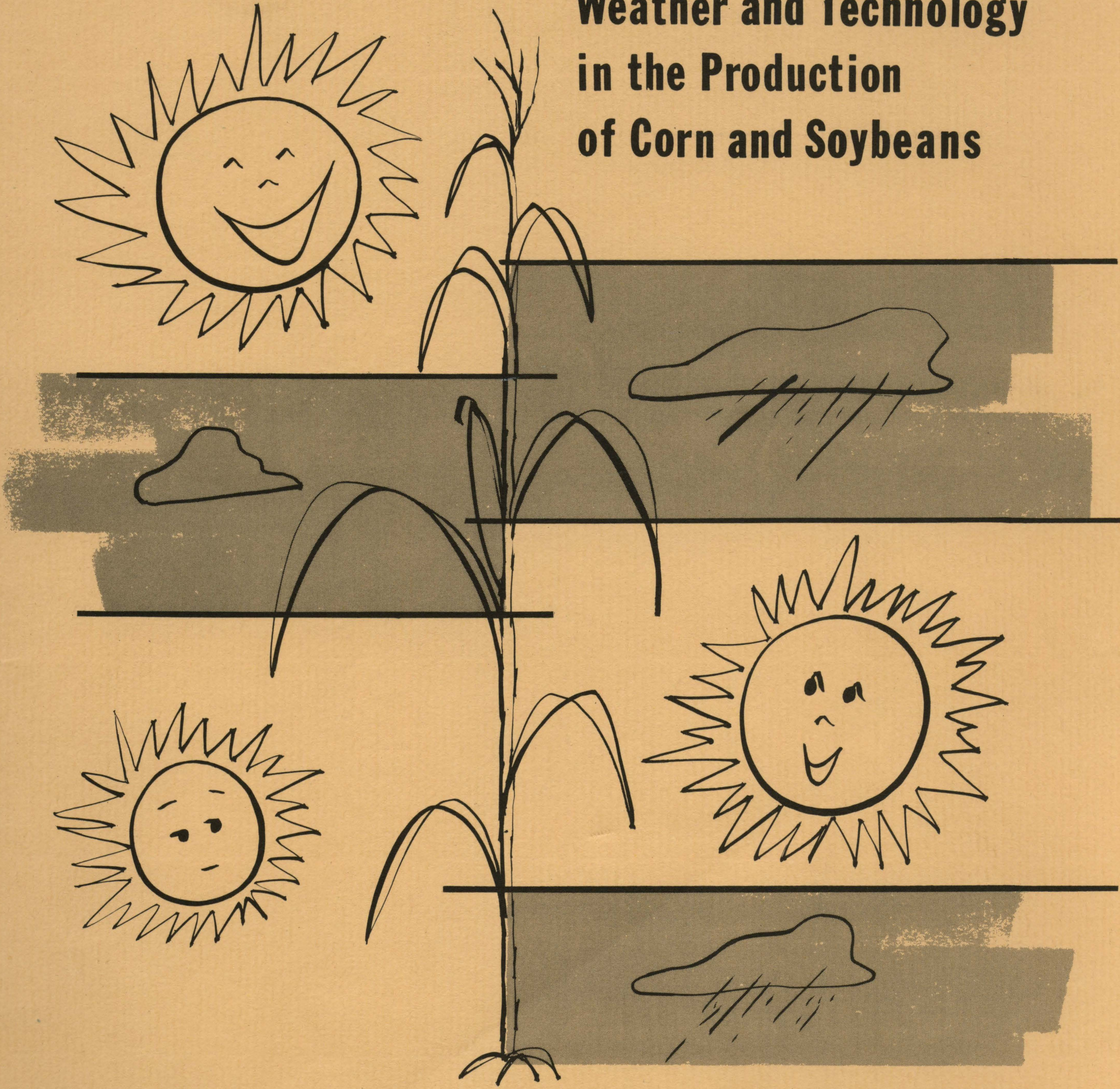
Weather and Technology in the Production of Corn and Soybeans



CAED Report 17

CENTER FOR AGRICULTURAL AND ECONOMIC DEVELOPMENT
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Weather and technology in the production of corn and soybeans

Louis M. Thompson
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WEATHER AND TECHNOLOGY
IN THE PRODUCTION OF
CORN AND SOYBEANS

by

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FOREWORD

These timely analyses were encouraged because of the importance they might have on the development of agricultural policy. Given the magnitude of production control programs and foreign surplus disposal during the period, Dr. Thompson interprets the contribution of weather to the surplus build-up after 1956. Studies of this nature are needed, along with those relating to food use in international development, to determine the sustained capacity of U.S. Agriculture and the likely demands on it in the decade ahead. Only then can we determine the extent of surplus capacity and the policies best adapted to it. For example, that portion of surplus build-up due to favorable weather might best be handled through storage programs; that due to other forces, by entirely different programs. Studies such as those reported here provide an important foundation for selecting among relevant policy elements.

Earl O. Heady, Executive Director
The Center for Agricultural
and Economic Development

ACKNOWLEDGMENTS

The helpful suggestions from the following scientists are gratefully acknowledged: Louis Bean, Mordecai Ezekiel, Oscar Kempthorne, John Pesek, Geoffrey Shepherd, Robert Shaw and George Snedecor.

COMMENT ON THE STATISTICAL METHODS

It is recognized that in regression and correlation analyses, there is sometimes a question of cause and effect relationships. The correlations in this study, however, are consistent with what is known from experimental studies with climate. It is believed that this fact lends considerable support to the statistical conclusion drawn from this study.

INTRODUCTION

The decade of the fifties will long be associated with rapid technological progress in agriculture and a period of increasingly burdensome surpluses. In 1961, an emergency feed grain program was established to reduce production. The outcome was greatly increased output per acre, resulting in almost as much feed grain production as in 1960 in spite of a 17 percent reduction in acreage from 1960 to 1961. Most observers attributed the increase in yield per acre to land selection and application of more fertilizer per acre. These were important factors, but there is evidence that weather was even more important in the increase in yield of corn per acre from 1960 to 1961. A statistical study of the Corn Belt states showed that weather in 1961 was more favorable for corn production than any year during the period from 1935 to 1961. The difference in weather was enough to account for two thirds or more of the increase in corn yields in the Corn Belt states from 1960 to 1961. This information was published as Technical Bulletin 12T by the Center for Agricultural and Economic Adjustment in 1962.

Studies were also published regarding the relation of weather to the production of wheat, soybeans and grain sorghums (25,26,27). In general, these studies indicated that weather was relatively unfavorable in the early fifties and relatively favorable in the late fifties in the Corn Belt and in the Great Plains from North Dakota to Texas. In other words, weather was an important factor in the build-up of surplus of wheat and feed grains during the late fifties.

This paper represents a revision of Technical Bulletin 12T. It also includes soybeans since the weather variables and states studied are identical for both corn and soybeans. Furthermore, this paper is based on greater refinement in statistical techniques in weather studies developed during the past year.

HISTORICAL

Weather has long been recognized as an important variable in crop production in the Corn Belt. An early statistical study was published by Smith (19) in 1914. By use of simple correlations he determined the most important weather variables in corn production in Ohio. Wallace (31), in 1920, made an important contribution to our understanding of weather and corn production by employing multiple linear regression techniques. Ezekiel (4) used multiple curvilinear regression techniques to study weather and corn production, describing his techniques in his book in 1941. He was limited in the number of variables he could handle with existing computing facilities. He used the total rainfall for the three summer months, the average summer temperature and the combined production of eight states. His correlations of weather with corn yields were not high, but the reasons are now apparent. June rainfall is generally higher than optimum, and June temperature is generally lower than optimum. The reverse is true for July rainfall and temperature. To average June and July rainfall, or June and July temperature, tends to cancel out positive and negative effects of the variables. In spite of the handicap of lack of computing facilities, Ezekiel developed the methods that became the foundation of the present study; that is, the multiple curvilinear regression techniques employed in this study can be credited to Ezekiel's book published in 1941.

Houseman (9), in 1942, used curvilinear regression to determine the period of the growing season when additional rainfall was of greatest value and when high temperatures were most favorable or most damaging. Further reference will be made to this important contribution.

In 1943, Hendricks and Scholl (8) used a rather sophisticated technique to study the effect on corn yields of rainfall and temperature during the growing season. They used multiple linear regression techniques with interactions between monthly rainfall and temperature. While their use of interactions provided valuable information, it is now apparent that linear regression analyses are inadequate to measure the effects of either rainfall or temperature.

There were many more weather studies published between 1920 and 1943, but the ones cited were responsible for shaping the ideas for the present study. The drouth years of the 1930's caused widespread interest in weather research, and hundreds of weather studies were published in the late thirties and early forties. But there was relatively little interest in "crop-weather" research after World War II until very recently (6,11,21,22). There appear to be two reasons for the lack of interest. One is that our unfavorable weather years of 1947 and in the early fifties were not associated with shortages in supplies of food or feed grains. The second reason is the shift of research funds to weather studies pertaining to air-travel activities and to forecasting of weather.

Odell and his students (13,14) at Illinois have been studying weather and crop yields recently as an aid to evaluating the productivity of soil types.

During the period of this research two other reports have been published that will have important influence on the development of agricultural policy. Gustafson and Johnson (5) made an intensive study of the factors affecting trends in production of food and feed grains. Their conclusions agree with those drawn from this study: that yields were adversely affected by weather in the early fifties and favorably affected by weather of the late fifties. Shaw and Durost (16) made a study of weather and corn yield trend in Iowa from 1929 to 1960. They used moving averages to establish the trend for technology. Their method led them to the conclusion that technology was introduced in two stages, during a period prior to 1942 and a period after 1954. Their method indicated a level trend for technology from 1942 to 1954. Their conclusions are not supported by those drawn from an entirely different method of analysis in this study. Their moving average for technology trend describes the weather trend even more than technology.

PLAN OF STUDY

The five Corn Belt states, Illinois, Indiana, Iowa, Missouri and Ohio were selected for analysis because these states produce about half of the corn and soybeans grown in the United States and because they were also judged to be the most homogeneous states with respect to climate and soil conditions. The states were analyzed separately to provide replication. Furthermore it was believed that the climate varied enough from one state to another to cause differences in response to deviations from average weather conditions. The nine crop reporting divisions of Iowa were analyzed separately as a check on the accuracy of using state averages. The results of this separate analysis indicated that, in a state as homogeneous as Iowa, state averages are quite satisfactory.

The years 1930 to 1962 were selected for analysis. Earlier analyses (27,28) were based on the period from 1935 to 1961. At that time it was believed that yields started climbing with the introduction of hybrid corn in 1935. It is now believed that technology was being introduced before 1935 but was obscured by a period of unfavorable weather in the mid-thirties. If one assumes a level trend in yields from 1900 to 1935 and that 1935 marks the trend upward, it turns out that the trend in yield from 1935 to 1945 is quite steep in relation to the period 1946 to 1962. This is hardly logical in view of the technological progress in crop breeding as well as soil and crop management since 1945.

The weather variables selected were May temperature, June rainfall, June temperature, July rainfall, July temperature, August rainfall, August temperature, interactions between rainfall and temperature for each of the three summer months, and preseason precipitation (from September to May inclusive). Both linear and quadratic equations were used for the weather variables. As crop yield and rainfall data (or crop yield and temperature data) are plotted on graph paper, it appears that a curvilinear relationship exists. A parabola best describes this relationship and is the result of a quadratic equation.

The earlier published papers of the author called attention to the fact that the regression equations overestimated yields in poor weather years and underestimated yields in good weather years. Dr. George Snedecor[1] suggested that this might be due to rainfall-temperature interaction. This was found to be true. Where both rainfall and temperature are favorable, an extra boost in yield occurs. Contrariwise, if both rainfall and temperature are unfavorable, an extra reduction in yield is the result.

It is recognized that technology trends are not perfectly linear throughout the period of analysis. A curvilinear trend does not ordinarily prove satisfactory in explaining technology, although one study with grain sorghums was published using a curvilinear trend (26). Curves tend to confound weather and technology. Dr. Mordecai Ezekiel[1] suggested a mathematical procedure to fit two linear trend lines simultaneously with all of the weather data for the entire period of the analysis.[2] One trend period from 1930 to 1945 represents the change to mechanization and adoption of improved crop varieties as well as improved practices in soil and crop management. The second trend period from 1946 to 1962 represents the rapid increase in the use of fertilizers, better varieties, land selection, use of chemical pesticides and further improved management practices. This method provided coefficients that indicated a slightly steeper trend from 1930 to 1945 than for 1946 to 1962 for corn in all five states. The trend yield for 1930 appeared to be considerably lower than the average yield from 1900 to 1930. This is believed to be due to the effect of the severe drouths in 1934 and 1936. There

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1/ Personal Communications

2/ Two coefficients for years are necessary. T_1 1930-1945, and T_2 1946-1962. During T_1 period, T_2 years are set at zero. During T_2 period, T_1 years are set at zero. For examples: in 1945, $T_1 = 16$ and $T_2 = 0$, or in 1962, $T_1 = 0$ and $T_2 = 33$ since years are coded with 1930 as year 1, 1931 as year 2, etc.

was no improvement in correlation by using two trend lines instead of one for either corn or soybeans. The results of this study are based on one linear trend line for technology.

The crop yield data were taken from USDA "Agricultural Statistics," annual publication of The USDA, and from crop reports of the Statistical Reporting Service. The weather data were taken from USDA Miscellaneous Publication 471 or Agricultural Statistics through 1960. The weather data for 1961 and 1962 were taken from Climatological Data published monthly for each state. The data are published as Division Averages. The division averages were converted to state averages by conversion factors furnished through the courtesy of the Weather Bureau, United States Department of Commerce. All of the weather and yield data used in the analyses are shown in the Appendix.

The statistical analyses were accomplished by the Computing Service of the Statistical Laboratory, Iowa State University.[3]

3/ Under the guidance of Mr. Howard Jespersen and Mrs. Mary Clem. Mrs. Elaine Crouse assisted with the collection and preparation of the data for analysis.

PART I

CORN

Results of Linear Analysis

Multiple linear regression coefficients provide an easily understood method of showing the effects of slight departures from average rainfall or average temperature. They are not suitable for predicting yields over a wide range of weather conditions. In linear regression it is assumed, for example, that each additional inch of rain in July would have the same effect on yield as the first inch. This is not the case, however, because each additional inch has less effect until a point is reached where additional rain may actually reduce yields.

Table 1 shows the partial regression coefficients for each of the five states. In Illinois, for example, the 2.43 figure listed under "July rainfall" indicates that an inch of rainfall above average caused an increase of 2.43 bushels of corn per acre. Under "August temperature," the -.38 means that a degree of temperature above average caused a decrease of .38 bushel of corn per acre. The .98 under

Table 1. Linear Regression Coefficients for Nine Variables and Their Effect on Corn Yields in Five States.[4]

	Bushels Per Acre Per Year								
States	Years	Pre. Precip.	May Temp.	June Rain	June Temp.	July Rain	July Temp.	August Rain	August Temp.
Illinois	.98	.22	.01	-1.06	-.31	2.43	-1.00	1.06	-.38
Indiana	.87	-.24	-.20	-.24	.14	2.75	-.96	-1.26	-.86
Iowa	.88	.79	-.46	-.78	.48	2.56	.06	.41	-.66
Missouri	.80	.18	.38	-1.07	-.41	1.67	-.88	-.71	-1.22
Ohio	.91	-.47	-.59	-1.01	.33	3.02	-.16	-1.64	-.34

4/ The Correlation Coefficients are: Illinois .93, Indiana .94, Iowa .86, Missouri .96, Ohio .93. The F values for analysis of variance are: Illinois 15.9, Indiana 17.7, Iowa 7.6, Missouri 30.5, Ohio 15.2.

"years" means an average increase of .98 bushel per acre each year from 1930 to 1962.

It appears that in Iowa, for example, best corn growing weather would be above average preseason precipitation, above average temperature in June and July, below average temperature in August, lower than average rainfall in June, but higher than average rainfall in July and August.

Yields of corn appear to be improved with higher May temperatures in Missouri and Illinois. On the other hand, it appears that Iowa, Indiana and Ohio corn yields might be adversely affected by higher than average May temperatures. The correlations were so low between corn yields and May temperatures in these latter states that the variable was not used in the curvilinear analyses to be reported later. May temperature was included in the curvilinear analyses for corn in Illinois and Missouri. Corn is planted early enough in May in Missouri and much of Illinois for May temperature to be important.

The size of the coefficients gives some indication of relative importance of the weather variables. It is apparent that July rainfall and August temperature stand out in all states. Best growing conditions for corn would appear to include higher than average July rainfall and lower than average August temperature. The relationships of the other variables will appear more clearly in curvilinear analyses.

One should be cautious in ignoring a variable with a very small coefficient. For example, if the average temperature happens to be optimum, the linear regression coefficient might be quite small. This is because the temperature curve is a parabola, and if the average temperature is optimum (and at the top of the curve) a deviation either way from average appears to have no effect in linear analysis. This is very near the situation for July temperature in Iowa. As will be shown later with curvilinear analysis, cooler than average temperature in Iowa is desirable if rainfall is less than average.

In determining the variables that contributed most to variations in crop yields, the following method was used in conjunction with examination of coefficients and their "t" values. The regression coefficient was multiplied by its appropriate Σxy, and this product ($b\Sigma xy$) was divided by the total sums of squares (Σy^2). The larger this fraction the more important the variable. This can be derived from the fact that in multiple regression the following relationship holds: $\Sigma y^2 = b_1\Sigma x_1y + b_2\Sigma x_2y + \cdots\cdots\cdots\cdots + b_n\Sigma x_ny + \Sigma(\text{Residuals}^2)$ It turns out that by use of the equation above, the most important variables in this study are years for technology, preseason rainfall, July rainfall and August temperature. These four variables in multiple curvilinear regression analysis provide over 80 percent of the yield variation. Further considerations in selecting the most important variables include examination of the size of the standard errors of the coefficients. If one is selecting a few variables for predicting yields, he would tend to reject a coefficient with a large standard error (or a low "t" value).

With the development of high speed computers, there is less need to eliminate the less important variables. When desk calculators were depended on, the idea was to select only a few of the most significant variables. The tendency now is to retain variables that add to the correlation. There is little additional cost for an analysis with many variables.

A word of caution should be added at this point. Large numbers of variables in multiple regression analyses may provide high correlations even though the variables are meaningless. Robert Shaw and Robert Dale drew random numbers within logical ranges for rainfall and temperature, and used actual corn yield data for a 27-year period in Iowa. They had 21 variables in the equation and obtained a multiple correlation coefficient of .86. However, none of the "t" values for the weather coefficient were significant at the 95 percent level of probability, and the mean square for deviations from regression was larger than the mean square for regression. Therefore, one should make an analysis of variance in conjunction with multiple regression dealing with a large number of variables and not look simply at the correlation

Table 2. Constants (a values) and Multiple Regression Coefficients (b values) For Years and Weather Variables and Their Relation to Corn Yields in Five States

	Illinois	Indiana	Iowa	Missouri	Ohio
	Constants (a values)				
	-3072.84	-2454.18	-3223.10	628.62	-2269.80
	Regression Coefficients (b values)				
X_1	.8069	.8605	.7045	.7012	.9472
X_2	1.0263	.5248	3.7065	- .6489	3.1553
X_2^2	- .0134	- .0165	- .0773	.0143	- .0637
X_3	-19.9559	----	----	-12.0473	----
X_3^2	.1570	----	----	.0927	----
X_4	-91.1648	-39.9844	-18.3570	-79.6712	- 8.4442
X_4^2	.8194	- .3249	.5067	.5437	.6745
X_5	3.4943	8.5441	48.0467	-24.1244	16.3843
X_5^2	- .0562	- .0781	- .3464	.1334	- .1186
X_6	17.2262	52.7694	-81.4565	-40.1511	-20.6316
X_6^2	- .2354	- .5343	1.6797	- .0247	- 1.2751
X_7	3.6315	12.5574	25.0782	-16.4336	- 1.2856
X_7^2	- .0316	- .0786	- .1851	.0892	- .0022
X_8	107.0276	104.2592	- 8.7055	14.9916	19.6940
X_8^2	- .2296	- 1.6697	- .3593	.1427	- .5797
X_9	92.6869	43.2209	22.7112	41.4311	49.7832
X_9^2	- .5818	- .2673	- .1697	- .2680	- .3477
X_4X_5	1.1520	.5945	.1597	.9905	.0355
X_6X_7	- .1665	- .6065	.9431	.5496	.4590
X_8X_9	- 1.3963	- 1.2351	.1598	- .2177	- .2021

The F values for Analysis of Variance: Illinois 32.2, Indiana 17.8, Iowa 17.5, Missouri 29.0, Ohio 16.1

X_1 = years, X_2 = Preseason precipitation, X_3 = May Temperature, X_4 = June Rain, X_5 = June Temperature, X_6 = July Rain, X_7 = July Temperature, X_8 = August Rain, X_9 = August Temperature

Total degrees of freedom = 32. One degree of freedom is assigned to each regression coefficient. With 20 degrees of freedom for regression and 12 degrees of freedom for residuals an F value of 3.86 would be significant at the 99% level of probability (20).

coefficients. The "F" values for all of the analyses reported in this paper are significant at the 99 percent level or higher.

Results of Multiple Curvilinear Regression Analysis

The results of the multiple curvilinear regression analyses are shown in Table 2. In order to use interactions it was necessary to retain both the rainfall and temperature variables for the month concerned. This resulted in the use of some variables for which the standard errors were large. However, as previously indicated, the analysis of variance shows significance at the 99 percent level of probability or higher for each of the multiple regression equations.

Figure 1 on page 12 shows the actual and calculated yields of corn in Iowa for the period from 1930 to 1962. Figures 2 and 3 show results for the other states. The actual yields are connected with dotted lines. The calculated yields are connected with solid lines. The trend for technology (representing average weather) is shown as a broken line. The method for calculating the actual yield is shown on page 55 of the Appendix. In this example, the year 33 represents 1962. Year 1 would be 1930. The actual weather data of 1962 are used to calculate 1962 yield. One may calculate the yield in 1963 by using year 34 and substituting the 1963 weather data for Iowa.

The wavy solid line in Figure 1 might be described as the weather-technology trend. If this point of view is acceptable, it becomes apparent that the period from 1950 to 1956 represented unfavorable weather, except in 1952, while the period from 1957 to 1962 represented a period of favorable weather. The drouths of 1934, 1936 and 1947 are well known. The weather of 1950 and 1951 was unfavorable because of cool-wet weather. The mid-fifties were characterized by hot, dry weather.

It appears that Iowa has had two periods of very favorable weather since 1930. One period reached a peak in 1942. The other favorable period reached a peak in 1962, the best weather year since 1942. It appears that weather improved from 1936

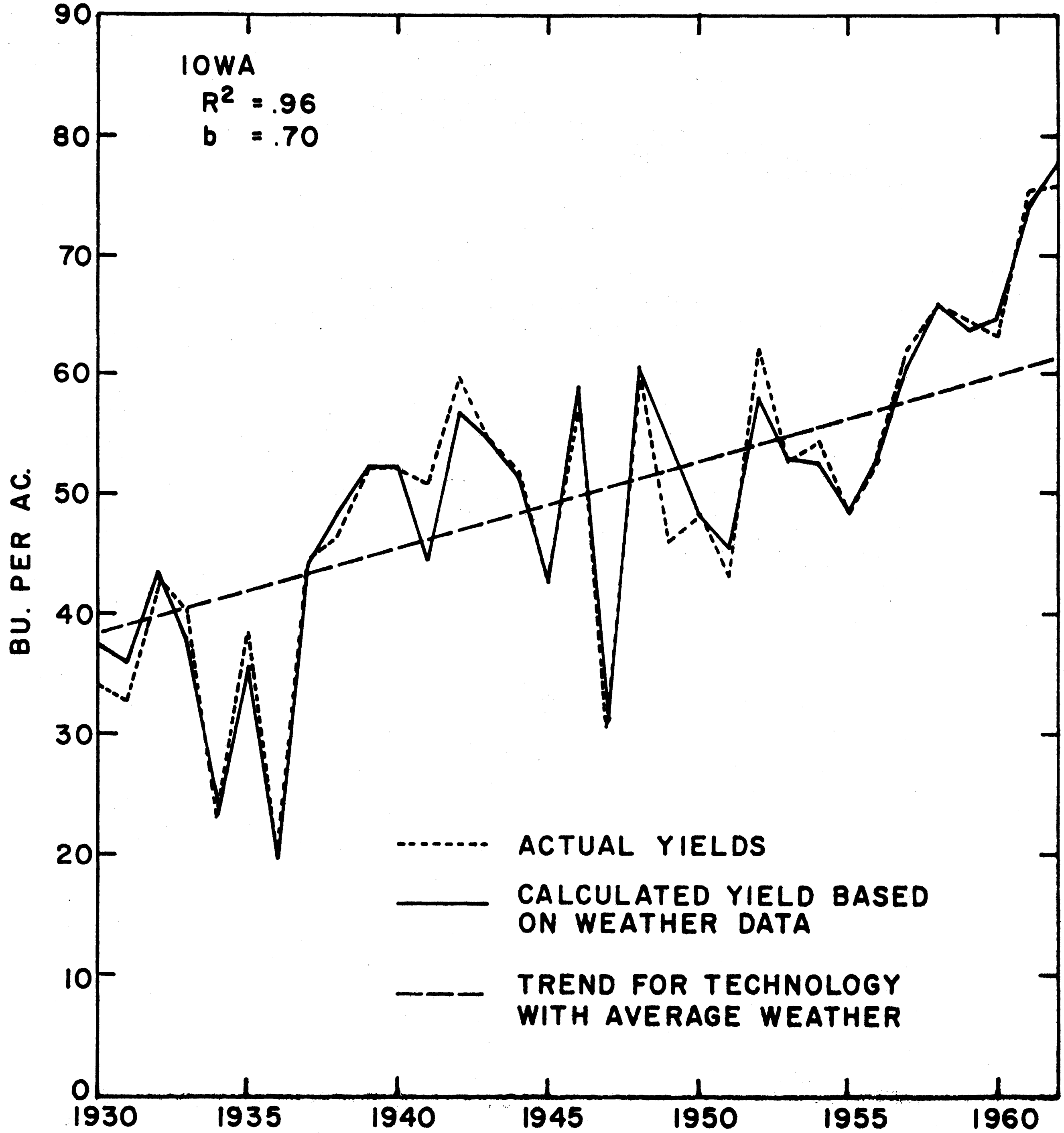

FIGURE 1. THE RELATION OF WEATHER AND TECHNOLOGY TO THE TREND IN YIELD OF CORN

to 1942 and from 1956 to 1962. From 1937 to 1946 there was only one year with yields below the trend line. From 1947 to 1956 there were only two years when yields were above the trend line. Yields were above the trend line from 1957 to 1962.

The other states show some similarity to Iowa in that high yields were associated with the periods 1937-1942 and 1957-1962. Low yields were associated with 1932-1936 and 1950-1956. The similarity of the weather-technology (solid) lines for adjacent states is most striking. Ohio and Indiana appear quite similar. Indiana and Illinois show great similarity. In Illinois and Missouri the annual fluctuations in weather were in the same direction except in 1950 and in 1962. The cool season in 1950 was beneficial in Missouri but adversely affected corn yields in the northern tier of Corn Belt states. In 1962 much of Missouri was affected by dry weather in August.

The graphs for Indiana and Ohio show less of grouping of good weather years and poor weather years than shown in other states. Furthermore, the fluctuation in yield is less in these two states than in Illinois, Missouri or Iowa. The mid-thirties are well known as drouth years and the graphs show this most strikingly. The mid-fifties were drouthy in Iowa, Missouri and Illinois, but not as severe as the mid-thirties.

Two favorable periods show up in all states. These are 1938-1943 and 1958-1962. However, in the former period, 1940 was unfavorable from Illinois through Indiana to Ohio.

The years of unusually high production across the Corn Belt were 1942, 1948, 1958 and 1961 and 1962. If one should wish to make a quick estimate of trend in yield per acre, a suggested method is to draw a line through the years of unusually high production. Such lines drawn indicate a steeper trend than the regression equations indicate. This might be explained on the basis that weather was relatively more favorable in recent years. Another factor may be more important: we are

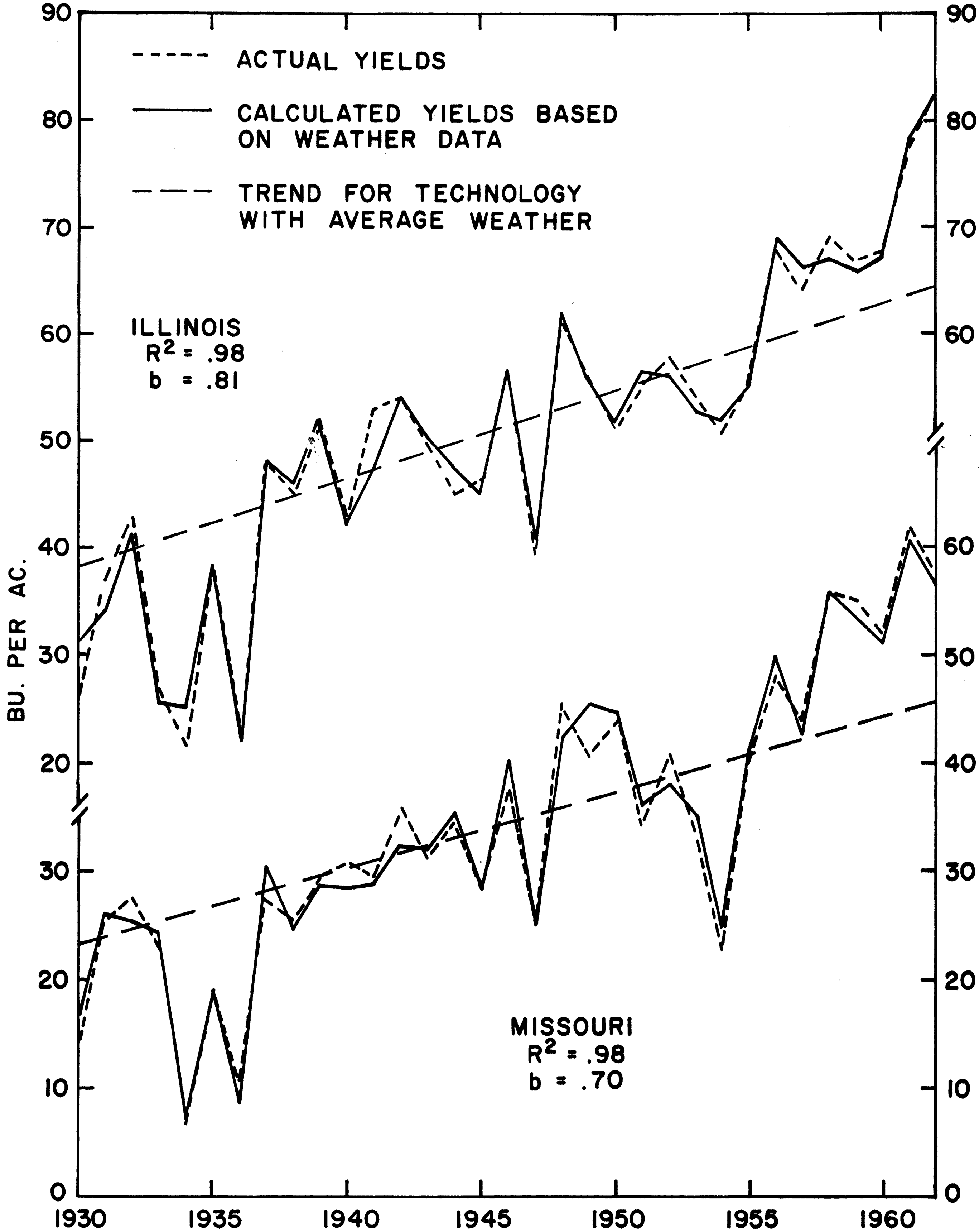

FIGURE 2. THE RELATION OF WEATHER AND TECHNOLOGY TO THE TREND IN YIELD OF CORN

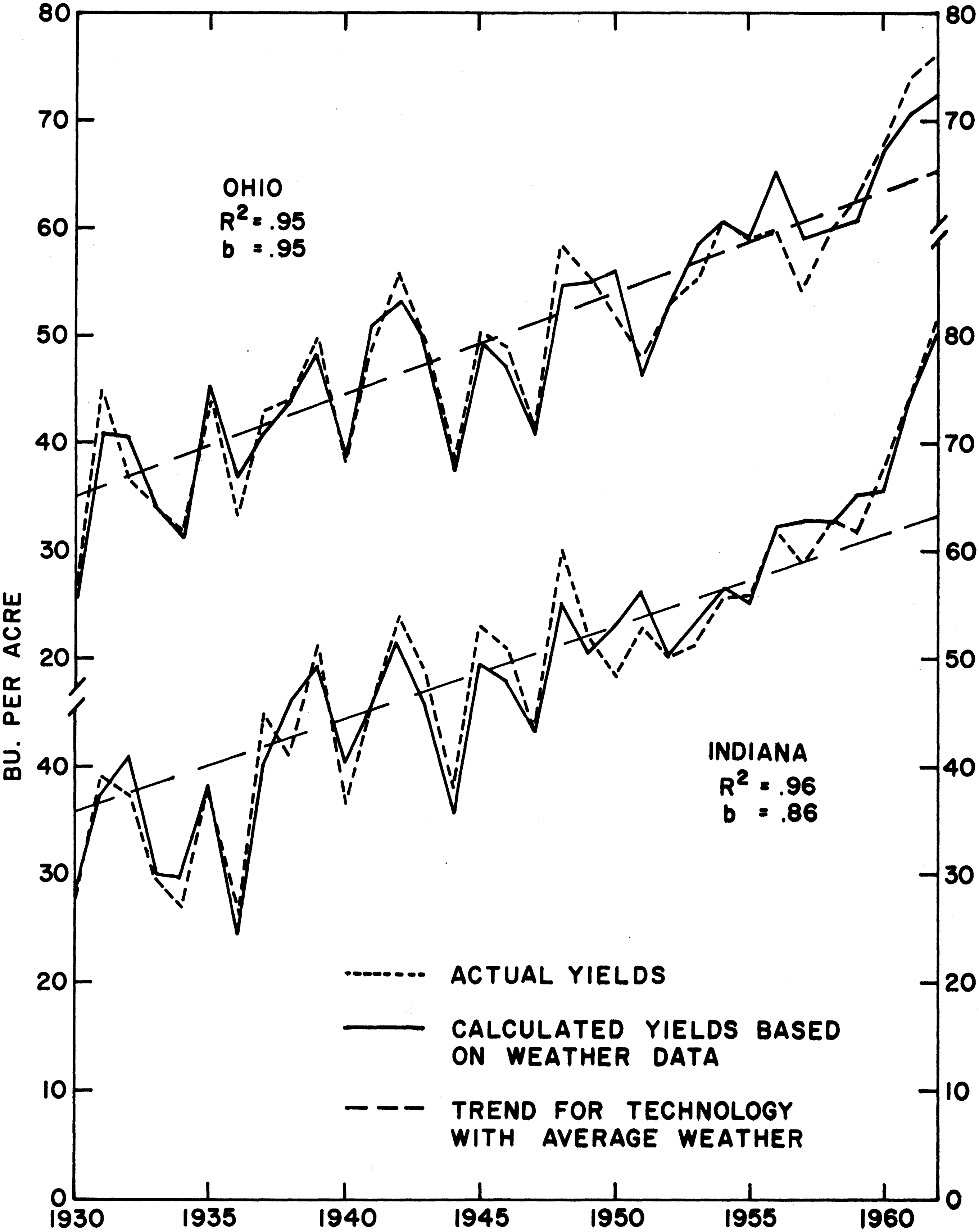

FIGURE 3. THE RELATION OF WEATHER AND TECHNOLOGY TO THE TREND IN YIELD OF CORN

experiencing a weather-fertility interaction that the equations do not measure. As more fertilizers are used, one would expect a greater increase in yield in a good weather year, compared to the trend yield.

Since all technology was considered in one variable (years), it was not feasible to develop a weather-fertility interaction in the regression equation. Interaction between extra soil moisture and nitrogen fertilizer is well known in agronomic research (23).

A Linear Trend for Technology

It cannot be argued that the progress of technology has been in a perfectly straight line. However, some mathematical expression is needed if a projection is to be made for technology. A linear trend is more logical than any curvilinear trend. The most important factor in the trend since 1945 is the increased use of fertilizers. Figure 4 shows the rate of increase in the use of fertilizers on corn from 1945 to 1961. The trend lines are based on a report by Adams and Ibach (1). From their data a calculation was made of the proportion of the nitrogen, phosphorus, and potassium used in each state that was used on corn in 1959. These proportions were used for calculating the amounts of the fertilizer used each year from 1945 to 1961.[5] The amounts per acre are based on the assumption that all planted acres were fertilized equally. It is recognized that all acres are not fertilized alike, but the method of calculation permits a comparison between states of total fertilizers used on corn each year. The percentages of fertilizers used in each state on corn vary slightly from year to year, but the variation is small

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5/ The estimated percentages of fertilizers applied to corn in each state from 1945 to 1961:

	N	P_2O_5	K_2O
Illinois	85	63	63
Indiana	72	63	65
Iowa	95	86	95
Missouri	65	46	49
Ohio	69	60	57

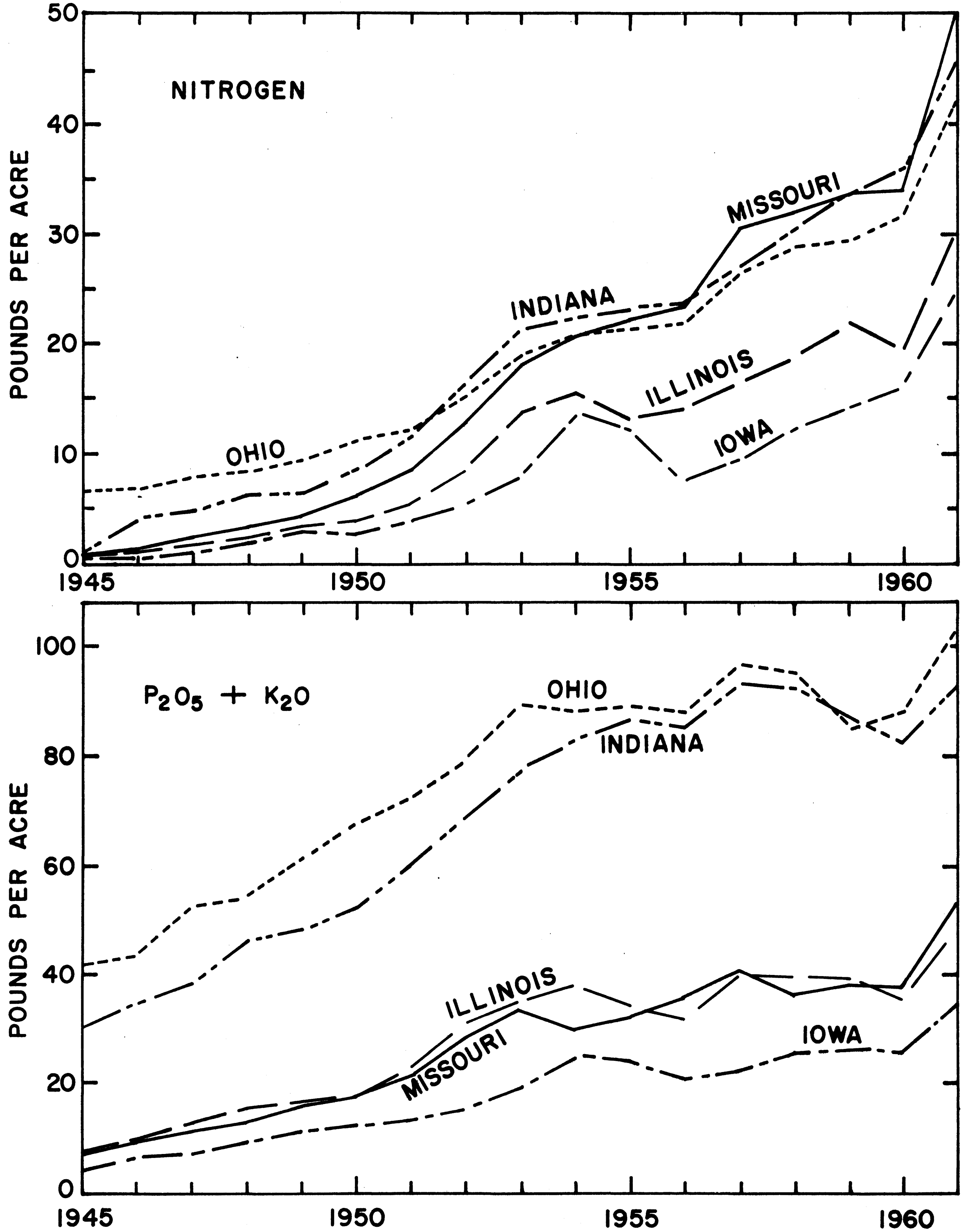

FIGURE 4. NITROGEN, AVAILABLE P_2O_5 AND K_2O USED ON PLANTED ACREAGE OF CORN

enough so that one may use the constant percentage to gain some notion of the shape of the trend lines.

The rates of increase in nitrogen utilization appear to be steeper than rates of increase for phosphorus and potassium. The rates of increase in utilization of phosphorus and potassium appear to have leveled off after 1954. The over-all picture results in an approximately linear trend in the increase in the use of fertilizers on corn since 1945.

Much of the effect of fertilizers each year is a residual effect from many years of fertilizer use. Year to year changes in fertilizer use may have small effect on yields. The important feature is that Corn Belt soils are gradually being improved by continued use of fertilizer. A good weather year results in a marked interaction between weather and fertility.

Illinois uses a large amount of rock phosphate while the other Corn Belt states use relatively small amounts. Had total P_2O_5 been used in figure 4 rather than available P_2O_5, the trend line for $P_2O_5 + K_2O$ for Illinois would have been closer to that for Indiana.

The drouth years of 1954 and 1955 caused the lag in use of fertilizers, particularly in Iowa and Illinois. There were sharp increases in fertilizer use in both 1954 and in 1961, but in general, the long-term trend is linear. It should be recognized that other factors, such as land selection, improved stands of corn, terracing and contour tillage, improved varieties, greater use of chemical pesticides and improved skills in operations, all contribute to gradually improved yields. It appears that technology has gradually been adopted over time at a fairly steady rate since about 1930.

One good test of this concept is to examine the differences between calculated and actual yields; in other words, the "residuals." In all states the residuals appear to be random, and they do not increase or decrease in size over time.

The trend for technology from 1930 to 1945 is most difficult to determine.

In the earlier analyses published in the technical bulletin, CAEA Report 12T (28), the trend yields plotted for 1935 appeared to be 4 to 5 bushels above the long-time average from 1900 to 1935. Thus it appeared that an extrapolation back in time would result in the yield starting upward around 1930. Of course, it could be argued that this requires the use of a curve from 1935 to 1945 rather than a linear trend from 1930 to 1945. To accept the latter position requires the assumption that only hybrid corn was responsible for the yield increases prior to 1946. This point of view is not acceptable. Many other factors affected production at that time, particularly mechanization, better rotations, greater use of lime, and improved management skills. The fact that an improvement in weather coincided with adoption of hybrid corn has caused many observers to attribute the increases in yield entirely to hybrid corn.

It is generally accepted that, in the Corn Belt, corn yield trends were level from 1890 to 1930 and started climbing some time after 1930. It turns out that the trend yield for 1930 for each state (shown in figures 1, 2 and 3) is near the same as the average yield from 1890 to 1930. Furthermore, the trend yields for 1962 are in proper relation as the various states are compared. The 1962 trend yields for Iowa, Illinois and Indiana are 61.2, 64.1, and 63.1 respectively. The latter two states use more fertilizer at the present time and would be expected to have higher trend yields than Iowa. The average yields for these states from 1890 to 1930 were 37.5, 36.0 and 35.5 bushels per acre respectively for Iowa, Illinois and Indiana. The higher yields in Iowa were associated with a naturally higher level of soil fertility. For the same reason, Illinois ranked ahead of Indiana.

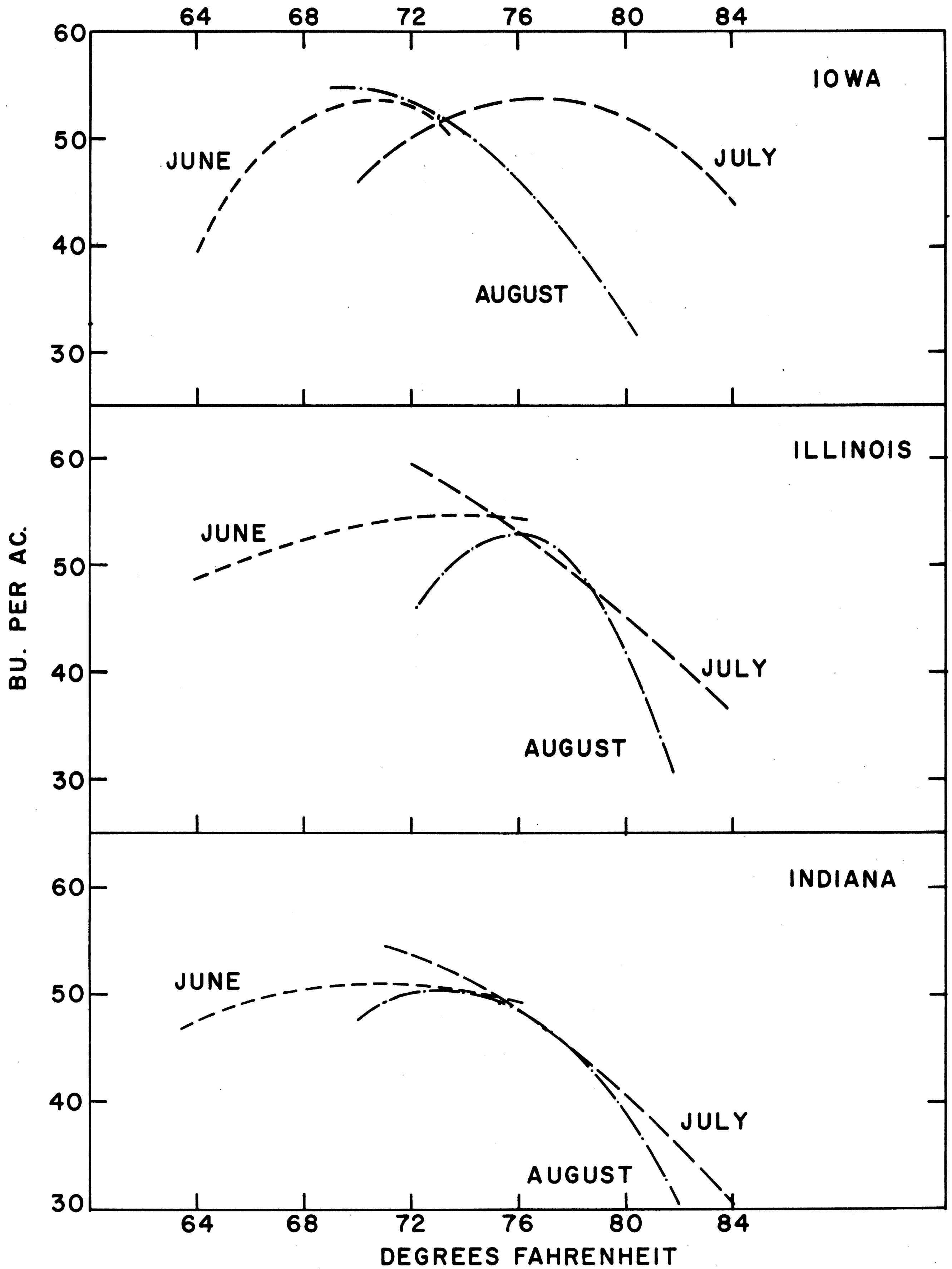

FIGURE 5. THE RELATION OF YIELD OF CORN TO AVERAGE MONTHLY TEMPERATURE

The Curvilinear Relationship of Weather Variables to Corn Yields

By use of curvilinear regression analysis without interactions, one can calculate only one curve for a variable. He must assume that all other variables are held at average conditions. By use of rainfall-temperature interactions, one can calculate curves for temperature at different levels of rainfall for a given month. Likewise one may calculate curves for rainfall with various temperature levels.

Figures 5 and 6 were calculated from coefficients in Table 2. Figure 5 shows temperature curves for Iowa, Illinois and Indiana with rainfall held at average. The optimum values for temperature vary slightly from one state to another, partly because of climate-crop variety interactions and partly because of rainfall-temperature interactions. From Figure 5 it appears that the optimum temperature for July is higher for Iowa than in the other states. Figure 6, however, shows that the optimum temperature for July in Iowa depends on the amount of rainfall. This relationship is extremely significant. This may help to explain why Iowa corn yields rarely climb above 150 bushels with superior management. High rainfall in July is usually associated with average temperatures below 74 degrees. But as the July rainfall increases above average, the optimum temperature is above 74 degrees. This general relationship was observed by Hendricks and Scholl in 1943 (8).

More than a third of the corn in Iowa is grown north of the northern boundary of Illinois. This may explain why June temperature is such an important factor in Iowa corn production. In most years, June weather is cooler and wetter than optimum in Iowa.

The interaction of dry weather with high temperature appears to have very damaging effects on yields. The low yield in Iowa in 1936 is hardly surprising when it is realized that the average rainfall in July was .51 inch and the average July temperature was 83.4 degrees.

The interaction of low temperatures and high rainfall in the summers of 1950

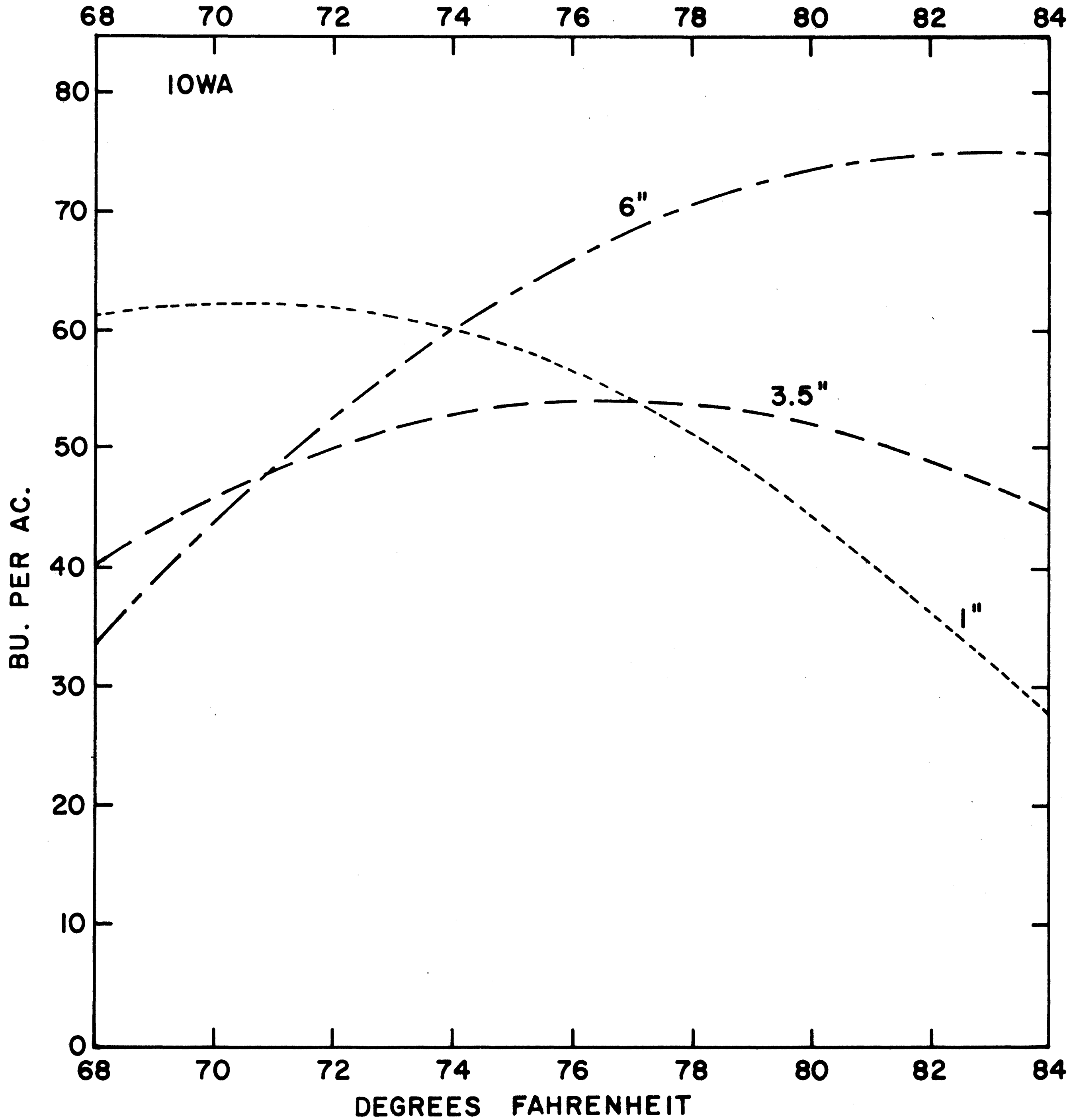

FIGURE 6. THE RELATION OF CORN YIELD TO JULY TEMPERATURE WITH DIFFERENT LEVELS OF RAINFALL IN IOWA

and 1951 in the Corn Belt caused lower than expected yields. This was particularly true in Iowa. In 1950, the July rainfall in Iowa was 4.65 inches but the average July temperature was only 69.7 degrees; and the August temperature averaged only 67.7 degrees.

The curves in Figure 5 indicate that average June temperature of around 70 to 72 degrees would be optimum, assuming average June rainfall. The curves also show that yields are quite adversely affected by high temperatures in August. In all three states, it appears that (with average rainfall) temperatures above 80 degrees are more damaging to corn in August than in July. The curves also indicate that weather can be too cool in August as well as too hot.

General Discussion of Weather

This study reaffirms the long recognized importance of July rainfall and July and August temperature in corn production all across the Corn Belt. The critical period of growth of corn in the Corn Belt is in late July and early August. Reports by Sayre (15) and Hanway (7) show that this is the period of maximum water requirement and maximum nutrient uptake.

Figure 7 is a schematic diagram which shows that July and early August are deficit rainfall periods in the production of corn. The curve for water requirement is based on the work of Shaw, Runkles and Barger (18). These authors estimate the total needs of water for corn in Iowa to be about 25 inches with a peak need of 6 inches in July. Their estimates include run-off and percolation losses as well as evapo-transpiration requirements. The curve in Figure 7 is an estimate of the actual needs of the crop.

The critical period of moisture stress in corn is at the time of silking. In Iowa, silking begins July 20 and is 75 percent complete by July 30, on the average. However, 75 percent of silking occurred as early as July 22 in 1939 and as late as August 12 in 1945. The first silks usually appear 60 to 70 days after planting (34).

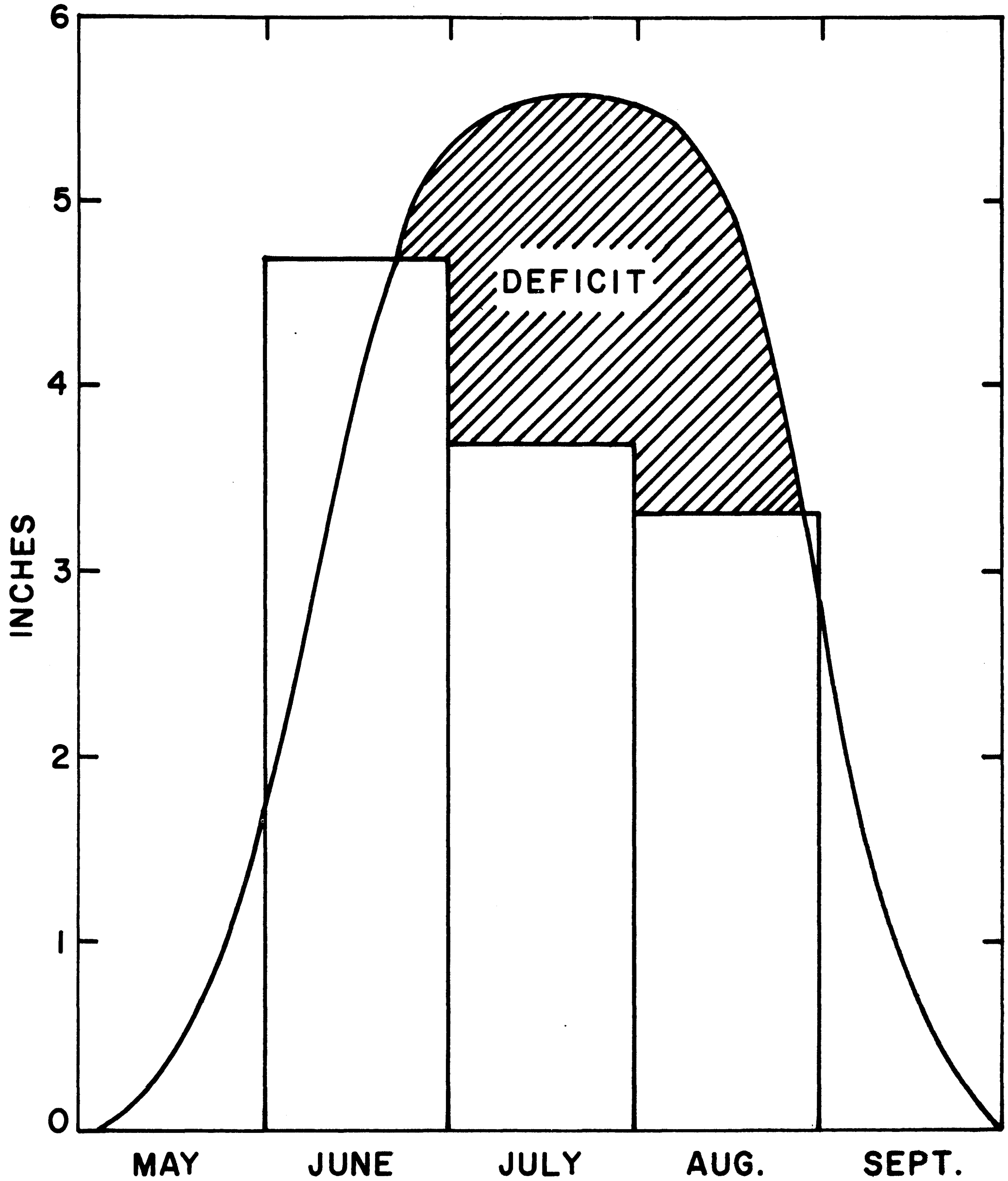

FIGURE 7. WATER REQUIREMENT CURVE FOR CORN IN RELATION TO SUMMER RAINFALL IN 5 CORN BELT STATES

Denmead and Shaw (3) studied the effects of moisture stress on corn; that is, allowing moisture to drop to the wilting point during three stages of growth: (a) vegetative (before silking), (b) silking, and (c) ear forming. Moisture stress during silking caused a yield reduction of 50 percent; moisture stress during the vegetative and ear-forming stages resulted in yield reductions of 25 to 21 percent, respectively.

Houseman (9) analyzed the relation of weather to yield of corn based on data from the station at Lincoln, Nebraska. He divided the growing season into five-day periods and used curvilinear regression techniques to study effects of rainfall and temperature. Cubic equations were used in the analysis to describe the curves for both rainfall and temperature effects on corn yields. The average value of an inch of rain in a five-day period increased from a low in May to a peak at the end of July. At the peak, an inch of rain in the five-day period increased the yield of corn about 5.6 bushels per acre.

Houseman's report showed that higher than average temperatures were favorable in May, unfavorable in July and particularly unfavorable in August. The greatest damage by high temperature occurred in late August rather than in early August, as one might expect. This study confirms Houseman's observation that high temperatures in August are more damaging than high temperatures in July.

The effects of July temperature are of little significance in accounting for yield variations in multiple regression analyses for Ohio and Indiana if July rainfall is included. However, July temperature and corn yields are significantly correlated if only two variables are analyzed. This is due to the intercorrelation of rainfall and temperature in July (as well as in other months). One may use either July rainfall or July temperature and find high correlation with corn yields; but starting with either variable and adding the second may cause little increase in correlation.

The average July temperature is slightly higher than the average August temperature in all five of the states. A possible explanation for the differences in effects of July and August temperature is that the warmer temperatures are desirable during the early part of July when corn is making its most rapid growth. High temperatures are undesirable during the latter part of August because they are associated with decreased storage of photosynthate. Miller (10) points out that high temperatures cause higher rates of respiration and less storage of sugar, starches and other products of photosynthesis. This is particularly true at the time the crop is producing seed.

As explained earlier, the July water requirement is so critical for corn that above average rainfall is extremely effective in raising the yield of corn. Analysis with only two variables, time and July rainfall, accounted for more variation than could be accounted for by any other combination of only two variables. As the lower percentage of variation was accounted for by reducing the number of variables, there was an increase in the size of the coefficient for time. If the only variable used in the regression analysis is time, the regression coefficient is larger and the percentage of yield variation accounted for is considerably smaller. In other words, a simple linear regression of yield on time gives an overestimate of the effect of technology on the trend in corn yields. This occurs because the general tendency has been for weather conditions to improve from 1930 to 1962.

Do Weather Cycles Exist?

During the early part of this century there was great interest in the weather cycle idea, particularly in the western part of the United States. Tree ring studies indicated the existence of alternate wet and dry periods, particularly in the subhumid and semiarid regions.

A popular notion now is that wide deviations from average weather tend to occur at random. It does appear that an unusually good year or an unusually poor year (with respect to weather for crops) may occur at any time, and evidence can be shown that wide deviations from average occur randomly. On the other hand, there is evidence that weather patterns change periodically.

The major periodic change in Iowa appears to be associated with summer temperatures. The favorable period since 1957 has been associated with cool summer weather rather than unusually high rainfall. This is generally true all across the Corn Belt.

Many studies dealing with correlation of annual rainfall and crop yields have been disappointing because of the time period selected for the weather data. It is illogical to use the calendar-year weather data for wheat or corn. The annual period for rainfall data for wheat should be from August through July of the next year in the United States. The annual period for rainfall in this study began in September of each year. To illustrate this idea, the Ames station in Iowa received 24.48 inches of rain in the calendar year of 1962. In this year of record corn yield, the rainfall from September, 1961, through August, 1962, was 35.35 inches at Ames.

The adoption of the annual rainfall period from August through July greatly improved the results in a wheat study reported by the author (25). It was observed that in North Dakota and South Dakota the "wheat weather" gradually improved from 1936 to 1942; then a downward trend occurred until the early fifties; thereafter an upward trend began. The time span of the wheat study was too short to draw any conclusions about weather cycles, but the changing weather patterns were very striking in the spring wheat states.

The weather cycle idea carries the connotation of regularity in alternation of favorable and unfavorable weather for crops. A more acceptable interpretation is that we do have periodic changes in weather patterns, but that they do not occur in any regular cyclical pattern.

A separate study was made of Iowa weather and corn yields from 1873 to 1962, a 90-year period. There was a group of years around 1922 that compared favorably with the trend in yield. One might suggest a 20-year cycle since there were two other groups of favorable years - around 1942 and 1962. However, there was no comparable group of years with high yields around 1882 or 1902. There were periods of high rainfall and cool summers around 1882 and 1902 even though yields were not high. However, the failure to obtain high yields may have been due to inadequate drainage, because it was around 1910 that much improvement was made in drainage systems in Iowa. The use of multiple regression equations developed for the period 1930-1962, and the use of 1902 weather data indicates that 1902 was more favorable for corn than any year in the 90-year period in Iowa. Yet the yield of corn in 1902 was only slightly above average for that period. The weather conditions of 1902 in Iowa would be near ideal in 1963 with our good drainage systems, mechanization, hybrid corn, and fertilizers.

Weakly (32) made extensive investigations of drouth periods in Nebraska by analyses of annual growth rings of trees. He concluded that drouth periods varied greatly in length as well as in distribution over time. The last four drouth periods recorded by tree ring growth in western Nebraska were: 1884-1895, 1906-1913, 1931-1940 and 1952-1957. These drouth periods are reflected also in a general way by corn and wheat yields in Nebraska and neighboring states.

With regard to tree ring growth and weather cycles in western Nebraska, Weakly (33) wrote the following in 1943:

"There is considerable irregularity in the length of period represented by the several climatic pulsations, so that the data are of little use in exact forecasting of probable climatic conditions. Their chief value lies in the fact that they show an alternation of wet and dry periods over a considerable extent of time, with no evidence that climate has changed greatly in the relatively recent past or is changing radically at present. In other words, droughts have occurred at more or less frequent intervals over the past 400 years and will in all probability continue to do so in the future. When these periods will occur and what will be their intensity or duration remain yet to be discovered."

In summary, the several studies completed recently confirm the long standing concept of changing weather patterns. These patterns result in periods of generally favorable weather, and periods of generally unfavorable weather. The changing weather patterns appear only slightly in Ohio, but become more obvious as one progresses westward to Iowa and Missouri and into the Great Plains states. Within a period of good weather or within a period of unfavorable weather, a very good year or a very poor year might occur at any time.

The Relation of Weather to the Feed Grain Surplus

The rapid rate of introduction of technology from 1950 to 1956 (primarily the increased use of fertilizers) was associated with favorable prices of corn (6). Even though 1953 was a relatively dry season, fertilizer consumption in 1954 was high because of the highly publicized advantage of fertilizers in the dry year of 1953. The year 1954 turned out to be a drouth year, particularly in the western part of the Corn Belt, and fertilizers were less effective than in 1953 because of the relatively dry subsoils at the beginning of the growing season.[6] The year 1955 was also unfavorable. During this period, when weather was relatively unfavorable, the rate of utilization of feed grains as livestock feed was somewhat retarded because of high price support for corn (around $1.50 per bushel) in relation to prices of livestock products.

As the support price for corn was reduced after 1955 there was a marked increase in the utilization of feed grains, but weather conditions improved steadily after 1955. The outcome was a relatively small addition to an already large carryover. Figure 8 shows this relationship.

The year 1958 was characterized by high rainfall in July with favorable summer temperature. All yield records were broken in the Corn Belt.

6/ See page 67 of reference no. (23) for an explanation of this phenomenon.

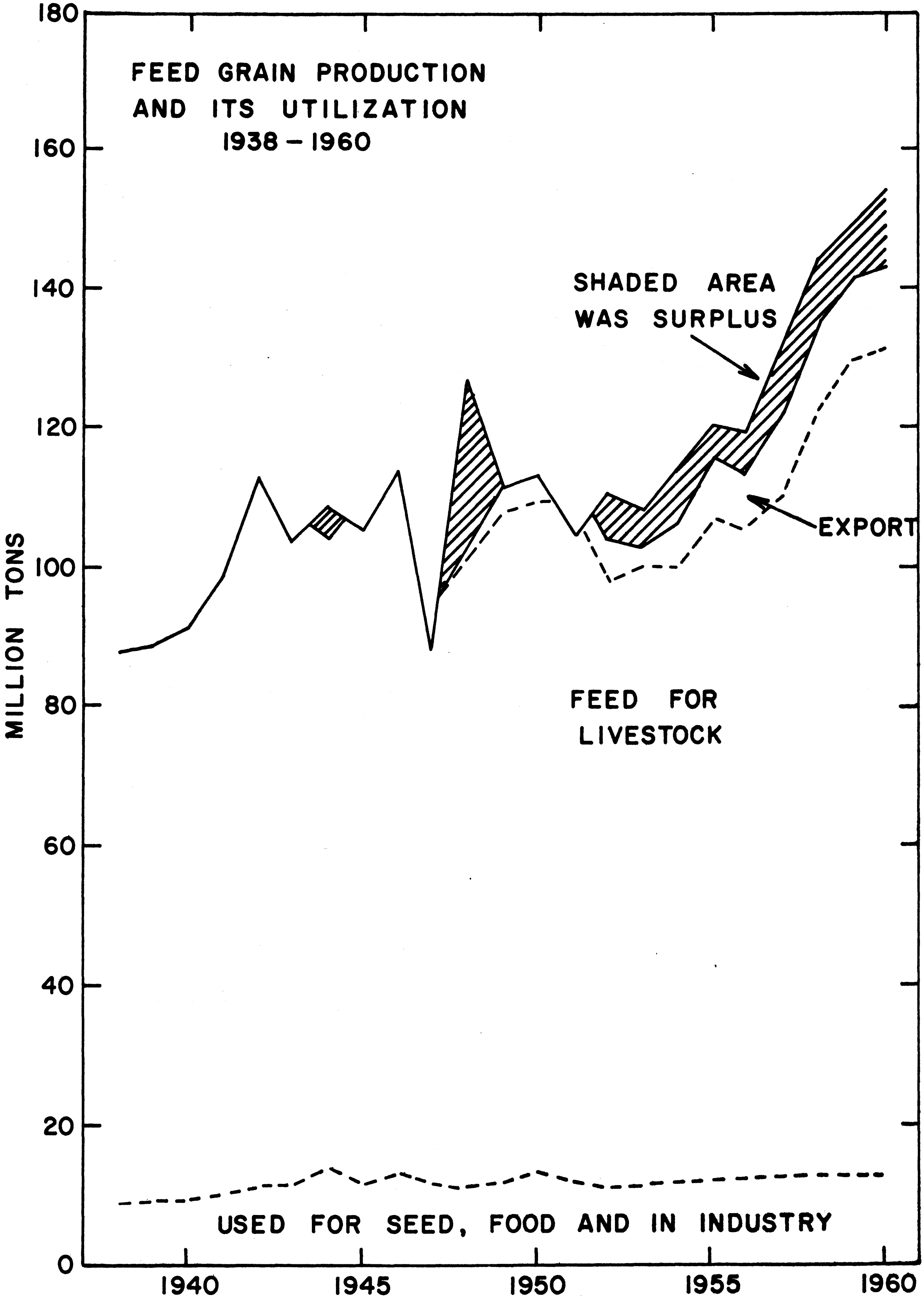

FIGURE 8. DATA FROM 1962 U.S.D.A. OUTLOOK CHARTS
BASED ON CROPS HARVESTED FOR GRAIN

The weather in 1959 and 1960 was not much better than average in terms of rainfall, but the summer temperatures were quite favorable. Another factor affecting the increased production of feed grains in 1959 and 1960 was the increase in acreage compared with 1958. But, had weather been just average and had trend yields been realized in the Corn Belt in 1958, 1959 and 1960, there would have been only about 92 percent as much corn as was actually produced. The difference in production due to favorable weather appears to be as much as was added to the surplus during the 1958-1960 period from these five states where half of the nation's corn is grown.

Thus, it appears that the continued build-up of the feed grain surplus after 1957 was associated with better than average weather. This concept is in contrast to the belief that an "explosion in technology" occurred in the decade of the 1950's. If one were to ignore weather and use simple regression as a measure of technology during the period from 1950 to 1960, he would obtain an average rate of increase of nearly twice that shown in this study. But to ignore weather in this period would be serious. The years 1950 and 1951 were cool-wet years with below average yields, and the years 1953, 1954 and 1955 were drouth years. The drouth years were followed by improved weather during the succeeding years. To extrapolate from a simple regression line drawn through yield data from 1950 to 1960 would require the assumption that weather will continue to improve at the same rate as from the early to the late fifties.

PART II

SOYBEANS

The yields of soybeans broke all previous records in 1961. Whereas there had never been a significant carry-over of soybeans, it appeared that a large carry-over might exist by the end of the 1962 crop year. It was generally believed that the trend in yield of the past 10 years would continue past 1962 and that supply management of soybeans might be necessary. There was considerable discussion in early 1962 of the need to control acreage of soybeans if corn acreage was also to be controlled.

A study was made of the relation of weather to soybean yields in the Corn Belt states for the period 1935 to 1961 (27). The results indicated that the amount of expected carry-over could be attributed to better than average weather in 1961.

Yields of soybeans were somewhat lower in 1962 than in 1961, and the total production declined even though there was an increase in total acreage. By November, 1962, the Secretary of Agriculture was advocating an effort to increase the reserves of soybeans.[7]

Importance of Soybeans

Soybeans were first grown as a commercial crop in the United States in the early 1920's. In 1924, for example, Iowa produced only about 10,000 acres of soybeans. By 1930, only 66,000 acres of soybeans were harvested in Iowa. But, by 1962 the soybean acreage in Iowa had grown to 3,405,000 acres. Other states experienced similar growth in soybean production. Illinois has been the leading state in soybean production, with 5,575,000 acres in 1962. The "Soybean Belt" is from Minnesota to Arkansas and from Iowa to Ohio. The five states included

7/ Speech made at the annual meeting of the Association of Land-Grant Colleges and Universities.

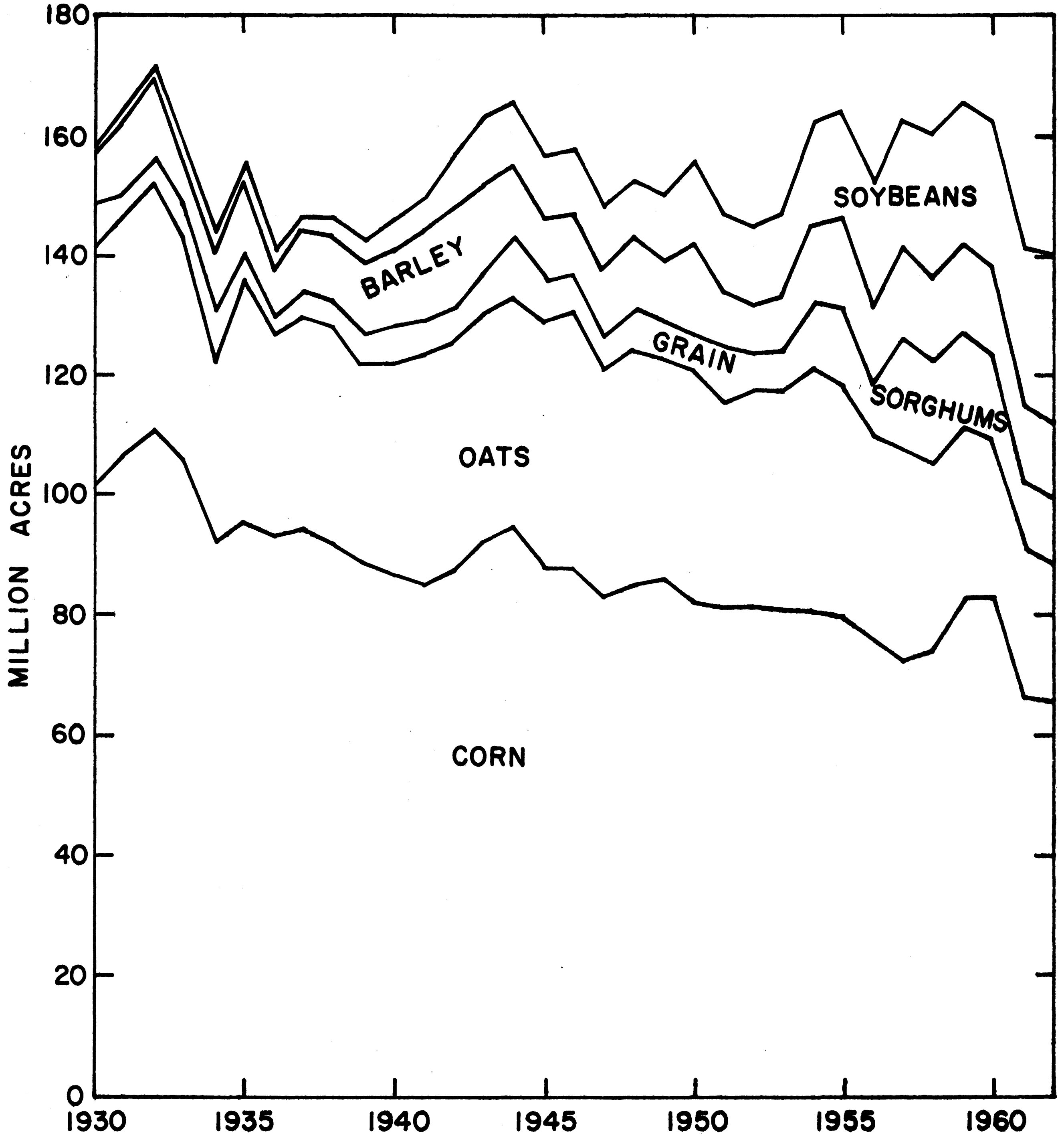

FIGURE 9. THE TREND IN ACREAGE HARVESTED OF SOYBEANS AND FEED GRAINS IN THE U.S.

in this study, Iowa Illinois, Indiana, Ohio and Missouri, produced 63 percent of the total production of soybeans in the United States in 1962.

In spite of the very rapid increase in soybean production since the 1920's new markets have been developed every year and carry-over has never been a problem. This crop has one of the most aggressive producers' associations behind it of any of the major crops. Not only have market outlets been stressed, but much emphasis has been placed on the quality of the product.

Soybeans really came into prominence in 1934 with the development of production controls for corn. Soybeans became an important alternative to corn as a cash crop in the Corn Belt.

To a very great extent soybeans have become a feed grain crop. During the period since 1940 nearly all of the increase in high protein feed concentrate utilized in the United States has been from soybean meal. By combining the acreage of soybeans and feed grains harvested in the United States one finds a nearly level trend in acreage of these crops from 1930 to 1960. While there was a downward trend in corn and oat acreage, there was a compensating trend upward in soybean acreage. Figure 9 shows about the same acreage of soybeans and feed grains in 1959 as in 1944, which was a peak year during World War II. This is not generally recognized, and the popular concept is that the United States is now using considerably less land for growing crops for feed concentrates than during World War II. This is true if one looks only at feed grain acreage. Furthermore, if the feed grain acreage is examined only from the standpoint of acres contributing to human food, there has been an increase since 1930 because of the reduction in the acreage producing feed grains for horses and mules.

The sharp drop in total acreage of soybeans and feed grains from 1960 to 1961 was due to the emergency feed grain program. Figure 9 does not show this very clearly, but the acreage of soybeans was greater in 1961 and 1962 than in 1959.

Results of Linear Analysis

Table 3 shows the linear regression coefficients for the nine variables used in the study. It is very striking to see the dominating influence of July and August rainfall. For example, in Illinois an inch of rainfall above average in July would be expected to increase yields by .92 of a bushel per acre. An inch of rainfall above average in August would be expected to increase yields of soybeans by .70 of a bushel. All of the five states show that additional rainfall above average in July and August caused increased yields.

Soybeans appear to respond favorably to higher than average June temperature in Iowa, Indiana and Ohio. Average June temperature is near optimum in Missouri and Illinois.

July temperature is warmer than optimum in Illinois and Missouri. In Ohio, Indiana and Iowa it appears that the optimum temperature for July would be above average. The curvilinear analysis shows that optimum July temperature is only slightly above average, however, in Ohio, Iowa and Indiana.

Table 3. Linear Regression Coefficients for Nine Variables and Their Effect on Soybean Yields in Five States.[8]

	Bushels Per Acre Per Year								
States	Years	Pre. Precip.	May Temp.	June Rain	June Temp.	July Rain	July Temp.	August Rain	August Temp.
Illinois	.23	-.01	.22	.08	-.11	.92	-.10	.70	-.13
Indiana	.35	.04	-.06	.20	.12	.78	.08	.46	-.16
Iowa	.37	.17	-.18	-.21	.07	.18	.19	.32	-.33
Missouri	.44	.06	.08	-.02	.01	.74	-.17	.42	-.40
Ohio	.30	-.02	-.08	.03	.11	1.17	.29	.29	-.01

8/ The Correlation Coefficients are: Illinois .93, Indiana .95, Iowa .90, Missouri .97, Ohio .92. The F values for analysis of variance are: Illinois 17.7, Indiana 26.4, Iowa 11.2, Missouri 39.8, Ohio 14.8.

Soybeans are planted early enough in Missouri and Illinois for May temperature to show some correlation with yield. Higher than average May temperatures are desirable in these states.

Although July temperature is usually higher than August temperature, it appears that higher than average August temperature is consistently more damaging to soybeans than higher than average July temperature in the five states. This relationship appears to hold for corn also. This is the period of seed filling, when high temperatures increase the rate of respiration and decrease the rate of storage of photosynthate.

Preseason precipitation appears to vary greatly in its effect between states. This is because of the curvilinear relation of preseason precipitation to soybean yield. The curve is such that in Ohio and Illinois the average rainfall is past the optimum point on the curve. In Indiana and Missouri the average preseason rainfall is about optimum and the linear coefficient is near zero. It appears that higher than average preseason precipitation would be desirable for soybeans in Iowa.

Results of Multiple Curvilinear Regression Analysis

Table 4 shows the regression coefficients and the "a" values for all variables included in the analysis. By use of weather data for any year of the study, or of the near future, one may calculate the yield for any of the five states. A method for calculating corn yield is shown on page 55. The same procedure is used for calculating yields of soybeans.

In order to show interaction between rainfall and temperature for any month in the equation it is necessary to retain some variables with coefficients that have large standard errors. The combinations that are most significant are, in the order, July, August and June. If one were to drop a combination, the June variables would be dropped. They were all retained in this study since the analysis of variance showed significance at the 99 percent level of probability or higher in all

Table 4. Constants (a values) and Multiple Regression Coefficients (b values) For Years and Weather Variables and Their Relation to Soybean Yields in Five States*

	Illinois	Indiana	Iowa	Missouri	Ohio
	Constants (a values)				
	- 149.66	- 759.61	- 584.16	- 45.27	- 346.18
	Regression Coefficients (b values)				
X_1	.1538	.3816	.3627	.4417	.3230
X_2	1.5485	.3870	1.9893	.3959	.5801
X_2^2	- .0303	- .0055	- .0462	- .0057	- .0089
X_4	-10.8952	- 4.0647	3.7090	-35.3622	-14.3448
X_4^2	- .0076	- .1794	- .0451	.3441	.1977
X_5	- 1.2985	4.8562	8.2147	- 7.3988	4.1331
X_5^2	.0049	- .0367	- .0568	.0381	- .0338
X_6	6.5067	31.9620	-17.8741	- 6.1286	11.6185
X_6^2	- .2086	- .2145	.5497	.0607	- .2414
X_7	-14.0420	3.1956	16.7425	- 6.3104	- 4.2850
X_7^2	.0892	- .0117	- .1121	.0380	.0337
X_8	32.6563	4.9427	-16.6925	9.1412	17.0282
X_8^2	- .4250	.3913	.1056	.1969	.1411
X_9	18.8386	11.1005	- 7.8983	16.7916	9.2816
X_9^2	- .1163	- .0726	.0452	- .1078	- .0606
X_4X_5	.1497	.0848	- .0522	.4335	.1834
X_6X_7	- .0499	- .3938	.1888	.0815	- .1160
X_8X_9	- .3876	- .0870	.2221	- .1324	- .2332

The F values for Analysis of Variance: Illinois 13.7, Indiana 20.4, Iowa 21.1, Missouri 27.1, Ohio 13.7

X_1 = years, X_2 = Preseason precipitation, X_4 = June Rain, X_5 = June Temperature, X_6 = July Rain, X_7 = July Temperature, X_8 = August Rain, X_9 = August Temperature

The degrees of freedom for total, regression and residual, respectively, are 32, 18 and 14. An F value of 3.58 would be significant at the 99% level of probability (20).

states.

Quadratic equations were used for rainfall and temperature variables. Linear equations were used for the time trend. Two time periods were considered: 1930-1945 and 1946-1962. The latter period represents the primary influence of fertilizers. Crop improvement has been important throughout the period of study. Land selection has been more important in the latter period because soybeans have become more competitive with corn for better land. Management skills have been more influential in the latter period. One would expect a higher trend in the second period. The coefficient for the second period was only slightly greater, however, than for the first period for all states except Missouri, where the two coefficients were the same. However, the correlation was not improved by using two time periods for any of the states. The data reported are for one linear time trend from 1930 to 1962.

Figures 10, 11 and 12 show the results of the curvilinear regression analyses. The trend for technology is shown by a broken line. The solid line connects points for calculated yields based on weather and technology. The dotted line shows the actual reported yields.

The trend yield stands at about 25 bushels for Illinois and near 26 for Iowa, Indiana and Ohio in 1962. The 1962 trend yield for Missouri is between 22 and 23 bushels in 1962.

The 1961 yields were well above the trend line in all five of the states. The yield fell off in 1962 in Missouri and Ohio because of drouth in August.

The greatest fluctuation in soybean yields occurs in Missouri. The fluctuation decreases in the direction of Indiana and Ohio. The "patterns" developed by the weather-technology lines are somewhat similar between Illinois and Missouri, and between the adjacent states of Ohio and Indiana.

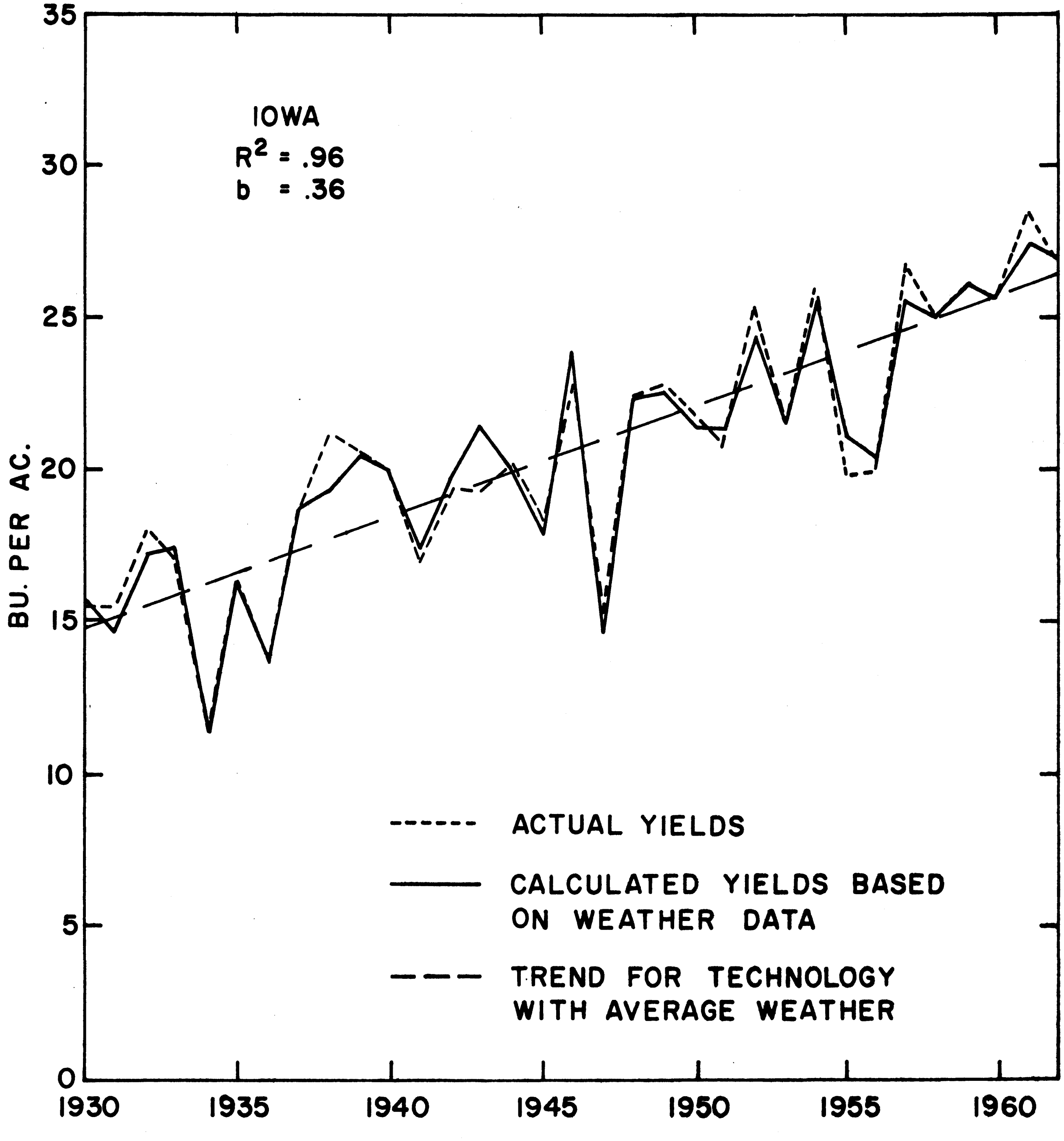

FIGURE 10. THE RELATION OF WEATHER AND TECHNOLOGY TO THE TREND IN YIELD OF SOYBEANS

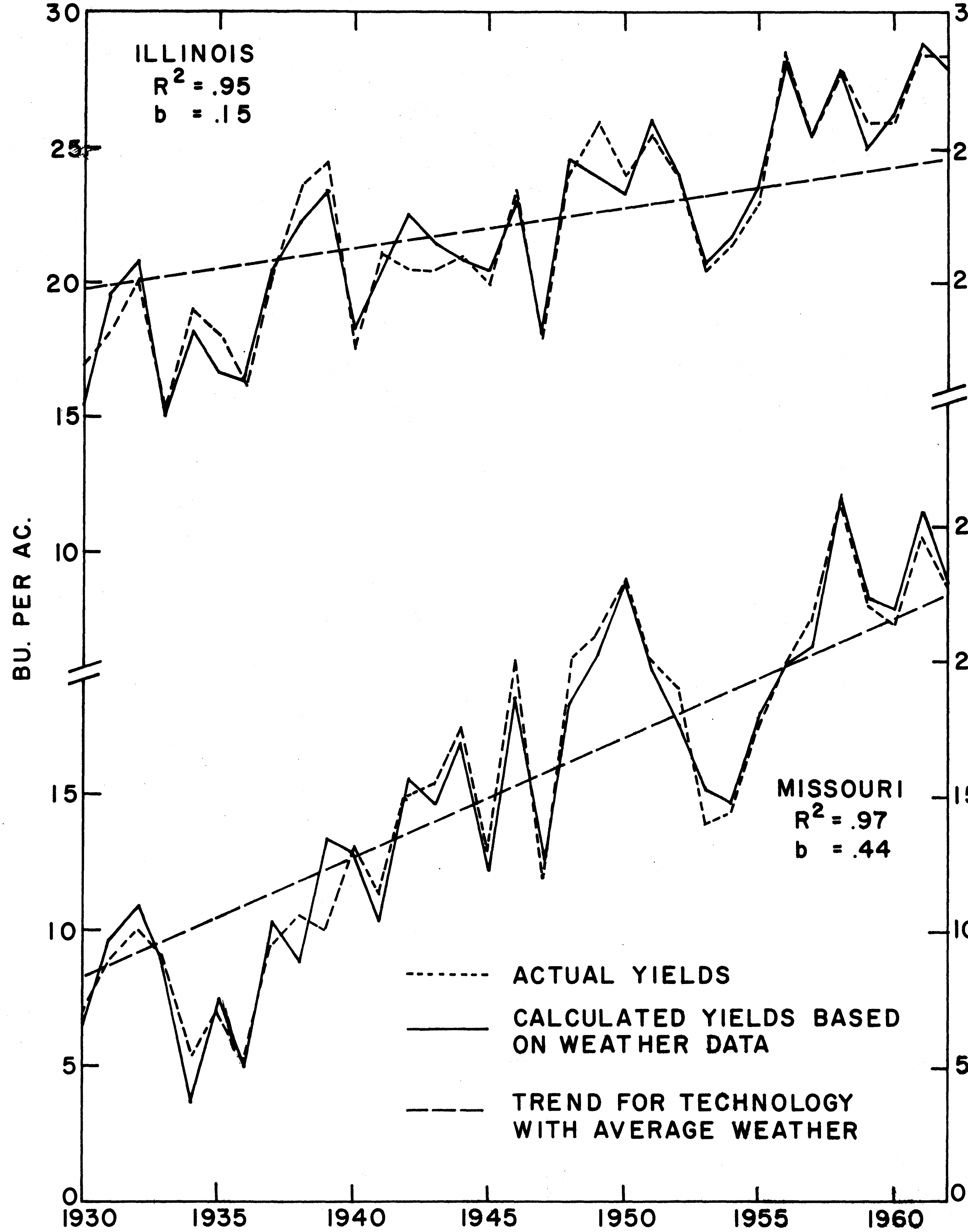

FIGURE 11. THE RELATION OF WEATHER AND TECHNOLOGY TO THE TREND IN YIELD OF SOYBEANS

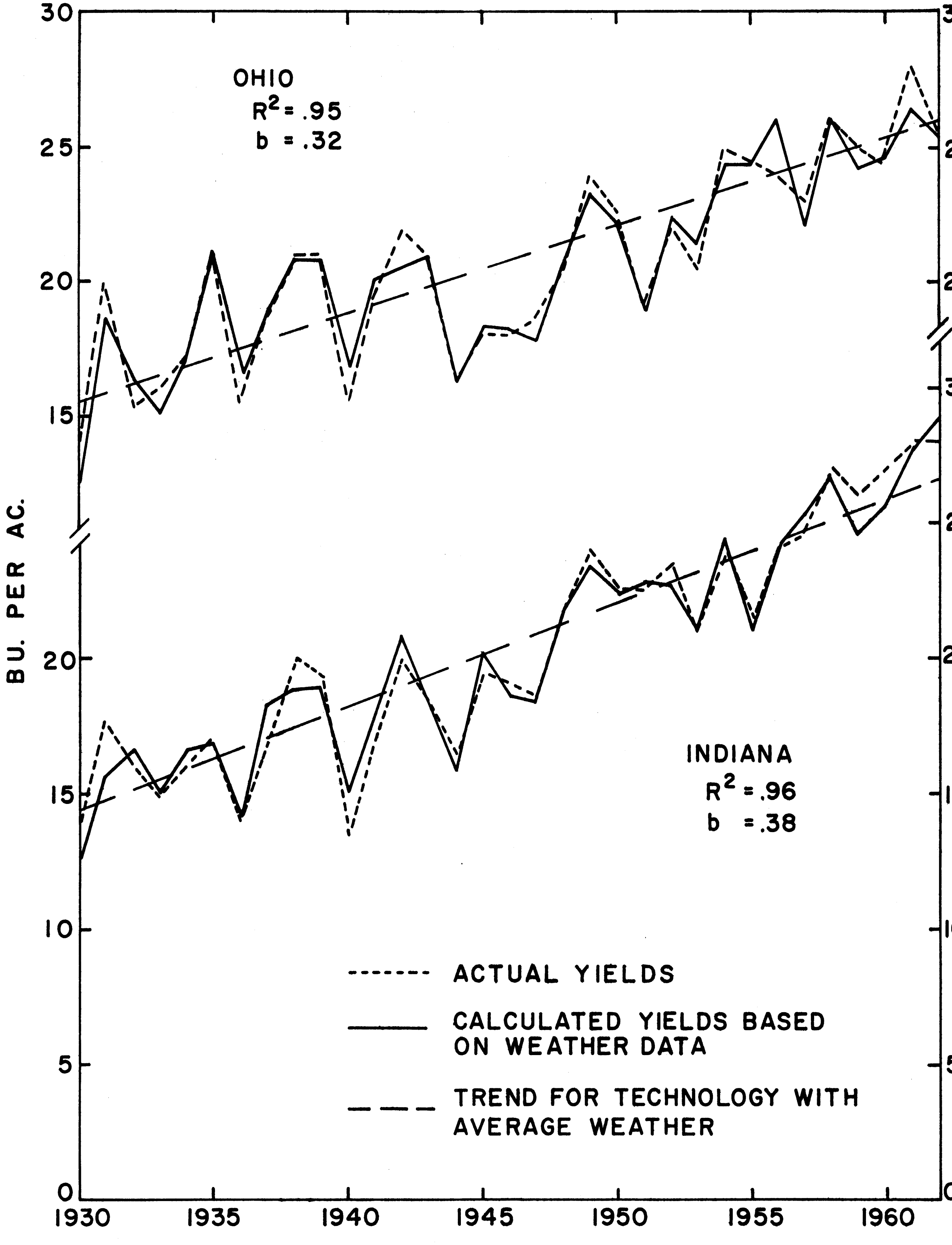

FIGURE 12. THE RELATION OF WEATHER AND TECHNOLOGY TO THE TREND IN YIELD OF SOYBEANS.

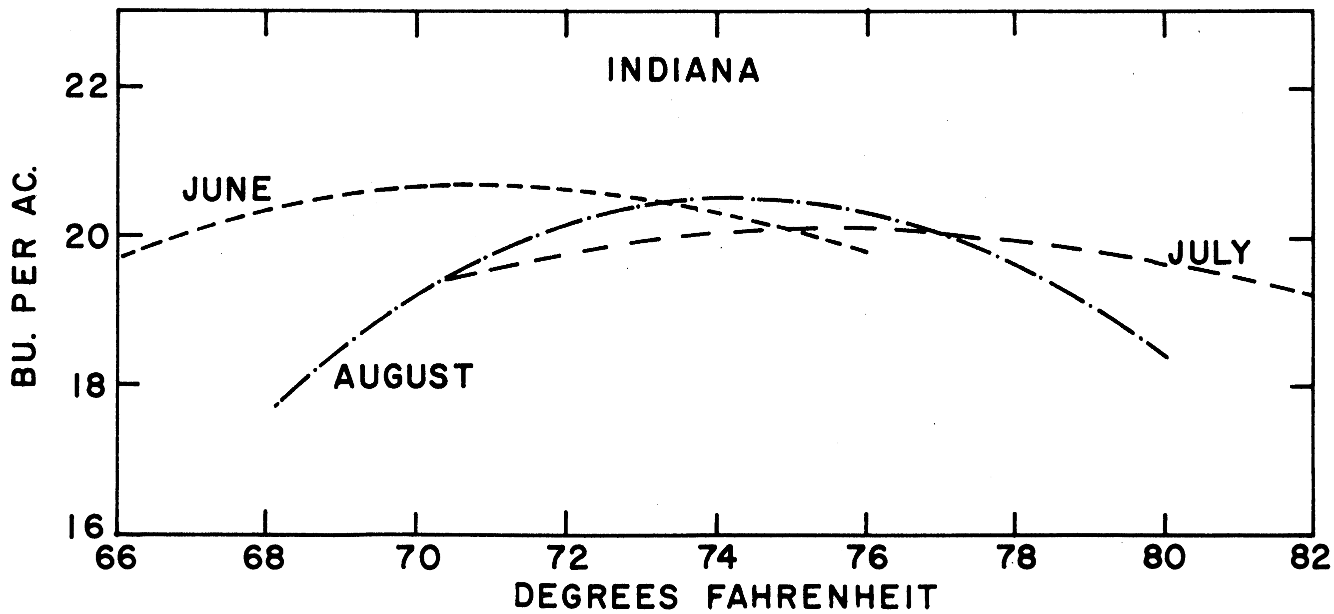

FIGURE 13. THE RELATION OF SOYBEAN YIELDS TO MONTHLY TEMPERATURES

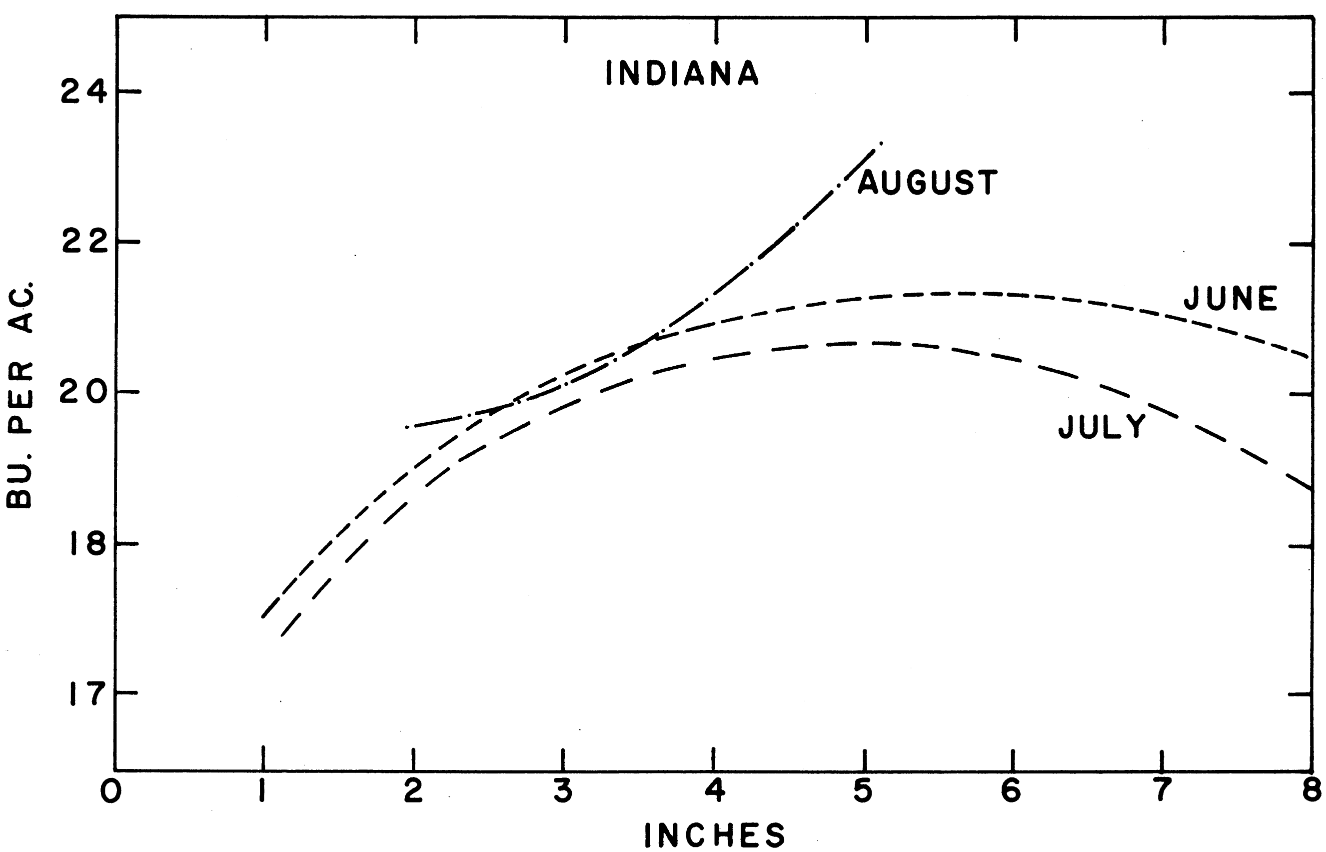

FIGURE 14. THE RELATION OF SOYBEAN YIELDS TO MONTHLY RAINFALL

Optimum Monthly Rainfall and Temperature Averages

By use of the regression coefficients one may calculate the curves for rainfall or temperature. Figure 13 shows the temperature curves for June, July and August with average rainfall in Indiana. Figure 14 shows the rainfall curves for June, July and August in Indiana with average temperature.

The results of this study indicate a close relationship between corn and soybeans in their temperature preferences. This helps to explain why the boundaries of the Corn Belt are similar to the boundaries that appear to be developing for the "Soybean Belt." The optimum average monthly temperatures for June, July and August appear to be about 72, 76 and 74, respectively, for varieties grown in Indiana. The rainfall in August in Indiana varies between 2 and 5 inches. The curve in Figure 14 shows a steep trend upward for August rainfall with highest yields at the maximum rainfall of 5 inches. It appears that too much rain sometimes occurs in June and July.

Soybean varieties have been developed for different latitudes from Arkansas to Minnesota in terms of response to temperature, day length and length of growing season. But, it would appear that over a period of years, soybeans, as a whole, are better adapted to regions where the average monthly temperatures are also most favorable for corn. Weather can be too cool in the Corn Belt for soybeans, just as for corn. The curves in Figure 13 indicate that weather may be too cool in any month of the growing season in Indiana.

Discussion Of Weather Variables

Weather variables are just as important in explaining yield variations in soybeans as for corn. In general, weather favorable to corn is also favorable to soybeans. There are distinguishable differences in weather preferences, however, and additional research is needed. Rainfall during August appears to be relatively more important for soybeans than for corn. The studies of Runge and Odell (13) at Urbana, Illinois, indicate that soybeans tend to have two peaks of moisture requirement. One is in mid-July when the vegetative growth is most rapid and blooming begins, and the other is in the latter part of August when seeds are filling out. Hard rains around the first of August are probably associated with shedding of young pods.

Soybean yields are related to the number of flowers produced, the number of pods that mature, and the size of the seed. Weather conditions that might cause shedding of flowers or young pods are extremely important in soybean yields. Probst and van Schaik (29, 30) in Indiana have observed that high temperatures are associated with shedding, and that varieties vary in their response to conditions that cause shedding.

It appears that subsoil moisture is relatively more important for corn than for soybeans, although it is important for soybeans. Corn is a deeper rooted plant. If adequately supplied with plant nutrients, corn will keep growing and yield fairly well with a dry August, provided subsoil moisture is adequate and the temperature remains favorable (23). Soybeans, being less deep rooted, depend more on summer rainfall than corn, particularly in August. This is only an hypothesis, but August rainfall may be closely related to the nitrogen supply for soybeans. Whereas corn will take up a large amount of nitrogen in July and maintain a "reserve" in the plant that can be translocated to the ear, soybeans take up the nitrogen as needed or cause it to be "fixed." If the soybean plant takes up a large amount of nitrogen from the soil, little fixation occurs. In soybean production little nitrogen fertilizer is ordinarily used. The plant depends on fixed nitrogen and that released by organic matter decomposition in the soil. Organic matter decomposition and release of nitrogen during August requires periodic "soaking" rains throughout the month. If August turns dry, soybean growth is limited by lack of nitrogen as well as lack of moisture in the surface soil where a high percent of the roots are growing. A large amount of nitrogen is utilized by soybeans in filling out the seeds in the latter part of August.

Discussion of the Technology Trend

Illinois became the leading soybean producing state rather early. The yields of soybeans were higher in this state compared to the other states in the Corn Belt; consequently the slope of the trend line is not as steep for Illinois as for the other states. On the other hand, the trend yield for 1962 is similar in Illinois, Iowa, Indiana and Ohio. In other words, the three other comparable states have made enough adjustments and changes to catch up with Illinois. It would be inadvisable to extrapolate the trend lines ahead very many years and assume that Illinois will drop behind. The more likely situation will be parallel trends in yields for these four comparable states.

Runge and Odell (13) reported that nearly all of the increase in yield of soybeans at the Agronomy South Farm at Urbana, Illinois, could be accounted for by changes in varieties. Plant breeding has been a very important factor in the increase in yields of soybeans throughout the period from 1930 to 1962 in all states.

Land selection has been an important factor in soybean production. Whereas soybeans were once grown on land less desirable for corn, the trend is to plant soybeans on the best land. Soybeans have become quite competitive with corn, and corn-soybean rotations have become quite popular across the Corn Belt.

Where soybeans are grown in rotation with corn the usual practice is to apply all the fertilizer to the corn and allow the soybeans to gain from the residual effects of the fertilizer. Much of the increase in yield of soybeans since 1945 can be attributed to the general rise in fertility of Corn Belt soils resulting from the continued use of commercial fertilizer.

Soybeans do not generally respond profitably to direct applications of nitrogen fertilizers. If soluble nitrogen is available it is used from the soil, and the amount fixed from the air by "nodule bacteria" is slight. On the other hand, if the soil is deficient in nitrogen, the bacteria in the nodules tend to fix nitrogen, provided the other nutrients are available in sufficient amounts. For this reason, if soybeans are fertilized it is usually only with phosphorus and potassium.

Soybeans have a very large nitrogen requirement and the amount provided by the nodule bacteria is not sufficient for high yields. Some supplemental nitrogen is needed and this appears to be best if derived from decomposing organic matter gradually throughout the growing season. Perhaps the recent high yields of soybeans resulted from the interaction of frequent summer rains on soils with considerable decomposable organic matter, along with favorable temperatures. The accumulation of decomposable organic matter can be attributed in part to the greater use of nitrogen on corn and the return of the residues to the soil.

There is no reason to believe that the linear trend in yield of soybeans will not continue for another ten years or longer, assuming of course that fertilizer utilization continues to increase in a linear fashion. The real handicap to high yields of soybeans at the present time is associated with the nitrogen problem in soil management. When this problem is solved, we should see a steeper increase in yield of soybeans for a few years.

SUMMARY

Multiple regression analyses were made of corn and soybean yields in five Corn Belt states for the period 1930 to 1962. Variables included were: years for technology, preseason precipitation (from September to May inclusive), May temperature, June rainfall, June temperature, July rainfall, July temperature, August rainfall and August temperature. The technology trend was found to be generally linear. The weather variables are related to yield in a curvilinear fashion, and quadratic equations were used. Interactions between rainfall and temperature were included for each summer month.

The correlation coefficients in all multiple curvilinear regression analyses reported were .97 or higher. All analyses of variance showed significance greater than the 99 percent level of probability.

Weather was relatively unfavorable for corn from 1950 to 1955 (except in 1952) but was relatively favorable for corn from 1957 to 1962. Weather was too wet and cool in 1950 and 1951 but turned hot and dry in the mid-fifties. Weather has been associated with accumulation of feed grain surpluses since 1957.

The most significant weather variables in the production of corn and soybeans are July rainfall and August temperature. Higher than average rainfall in July is desirable, and lower than average August temperature is desirable. August rainfall is often more of a limiting factor in soybean production than in corn production.

The year 1961 was unusually favorable for soybean production and was enough above average to account for the 1962 carry-over of soybeans.

Corn yields climbed at an average rate of .81, .86, .70, .70, and .95 bushels per acre for Illinois, Indiana, Iowa, Missouri and Ohio, respectively, from 1930 to 1962.

Soybean yields climbed at an average rate of .15, .38, .36, .44, and .32

bushels per acre for Illinois, Indiana, Iowa, Missouri and Ohio, respectively, from 1930 to 1962.

Some evidence of changing weather patterns has been provided. The periodic changes are more evident in the western part of the Corn Belt. There was a period of unfavorable weather prior to 1937. A period of generally favorable weather occurred from 1937 to 1946 and after 1957 in the western part of the Corn Belt.

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APPENDIX

Methods of Calculation:

TREND YIELD OF CORN IN IOWA IN 1962

$$Y = \bar{y} + b_1(X_1 - \bar{x}_1) + b_2(X_2 - \bar{x}_2) + \text{etc.}$$

$X = 33$, $\quad Y = 50 + .7045(33-17) = 61.27$

The assumption is that there are no deviations from the mean of each weather variable, therefore $b_2(X_2 - \bar{x}_2) = 0$, etc.

CALCULATED 1962 CORN YIELDS IN IOWA

Constant = -3223.10

X_1	.7045	33.00	23.25
X_2	3.7065	26.61	98.63
X_2^2	- .0773	708.10	- 54.74
X_4	-18.3570	3.12	- 57.27
X_4^2	.5067	9.73	4.93
X_5	48.0467	69.10	3320.03
X_5^2	- .3464	4774.80	-1653.99
X_6	-81.4565	6.27	- 510.73
X_6^2	1.6797	39.31	66.03
X_7	25.0782	71.60	1795.60
X_7^2	- .1851	5126.60	- 948.93
X_8	- 8.7055	4.31	- 37.52
X_8^2	- .3593	18.58	- 6.68
X_9	22.7112	72.50	1646.56
X_9^2	- .1697	5256.30	- 891.99
X_4X_5	.1597	215.60	34.43
X_6X_7	.9431	448.90	423.36
X_8X_9	.1598	312.50	49.94
		1962 Yield =	77.81

Illinois

X_1 Year	X_2 Pre-Season Precip.	X_3 May Temp.	X_4 June Rain	X_5 June Temp.	X_6 July Rain	X_7 July Temp.	X_8 August Rain	X_9 August Temp.	Corn Yield	Soy Bean Yield
(1930) 1	23.26	64.3	3.36	71.9	1.01	79.1	1.97	76.4	26.5	17.0
2	20.26	59.6	3.19	75.5	2.97	79.3	3.90	74.5	37.0	18.0
3	27.17	64.3	4.08	74.0	3.32	77.6	5.53	74.9	43.0	20.0
4	32.27	64.6	1.48	78.2	2.41	78.1	2.67	73.7	27.0	15.0
5	15.93	68.2	3.01	79.0	3.24	81.7	3.82	75.5	21.5	19.0
6	34.66	57.7	5.99	68.2	3.33	79.0	2.59	75.7	38.5	18.0
7	20.59	67.4	1.66	72.8	1.22	83.5	2.66	81.0	24.0	16.0
8	31.99	63.8	5.07	71.7	3.18	75.7	2.39	78.1	48.0	20.0
9	29.25	63.0	5.23	70.6	4.74	77.1	3.33	77.7	45.0	23.5
10	25.67	66.2	5.13	73.6	3.37	76.7	4.78	73.5	52.0	24.5
11	17.76	60.0	2.92	73.2	1.53	76.9	4.01	75.2	43.0	17.5
12	19.00	67.0	4.34	73.4	2.75	77.0	2.74	76.5	53.0	21.0
13	32.97	63.0	5.44	72.4	4.89	76.8	3.53	73.4	54.0	20.5
14	30.33	61.6	3.84	75.1	3.00	77.5	2.97	77.0	50.0	20.5
15	25.52	67.8	2.42	76.0	1.83	76.2	3.80	75.5	45.0	21.0
16	28.24	58.2	6.65	68.4	1.46	73.8	3.47	74.2	46.5	20.0
17	29.06	59.9	4.40	72.3	2.41	76.3	5.97	70.7	57.0	23.5
18	27.78	59.4	6.31	69.8	1.86	73.0	2.20	81.9	39.5	18.0
19	25.88	60.9	3.93	71.8	5.45	75.5	1.74	74.9	61.0	24.0
20	27.38	65.1	4.19	74.7	4.40	78.6	2.90	74.6	56.0	26.0
21	34.40	64.5	5.63	71.2	3.98	72.9	3.63	70.4	51.0	24.0
22	25.43	64.7	6.17	69.7	4.63	74.8	3.71	73.0	55.0	25.5
23	27.61	62.6	4.64	77.8	3.44	78.1	2.97	73.7	58.0	24.0
24	21.64	64.0	3.42	77.1	3.67	77.4	1.12	75.5	54.0	20.5
25	18.71	59.0	3.56	76.3	2.79	79.3	5.04	75.4	50.5	21.5
26	26.20	65.2	3.86	68.6	3.41	80.5	2.56	77.5	56.0	23.0
27	23.31	65.0	2.63	74.0	4.76	74.9	3.82	75.2	68.0	28.5
28	26.69	62.7	6.47	72.5	4.33	77.1	2.91	74.7	64.0	25.5
29	22.64	63.7	6.16	68.2	8.12	73.9	3.33	74.7	69.0	28.0
30	24.19	67.4	1.56	73.7	3.31	75.2	4.29	78.0	67.0	26.0
31	28.08	60.3	5.59	70.4	2.98	73.9	2.92	75.4	68.0	26.0
32	23.69	58.7	3.28	70.8	5.80	75.0	3.16	73.8	77.0	28.5
(1962) 33	31.09	70.2	3.38	72.5	4.89	73.8	2.51	74.1	83.0	28.5
Averages: 17	26.02	63.3	4.21	72.9	3.47	76.9	3.30	75.3	51.2	22.2

Indiana

X_1 Year	X_2 Pre-Season Precip.	X_3 May Temp.	X_4 June Rain	X_5 June Temp.	X_6 July Rain	X_7 July Temp.	X_8 August Rain	X_9 August Temp.	Corn Yield	Soy Bean Yield
(1930) 1	28.54	63.6	2.60	71.0	1.78	77.4	2.07	74.4	27.5	14.0
2	19.81	59.3	3.61	73.9	3.08	78.4	4.38	73.8	39.0	17.8
3	29.74	62.8	4.64	72.9	3.48	76.4	3.67	74.0	37.5	16.0
4	40.15	65.0	1.16	77.2	2.56	77.0	2.79	72.8	29.5	15.0
5	19.10	66.4	3.55	77.5	2.42	80.6	4.68	74.2	27.0	16.0
6	29.36	57.9	4.75	68.2	3.57	78.0	3.12	75.2	38.0	17.0
7	21.59	65.8	1.37	71.8	1.59	81.4	3.04	79.4	25.5	14.0
8	37.46	62.7	4.56	71.0	3.67	74.6	3.56	76.4	45.0	17.0
9	31.46	62.6	5.22	69.8	5.25	75.6	3.21	76.2	41.0	20.0
10	28.07	65.2	6.12	73.6	4.19	75.2	2.65	73.8	51.5	19.5
11	22.17	59.0	3.10	72.2	1.49	75.9	2.74	75.5	37.0	13.5
12	17.63	65.4	5.64	72.4	2.54	76.4	2.33	74.8	45.0	17.0
13	30.05	63.5	5.55	72.3	4.03	76.2	3.71	73.0	54.0	20.0
14	30.96	62.4	3.58	75.6	4.22	76.3	2.51	75.4	49.0	18.5
15	26.29	68.0	1.80	75.6	1.68	76.2	4.01	75.2	38.0	16.5
16	29.45	57.6	6.65	68.2	3.44	73.2	3.60	73.0	53.0	19.5
17	30.08	60.0	4.12	71.3	2.62	75.1	3.31	69.6	51.0	19.0
18	29.18	59.0	5.21	69.0	3.12	71.2	3.44	79.8	43.0	18.5
19	26.53	60.7	4.37	71.8	4.48	74.9	1.95	73.6	60.0	22.0
20	34.44	63.6	5.36	74.7	3.50	78.4	3.66	73.8	52.0	24.0
21	39.93	63.5	5.76	69.6	3.78	72.1	3.47	70.5	48.5	22.5
22	31.38	63.7	4.63	70.0	3.89	74.1	2.60	72.1	53.0	22.5
23	32.72	61.2	4.84	76.2	2.49	77.3	2.92	72.8	50.0	23.5
24	25.89	64.2	2.72	75.3	4.40	75.8	2.06	74.3	51.5	21.0
25	20.37	57.5	2.91	74.7	3.24	76.9	4.93	73.7	55.5	24.0
26	29.09	63.8	3.28	67.2	4.80	79.2	2.68	76.5	56.0	21.5
27	31.50	62.5	3.25	72.3	3.49	73.7	2.93	73.2	62.0	24.0
28	26.92	62.1	7.09	71.7	4.19	75.0	2.81	72.8	59.0	24.5
29	26.71	61.1	8.08	66.8	8.07	73.4	4.42	72.2	63.0	27.0
30	28.82	66.2	2.46	71.9	4.04	74.2	3.07	77.0	62.0	26.0
31	27.12	59.1	6.05	69.1	3.38	72.2	3.13	74.3	68.0	27.0
32	26.93	57.2	4.19	68.8	4.66	73.8	3.20	72.4	74.0	28.0
(1962) 33	27.35	68.6	3.04	71.4	5.58	72.6	3.15	72.6	82.0	28.0
Averages: 17	28.39	62.5	4.28	71.8	3.60	75.7	3.21	74.2	49.3	20.4

Iowa

X_1 Year	X_2 Pre-Season Precip.	X_3 May Temp.	X_4 June Rain	X_5 June Temp.	X_6 July Rain	X_7 July Temp.	X_8 August Rain	X_9 August Temp.	Corn Yield	Soy Bean Yield
(1930) 1	17.75	60.2	5.83	69.0	1.49	77.9	2.42	74.4	34.0	15.5
2	14.76	57.5	3.83	75.0	2.72	77.2	3.30	72.6	32.9	15.5
3	27.99	62.3	5.17	72.0	3.12	75.8	7.10	72.2	43.0	18.0
4	16.76	60.5	1.64	77.8	3.45	76.1	3.01	70.5	40.0	17.0
5	11.36	69.5	3.49	77.2	3.85	79.7	2.84	73.4	23.0	11.5
6	22.71	55.0	7.00	65.9	3.35	79.4	2.42	73.6	38.4	16.3
7	17.91	66.2	2.85	70.1	.51	83.4	3.48	79.2	20.0	13.8
8	23.31	61.8	3.80	69.0	2.63	75.9	3.99	77.8	44.6	18.5
9	18.53	59.5	4.67	69.2	4.24	76.5	3.82	75.7	46.3	21.1
10	18.56	66.4	5.32	71.4	3.15	76.2	4.72	70.7	52.2	20.6
11	12.45	58.4	3.56	71.3	4.57	76.7	6.44	70.7	52.3	19.9
12	16.05	66.0	6.20	70.0	2.24	75.1	1.94	75.1	51.0	16.9
13	27.10	59.3	5.93	69.7	4.89	74.3	3.17	72.2	59.9	19.3
14	19.05	57.5	6.16	71.6	4.56	75.4	5.07	74.0	54.7	19.2
15	20.79	64.6	5.88	71.7	3.73	72.6	5.88	71.8	52.0	20.1
16	21.88	55.1	4.70	64.1	2.96	72.1	3.43	72.5	43.5	18.2
17	20.02	56.5	6.41	69.8	2.45	73.8	3.56	68.9	56.7	22.8
18	23.17	55.6	10.39	66.3	1.72	72.8	1.49	80.6	30.5	15.2
19	19.15	59.2	3.42	68.6	4.14	75.0	2.54	73.9	60.5	22.4
20	18.28	63.5	5.51	72.4	3.47	76.2	2.34	73.0	46.1	22.8
21	18.45	59.8	5.70	68.4	4.65	69.7	2.39	67.7	48.2	21.7
22	22.00	62.2	6.11	65.2	4.45	72.1	6.21	70.5	43.1	20.6
23	19.05	59.6	5.40	74.2	3.84	74.7	4.78	70.0	62.2	25.3
24	15.67	60.0	5.31	73.2	3.28	74.6	2.33	73.2	52.9	21.4
25	15.92	55.6	6.36	72.9	1.79	77.4	7.10	72.1	53.9	26.0
26	16.75	63.6	3.07	67.2	3.29	79.8	1.79	77.2	48.4	19.8
27	12.34	62.4	2.56	74.7	4.51	72.7	4.42	73.0	52.8	19.9
28	15.82	59.0	4.84	68.9	3.54	77.9	3.76	72.9	62.1	26.7
29	15.24	62.5	3.80	66.4	7.55	70.5	2.55	73.0	66.0	25.1
30	21.72	62.8	4.11	71.5	2.29	72.3	4.92	76.3	64.2	26.1
31	25.08	59.7	4.43	67.4	2.76	72.6	5.36	73.2	63.2	25.7
32	17.79	57.4	3.36	69.4	5.51	72.6	3.04	72.4	75.4	28.5
(1962) 33	26.61	66.6	3.12	69.1	6.27	71.6	4.31	72.5	76.0	27.0
Averages: 17	19.09	60.8	4.85	70.3	3.55	75.2	3.82	73.2	50.0	20.6

Missouri

X_1 Year	X_2 Pre-Season Precip.	X_3 May Temp.	X_4 June Rain	X_5 June Temp.	X_6 July Rain	X_7 July Temp.	X_8 August Rain	X_9 August Temp.	Corn Yield	Soy Bean Yield
(1930) 1	24.82	64.7	3.77	72.4	1.00	81.2	1.99	78.5	15.0	7.0
2	25.41	61.0	2.75	77.1	3.31	80.3	4.97	74.9	25.5	9.0
3	26.81	66.1	4.81	75.2	3.61	79.8	5.70	77.2	27.5	10.0
4	31.92	65.9	1.47	78.4	2.67	79.3	3.82	75.4	23.5	9.0
5	20.10	69.0	2.82	80.4	1.18	86.2	4.01	80.6	6.5	5.5
6	38.03	60.3	9.25	69.6	3.12	80.8	2.26	77.7	19.0	7.0
7	21.14	68.8	1.42	76.5	1.52	85.3	.84	84.6	10.5	5.0
8	34.21	66.2	4.93	74.4	4.06	77.9	2.05	80.5	27.5	9.5
9	29.86	65.0	4.77	72.4	3.50	79.7	2.62	81.1	25.5	10.5
10	27.36	67.4	5.64	74.6	2.91	80.0	4.80	75.4	29.5	10.0
11	18.96	62.7	4.36	73.5	1.58	77.7	5.78	75.6	31.0	13.0
12	20.04	68.9	4.23	74.1	2.75	79.3	3.15	79.2	29.5	11.5
13	36.32	63.8	7.70	73.3	2.85	78.8	4.24	75.1	36.0	15.0
14	32.22	63.9	6.39	75.8	2.49	79.6	2.46	79.8	31.5	15.5
15	28.40	68.4	2.55	76.4	2.62	77.6	6.09	75.9	34.5	17.5
16	34.92	60.5	8.84	69.5	2.10	75.1	2.08	76.8	28.5	13.0
17	33.42	61.4	2.72	73.9	2.68	78.9	5.64	74.0	37.5	20.0
18	29.66	62.3	8.19	72.6	2.17	75.0	1.81	83.4	25.0	12.0
19	26.64	63.9	7.43	73.3	5.45	77.4	2.14	76.1	45.5	20.0
20	29.00	67.6	6.55	75.2	4.90	78.8	3.04	75.1	41.0	21.0
21	34.57	65.8	4.14	72.9	4.47	72.8	6.72	71.2	44.0	23.0
22	21.93	65.4	8.95	71.0	5.59	76.7	5.14	76.2	34.0	20.0
23	28.81	65.1	2.27	80.8	3.48	79.7	5.12	75.7	41.0	19.0
24	21.98	65.5	2.14	80.4	1.92	79.2	1.31	77.7	33.5	14.0
25	19.27	60.8	3.21	77.2	1.40	84.2	5.06	80.1	23.0	14.5
26	27.25	67.1	4.62	69.6	3.02	81.4	2.69	78.3	40.0	17.5
27	20.22	68.8	3.39	74.8	5.57	77.9	3.05	78.8	48.0	20.0
28	29.91	65.4	6.75	73.5	3.27	79.3	2.12	77.1	44.0	21.5
29	28.84	66.1	5.30	72.3	10.12	76.4	2.32	76.8	56.0	26.0
30	24.93	68.5	2.27	74.0	3.92	75.4	3.09	79.0	55.0	22.0
31	28.56	62.9	3.89	72.6	3.62	75.5	2.97	77.6	52.0	21.5
32	29.45	61.1	3.38	71.1	6.10	76.3	2.70	74.7	62.0	24.5
(1962) 33	34.76	72.6	4.15	73.0	3.17	77.2	2.28	77.2	58.0	22.5
Averages: 17	27.87	65.2	4.70	74.3	3.40	78.8	3.46	77.5	34.6	15.4

Ohio

X_1 Year	X_2 Pre-Season Precip.	X_3 May Temp.	X_4 June Rain	X_5 June Temp.	X_6 July Rain	X_7 July Temp.	X_8 August Rain	X_9 August Temp.	Corn Yield	Soy Bean Yield
(1930) 1	28.33	62.8	2.26	70.0	1.54	75.6	2.40	72.0	26.5	14.0
2	19.53	59.1	3.54	70.8	3.99	77.2	5.11	72.7	45.0	20.0
3	26.52	61.6	4.03	71.0	4.42	73.7	2.10	72.8	36.5	15.5
4	33.12	63.6	1.82	74.4	2.55	74.7	3.65	72.1	34.0	16.0
5	18.87	64.1	3.59	76.0	2.73	78.6	4.27	71.9	32.0	17.0
6	22.06	56.3	3.96	67.4	4.93	76.7	6.03	73.2	44.0	21.0
7	22.54	64.1	1.74	70.3	3.06	77.0	3.59	76.1	33.0	15.5
8	32.59	60.5	6.07	69.7	4.27	73.2	3.20	74.7	43.0	19.0
9	28.25	61.3	4.08	68.5	4.99	74.2	3.10	74.9	44.0	21.0
10	26.66	63.7	6.55	72.5	4.15	72.9	2.02	72.7	50.0	21.0
11	25.14	58.6	4.79	70.6	1.93	73.3	4.18	72.8	38.0	15.5
12	17.52	63.4	5.91	70.9	4.15	75.1	3.35	71.7	49.5	19.5
13	24.22	62.5	4.19	71.2	3.98	74.7	3.48	71.3	56.0	22.0
14	30.11	61.2	3.37	74.7	6.01	74.2	2.88	72.4	49.5	21.0
15	22.14	66.7	3.08	73.1	1.69	74.3	4.02	73.7	38.0	16.5
16	29.03	56.1	4.91	67.5	3.57	71.7	1.98	71.6	50.5	18.0
17	28.35	58.9	5.94	69.0	3.09	72.7	2.51	67.0	49.0	18.0
18	27.92	57.8	5.55	67.8	3.79	69.4	4.39	77.3	41.0	18.5
19	27.94	58.7	4.01	70.1	3.62	73.6	2.57	72.4	58.5	20.5
20	30.30	62.6	4.25	73.5	4.22	75.5	3.31	73.2	56.0	24.0
21	30.92	62.0	4.37	68.2	4.30	70.8	2.88	69.5	52.0	22.5
22	32.18	61.9	4.59	69.7	2.60	73.2	1.30	71.0	48.0	19.0
23	32.16	59.8	2.80	74.2	3.16	76.3	2.72	71.9	53.0	22.0
24	23.11	64.0	2.81	72.6	3.54	74.4	2.10	72.8	55.0	20.5
25	19.21	56.7	3.43	72.0	3.36	73.3	4.85	71.3	61.0	25.0
26	26.64	63.1	2.66	66.4	4.19	77.4	3.23	75.6	59.0	24.5
27	30.56	60.2	3.92	69.8	4.51	72.4	3.94	71.6	60.0	24.0
28	24.22	61.2	5.78	70.8	2.72	73.2	1.72	71.3	54.0	23.0
29	25.33	59.4	6.18	65.5	7.89	73.0	4.41	70.4	60.0	26.0
30	27.14	65.3	2.81	70.1	4.28	73.8	2.45	75.9	63.0	25.0
31	25.33	58.6	3.62	68.3	3.91	70.7	3.24	73.2	68.0	24.5
32	24.33	56.2	4.26	68.1	5.07	72.5	3.18	71.9	74.0	28.0
(1962) 33	23.96	66.8	1.98	70.3	4.47	71.3	1.83	71.7	76.0	25.5
Averages: 17	26.25	61.2	4.03	70.5	3.84	74.0	3.21	72.6	50.2	20.7