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ASSESSMENT OF EFFECTS AND PREDICTABILITY OF CLIMATE FLUCTUATIONS AS RELATED TO AGRICULTURAL PRODUCTION

by

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INTRODUCTION

Purpose and Scope of Research

The research discussed in this final report under NSF Grant ATM76-11379 has involved a 3-year, 2-phase program whose major objective has been to develop methods which will provide useful estimates of future variations in crop production due to weather. Research has been centered on the 5-state Corn Belt, consisting of Iowa, Illinois, Indiana, Missouri, and Ohio, and on the two major crops in this region, corn and soybeans (Fig. 1). Analyses were performed separately for each of the nine crop districts in each state and then combined to determine average relationships for the several states and various combinations of these states.

The major objective of Phase I has been to develop methods which will provide quantitative estimates of future time-space variations in crop production that are caused by natural fluctuations in agriculturally-relevant climatic factors. These fluctuations are principally the result of time and space variations in precipitation and temperature during the growing seasons. These variations are viewed as largely uncontrollable, and, therefore, must be accounted for in estimating future crop production expectancies. In our studies, we have concentrated on defining the effect of these natural weather fluctuations on crop yields for one to five consecutive growing seasons. Time-space relationships have been expressed in terms of probability estimates for areas of various sizes and time periods.

Although considerable past effort has been devoted to investigations of weather effects on crop production in the Midwest, no comprehensive evaluation

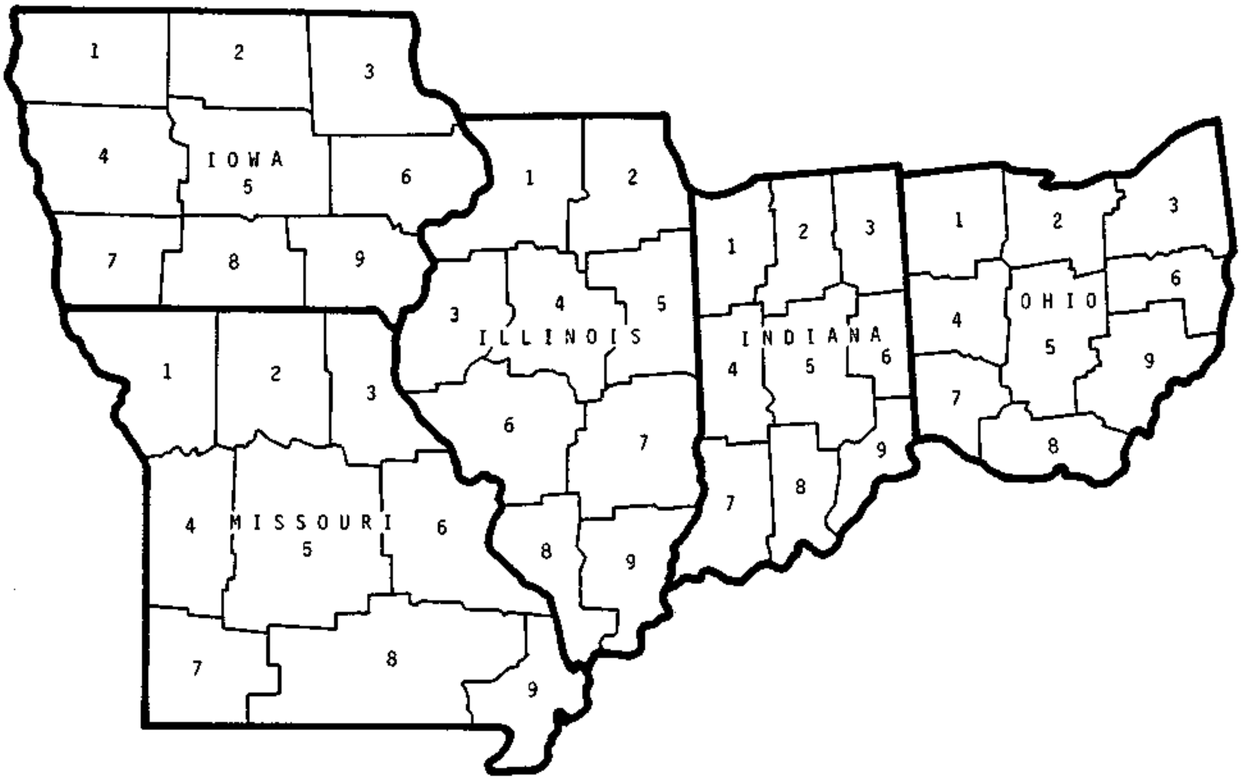


Figure 1. Study area map of states and crop reporting districts.

of the actual time-space relationships in terms of crop yield probabilities has been made for the Corn Belt or portions thereof. This type of information is provided by the research summarized in this report. Assessment of short-term (1 to 5 years) climatic fluctuations is essential to accurate evaluation of weather-induced effects on crop yield. It is anticipated that agricultural technology will be able to adjust to slow, long term types of climatic change (Thompson, 1975), but future technology and complex global economic interactions will not be able to respond fully to large, temporary excursions from the normal climate, such as those produced by excessive rainfall, drought, and early freezes.

The objective of Phase II has been to investigate, develop, and test statistical methods for the prediction of trends in rainfall for one to three years in advance, with emphasis upon agriculturally-relevant seasonal predictions. Efforts have been concentrated on applications of methods for computing climatological oscillations that occur with a considerable degree of regularity. For this purpose, spectrum analysis followed by band pass and filters has been the primary investigative procedure. The filtering technique was originally employed with considerable success by Bowen in predicting annual precipitation trends in Australia. Since crop yields are strongly related to growing season precipitation, successful trend prediction for periods of one to five years in advance would be a major component for crop planning and estimation of future yields. Phase II development and testing of statistical techniques for prediction of trends in annual and seasonal rainfall will appear in a separate report.

Data Used in Studies

Crop yield data for the 45-year period, 1931-1975. were used in Phase I. Satisfactory corn yield data were available in all five states for these 45 years, and soybean data were available in two states (Iowa, Illinois) for the 45-year period and in the other three states during 1944-1975. Satisfactory precipitation and temperature data were available for 75 years, 1901-1975. In Phase I, precipitation and temperature analyses were concentrated on July and August, since earlier studies (Odell, 1959; Changnon and Neill, 1967, 1968; and Changnon and Huff, 1971) had shown that the weather in these two months is most critical to corn and soybean yields. In Phase II, precipitation was the primary climatic variable studied. Various combinations of the 1901-1975 sample were used in this phase of the work. Crop yield data were obtained through the agricultural departments of the several states, and climatic data from the Asheville Climatic Center of the National Weather Service.

CROP WEATHER MODEL DEVELOPMENT

Model Introduction

The search for an optimum model or models to represent crop-weather relationships was performed basically on Illinois data. The data consisted of 1) monthly average temperature and monthly total rainfall, and 2) annual corn and soybean yield averages. These were determined for each of the nine Illinois crop reporting districts for 1931 through 1975. This period included two severe droughts (one in the 1930's and the second in the 1950's). Favorable weather for crop production occurred between the droughts with a period of very favorable crop weather following the drought of the 1950's. A progression of crop improvement and production factors also began in the late 1930's and continued through the study period. These factors presented an almost continuous increase in production capability throughout the period following the cessation of the 1930's drought. Improvement in crop production included hybrid corn, improved soybean varieties, greater and more efficient use of fertilizer, higher plant population density, herbicides, insecticides, and improved machinery.

Any study involving the effects of weather fluctuations on crop production during 1931 through 1975 must deal with the problem of separating weather and technological influences. Since technology factors are not documented over areas the size of a crop reporting district or a county, it was necessary to select a "proxy" to represent them in the crop weather model development. The authors tested the year of observation as a linear, a quadratic, and a cubic factor to represent the expected yield increase over the study period resulting from the introduction of improvements in crop production. The authors realize the linear, quadratic, and cubic proxies represent a smoothed and, most likely, an over simplification of the introduction and true effect of technological improvements. However, it is obvious that several years would be required for all farmers of an area the size of a crop district to implement each new technological advance. Therefore, a smooth and continuous representation of technological factors is considered a reasonable assumption or hypothesis.

The initial crop-weather analyses involved multiple regression of crop yield as the dependent variable. June, July, and August mean temperature, and rainfall totals, plus the year of observation (1, 2, 3,_____) were used as the independent variables. These six weather factors were used in the early regressions because of their generally accepted importance in corn and soybean growth and development in Illinois and the Midwest. Regression analysis involved a 39-year period from 1931-1969. The last six years of the 45-year period, 1970-1975, were reserved for testing the validity of the selected model.

Tests of significance, involving partial regression coefficients for yield on June, July, and August monthly average temperature and monthly total rainfall with the technology trend assumptions were used as guidelines in the initial analyses for determining whether crop-weather relationships differed in adjacent districts. These tests revealed a relatively low degree of heterogeneity among coefficients (generally not significant at the 5% level) of districts in an east-west orientation. In a north-south orientation, significant differences between coefficients were found. These test results are in general agreement with the main climatic and soil productivity features of Illinois. These include 1) a north-south temperature gradient, 2) a more uniform time and space distribution of crop season rainfall in the northern half of the state, and 3) lower soil productivity characteristics in the southern third of the state, primarily resulting from past glacial influences.

On the basis of significance tests for partial regression coefficients, data for adjacent east-west districts were averaged for use in larger area model development. Combining district pairs formed four regions (North, Central, South Central and South) as shown in Figure 2. Crop-weather model testing was continued with the averaged data of these four Illinois areas.

Figure 2. Four Illinois crop-weather study regions.

Deviations from Trend

Frequency (probability) estimates and impacts resulting from weather-induced variations in corn and soybean yields were a major objective of this phase of the agro-climate research. These estimates required crop-weather model development for separating the portion of annual yield variations caused by weather fluctuations from those due to technological influences. This "problem of separation" was approached by determining an expected yield (smooth trend) to represent technological influences with weather variations held constant. This was accomplished by substituting monthly averages of temperature and rainfall during 1931-1969 into the original regression equations (crop-weather models). For example, assume a crop-weather model expressed as:

$$\text{Yield} = k + a\ (\text{Jul temp}) + b\ (\text{Jul rain}) + c\ (\text{Year of observation}),$$

where k, an intercept value, and the regression weights (partial regression coefficients) a through c are determined by multiple regression techniques. Substituting averages for each of the weather variables produces constant values for weather factors in the model expression. These constants can be added to k to obtain an adjusted intercept value, K. The adjusted empirical equation can then be rewritten as

$$\text{Yield} = K + c\ (\text{Year})$$

which is assumed to represent an expected yield with weather influences held constant and technologlical advances estimated by increasing the year variable through the range of 1, 2, ---, 39. Figure 3 illustrates plots of expected yield curves with 1931-1969 average weather and two assumed trends (quadratic and cubic) for corn yield. The quadratic illustration is explained more fully in a later section (Corn Yield Deviations from Trend) of this report.

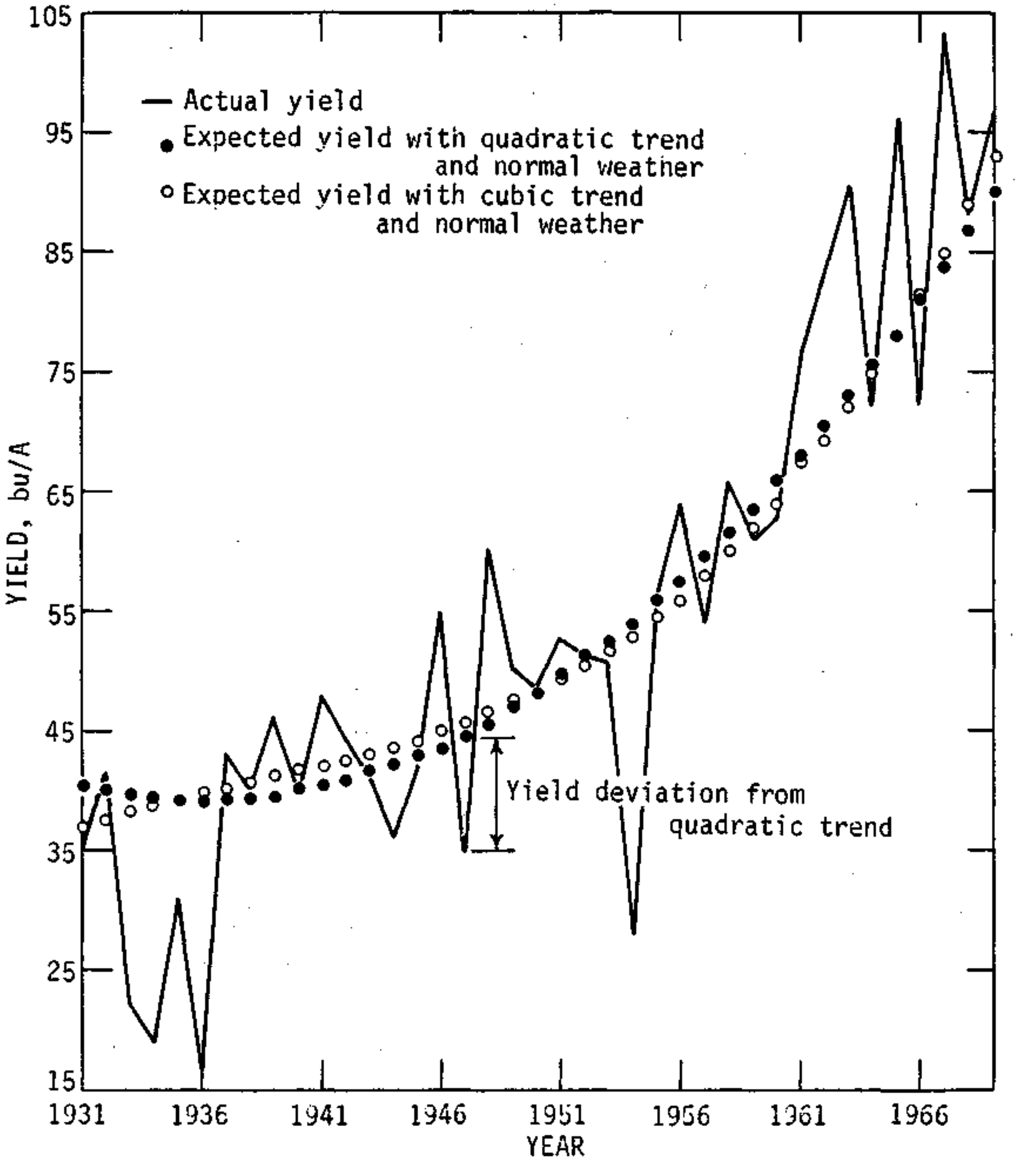


Figure 3. Comparison of expected corn yield from quadratic and cubic technology trend with actual yield in south central Illinois, 1931-1969.

Annual crop yield deviations from the smoothed technological trend were assumed to be due primarily to monthly rainfall and temperature fluctuations. These deviations were correlated with weather parameters involved in the respective models to determine their strength of association with weather. This estimate of association between deviations and weather was expressed as a percent of deviation variance explained.

Model Development for Four Illinois Areas

Regression analyses involving four combinations of weather factors and three technology proxies were done for each of the four Illinois areas. Table 1 provides a summary of the variable combinations and the analytical results. Specifically, the table contains 1) percent of variance explained for corn and soybean yields by various weather and trend assumptions, and 2) percent of yield deviation from trend variance explained by weather factors alone. Table 1 provided much of the information used in selecting separate crop-weather models for corn and soybeans for application in subsequent 5-state (Ohio, Indiana, Illinois, Iowa, and Missouri) analyses.

Selection of Trend Factor for Corn Model. The choice of a corn yield trend assumption from the three under study (linear, quadratic, and cubic) was based primarily on results shown in Table 1. Increases in percent of crop variance explained by area quadratic models as compared to that by linear models was determined from Table 1 and presented in Table 2. Corresponding increases for cubic models over quadratic models are also shown in the same table.

Inclusion of the quadratic term in corn multiple regression models with the four combinations of weather factors produced significant increases (%

for linear, Table 2) in yield variance explained for the central, south central, and southern Illinois areas. Yield deviations from quadratic trend models were also correlated better with involved weather factors than deviations from linear models in the same three areas. The difference in yield variance explained (1%) by quadratic over linear was not statistically significant in northern Illinois.

A cubic trend hypothesis is a more logical choice for technological influences than either linear or quadratic. Both linear and quadratic assume undiminished upward yield increases. However, it is generally believed that a physical upper limit should be approached some time in the future. A cubic trend factor would be expected to reflect a "leveling off" in yield increases. However, yields of the Illinois areas generally continued to rise rather rapidly during the latter part of the 1931 to 1969 sample period. A cubic trend proxy did not, therefore, reflect or demonstrate any expected levelling off in corn yield trend. Cubic and quadratic trends were plotted for visual comparison in Fig. 3 for the south central Illinois area. Both trends are very similar after 1936. The percent of corn yield variances explained (0 and 1%) by the cubic was not significantly greater than that explained by quadratic trend in this area. Cubic and quadratic comparisons in central and southern Illinois were very similar to that in the south central area. In northern Illinois, the cubic explained 2 percent (enough for significance at the 5% level) more corn yield variance than the quadratic. The cubic trend in the northern region also continued to increase rapidly to the end of the period as it had in the other three Illinois areas.

Thus, cubic was significant over the quadratic in only one of four Illinois regions, the levelling off of cubic trend was not demonstrated in

Table 1. Percent of Crop Yield Variance Explained by Weather and Technology Trends and Percent of Yield Deviation Variance from Trend Explained by Weather Variables (Illinois 1931-1969).

	% of Variance Explained							
	3 Variables[1]		4 Variables[2]		6 Variables[3]		7 Variables[4]	
Area	Yield	Deviations from Trend	Yield	Deviations from Trend	Yield	Deviations from Trend	Yield	Deviations from Trend
CORN								
Linear Trend								
North	89	12	89	13	89	13	89	13
Central	87	27	87	29	89	38	89	38
S. Central	86	49	86	49	87	53	87	53
South	84	50	84	53	85	58	87	64
Quadratic Trend								
North	90	14	90	16	90	16	90	17
Central	91	41	91	43	92	48	92	49
S. Central	91	62	91	62	91	62	92	64
South	92	71	92	71	93	72	94	77
Cubic Trend								
North	92	19	92	22	92	24	92	24
Central	92	46	93	49	93	53	93	54
S. Central	92	62	92	63	92	64	92	65
South	92	71	92	71	93	72	94	77
SOYBEANS								
Linear Trend								
North	89	18	90	24	91	29	91	29
Central	88	42	89	48	89	49	89	49
S. Central	85	56	88	64	88	64	88	64
South	89	67	91	71	91	72	92	76
Quadratic Trend								
North	89	18	90	23	91	29	91	29
Central	88	44	89	50	90	52	90	52
S. Central	87	59	90	66	90	66	90	66
South	89	69	91	72	91	72	92	76
Cubic Trend								
North	90	19	90	25	91	29	91	29
Central	89	49	91	57	91	58	91	58
S. Central	87	61	91	69	91	69	91	69
South	89	69	91	72	91	72	92	76

---

1) Jul T, Jul R, Aug T
2) Jul T, Jul R, Aut T, Aug R
3) Jun T, Jun R, Jul T, Jul R, Aug T, Aug R
4) Same as 3) with Mar, Apr, and May Rain Total (Preseason precipitation)

Table 2. Difference in Percent of Variance Explained by Linear and Quadratic Trend and Between Quadratic and Cubic Trend with Four Combinations of Weather Variables (Illinois 1931-1969).

% of Difference in Variance Explained

	3 Variables[1]		4 Variables[2]		6 Variables[3]		7 Variables[4]	
Area	Yield	Deviations from Trend	Yield	Deviations from Trend	Yield	Deviations from Trend	Yield	Deviations from Trend
CORN								
% for Quadratic Minus % for Linear								
North	1	2	1	3	1	.3	1	4
Central	4	14	4	12	3	10	3	11
S. Central	5	13	5	13	4	9	5	11
South	8	21	8	18	8	14	7	13
% for Cubic Minus % for Quadratic								
North	2	5	2	6	2	8	2	7
Central	1	5	2	6	1	5	1	5
S. Central	1	0	1	1	1	2	0	1
South	0	0	0	0	0	0	0	0
SOYBEANS								
% for Quadratic Minus % for Linear								
North	0	0	0	1	0	0	0	0
Central	0	2	0	2	1	3	1	3
S. Central	2	3	2	2	2	2	2	2
South	0	2	0	1	0	0	0	0
% for Cubic Minus % for Quadratic								
North	1	1	0	2	0	0	0	0
Central	1	5	2	7	1	6	1	6
S. Central	0	2	1	3	1	3	1	3
South	0	0	0	0	0	0	0	0

---

1) Jul T, Jul R, Aug T
2) Jul T, Jul R, Aug T, Aug R
3) Jun T, Jul T, Aug T, Jun R, Jul R, Aug R
4) Same as 3) with Mar, Apr, and May Rain Total (Preseason precipitation)

any of the four areas with the data samples, and the quadratic trend generally explained a significantly greater amount of variance than the linear hypothesis. Therefore, the quadratic trend was accepted as an adequate choice for representing a smooth technological trend for Illinois corn yield for 1931 through 1969. It is also apparent that differences in percent of assumed yield deviations associated with weather (Table 2 under the column headings of "deviations from trend") were considerably larger when quadratic was included with linear than differences (many of them were nonsignificant) produced by adding the cubic term to the quadratic models. This suggested the mathematical system under study was approaching an optimum with the quadratic trend proxy for the Illinois data sample. Addition of further trend terms would be an unnecessary complication of the model for subsequent analyses involving the 1931-1969 study period.

Selection of Weather Variables for Corn Yield Model. The optimum weather variable combination to be used as the independent variable matrix in the model was the next choice that had to be made following the selection of the quadratic trend to represent technological advances. Attention is directed to the quadratic trend section of Table 1 for a partial answer pertaining to the choice of weather parameters. The additional yield variance explained by additional weather variables from the 3-variable set to the 7-variable set was only an occasional 1% (not enough for statistical significance). This evidence suggested the 3-variable set (July and August temperature and July rainfall) with quadratic trend was adequate for further analysis of corn yields in Illinois and the other four states.

Additional evidence for the selection of July and August temperature and July rainfall for the corn yield model was available from results of significance tests for partial regression coefficients (Table 3).

Table 3. Significance of Partial Regression Coefficients of Corn for June through August Temperature and Rainfall with Quadratic Trend in Illinois, 1931-1969.

	Temperature			Rainfall		
Area	Jun	Jul	Aug	Jun	Jul	Aug
North	-	-	-	-	-	-
Central	-	2	1	-	2	-
S. Central	-	4	2	-	2	-
South	-	4	3	-	-	-

- not significant at the 10% level, 1 significant at the 10% level, 2 significant at the 5% level, 3 significant at the 1% level, and 4 significant at the 0.1% level.

There were no significant coefficients for June temperature, June rainfall, and August rainfall for any of the four Illinois areas. There were also no significant coefficients for <u>any</u> of the six variables in northern Illinois, which indicates a very stable crop-weather regime in this area during the study period.

Significance levels of the three primary weather variables (July and August temperature, and July rain) remained virtually the same as June temperature and rain, August rain, and preseason precipitation were inserted and deleted during regression testing of various variable combinations. This result suggested that partial regression coefficients for the three primary weather variables were very stable and that they were not significantly influenced by intercorrelations among variables in the independent variable matrix. On the basis of the statistical evidence at hand, the 3-variable combination of July temperature, August temperature, and July rainfall with quadratic trend was accepted as the corn-weather model for further study and use in the five states (Illinois, Indiana, Iowa, Missouri, and Ohio) analyses.

The authors realize there were other weather and weather related events (a severely wet or dry May or June, very favorable crop disease weather, early freeze, for example) which influenced corn yield during the 1931-1969 study period. However, such fluctuations did not occur frequently and consistently enough to be recognized in a regression modelling analysis.

Previous research in the field of corn-weather production relationships (Changnon and Huff, 1971), (Dale and Hodges, 1975), (Odell, 1959), (Thompson, 1969) have indicated that the primary weather influences on corn production occur during the months of July and August with the greater weather effects occuring in July. This is true primarily because July weather generally coincides with the relative short (2 to 3 weeks) reproductive (grain formation) stage of corn fields in the Midwest. Thus, favorable August weather can only enhance the potential yield that was set during the July reproductive period.

The selected corn-weather model may be expressed mathematically as follows:

$$\text{Yield} = k + a\ (\text{Jul temp}) + b\ (\text{Jul rain}) + c\ (\text{Aug temp}) + d\ (\text{year}) + e\ (\text{year}^2)$$

where k represents an intercept value and a through e are partial regression weights to be determined by the least squares curve fitting technique in multiple regression analysis. In this manner, the model is adjusted to data from different areas in Illinois and the other four states in the study. Coefficients for the four Illinois areas are listed as follows:

	k	a	b	c	d	e
North	119.2	-0.575	-0.518	0.413	0.696	0.018
Central	188.5	-1.281	-0.729	1.558	-0.097	0.040
S. Central	262.7	-1.948	-1.028	1.902	-0.581	0.047
South	269.4	-1.849	-1.184	0.813	-0.809	0.043

Variation in the coefficients represent adjustments in the general corn-weather model (weather and technology) which are necessary to adapt it to different districts and areas in the 5-state study.

The a and b coefficients, for July and August temperature, are all negative. The c coefficients for July rainfall are all positive. This agrees with the general belief that above normal July and August temperature is detrimental to corn production in this area and that above normal rainfall is beneficial.

A clearer understanding of the relative importance of each of the three weather variables within and between areas follows from an examination of corresponding standardized partial regression weights. Standardized regression weights represent a normalized version of the a, b, and c weights. Standardized regression of corn yield on July temperature was obtained by multiplying a by the ratio of the standard deviations of July temperature to corn yield. These weights for the four Illinois areas are listed as follows:

	A	B	C	D	E
North	-.073	-.070	.031	.430	0.451
Central	-.144	-.083	.111	-.050	0.857
S. Central	-.234	-.125	.147	-.304	1.013
South	-.274	-.189	.087	-.571	1.237

The A and B weights increase in absolute value from north to south. This trend indicates an increasingly detrimental effect of July and August temperature on corn production from north to south in Illinois during the study period. A crop production risk variation due to the July and August temperature regimes of each region is evident. The July temperature influence increased by a ratio of .274/.073 from north to south and the August temperature influence increased by a ratio of .189/.070. July and August temperature influences are about equal in northern Illinois (nonsignificant effects according to Table 3) but the August temperature influence is considerably less than that for July in the other three areas. According to the standardized coefficients, C, the relative rainfall influence is considerably larger in central and south central Illinois (greatest in south central) than it is in either northern or southern Illinois. In fact, the rainfall effect in northern and southern Illinois was not significant (Table 3). This statistical result seems "out of order" with regard to rainfall, especially in southern Illinois. It surely doesn't mean that more July rainfall in this area wouldn't produce any more corn. The statistical nonsignificance of July rainfall must be due to July rainfall variation being within or below a limit that produces significance in a regression analysis. The same reasoning with regard to July rainfall may apply in northern Illinois, also. However, the temperature influences were not statistically significant in this area, whereas they were highly significant in southern Illinois (Table 3).

Consequently, hot temperatures in southern Illinois may have essentially negated the beneficial rainfall increase, making it too small to be significant in the regressions for the 1931-1969 sample period. Regression analyses only reflect the degree of importance of certain weather variables on the basis of variation in the weather sample of an area. The reader will note in Figure 5 that regression coefficients for corn yield with July rainfall were significant in both crop reporting districts of this southern Illinois area for the sample period 1931-1975.

Corn Yield Deviations from Trend. An illustration of corn yield deviations was shown in Fig. 3 for the south central area of Illinois. The construction of this diagram can now be explained by using the coefficients (a, b, c, d, and e) listed above for the south central area. The crop-weather model for this area is:

$$\begin{aligned}\text{Corn Yield} = {} & 262.7 - 1.948\ (\text{Jul temp}) - 1.028\ (\text{Aug temp}) \\ & + 1.902\ (\text{Jul rain}) - 0.581\ (\text{year}) + 0.047\ (\text{year}^2).\end{aligned}$$

With the substitution of the 1931-1969 climatic averages, the model becomes:

$$\begin{aligned}\text{Corn Yield} = {} & 262.7 - 1.948\ (77.4\ \text{degs.}) - 1.028\ (75.5\ \text{degs}) \\ & + 1.902\ (3.5\ \text{inches}) - 0.581\ (\text{year}) + 0.047\ (\text{year}^2)\end{aligned}$$

An algebraic addition of constant terms (products) produced an equation for a quadratic technology trend. This equation (Yield = 41.0 - 0.581 (year) + 0.047 (year)) is an equation for "expected" corn yield from technology and normal weather conditions. Annual yield deviations from the trend (Fig. 3) are assumed to be primarily the result of annual fluctuations of July temperature, August temperature, and July rainfall from their respective averages.

Selection of Trend Factor for a Soybean Crop-Weather Model. Attention is directed to the "soybean portion" of Table 1 and the "quadratic minus % linear section" of Table 2. A very small gain in yield variance explained was obtained by going from linear to quadratic trend. The largest percent increase in variance was a consistent 2% increase in yield variance explained by the quadratic assumption in the south central area (Table 2) for each of the four weather variable combinations. This 2% increase fell short of the additional amount of "explained variance" required for statistical significance at the 5% level. The above evidence is adequate statistical evidence for accepting the linear trend hypothesis for a soybean crop-weather model in Illinois based on the 1931 through 1969 record.

Selection of Weather Variables for Soybean Model. It is necessary to return again to Table 1 for guidance in the selection of weather variables for the soybean model. Including August rainfall with the 3-variable combination (July and August temperature and July rain) with linear trend increased the percent of soybean yield variance explained by 1, 1, 3, and 2 percent for the North, Central, South Central and South, respectively. The 3% increase in the south central area was significant at the 5% level. THe other three increases were only large enough to be significant at the 10% level. Increases in yield variance explained when June weather was included with July and August was 1, 0, 0, 0 percent (nonsignificant) from north to south, respectively.

Further information on the significance of the June through August weather for soybean production in Illinois is presented in Table 4. With the nonsignificance in the 6-variable section of this table and the lack of increased yield variance explained (1, 0, 0, 0 noted above from Table 1), it is clear that June temperature and rainfall did not influence soybean production significantly. The 4-variable section of Table 4 indicates that July and August rainfalls are very significant for soybean production. The evidence for including July and August temperatures in the model is much weaker. There was also some tendency for a reduction in significance for temperature when August rain was included. The evidence for using the temperature variables in the model is not strong and consistent but temperature was significant in some cases in Illinois and was expected to be in some districts of the other four states; therefore, it was retained in the model.

August rain was definitely more influential in soybean production than it was for corn. The general statistical significance of the partial regression coefficient for August rain is in agreement with the "down on the farm" saying that "August rain can still save the bean crop". Many soybean varieties have a long blooming and pod setting period that extends over much of July and into August. Consequently, soybeans can benefit more than corn from early August rain following the occurrence of high temperature and moisture stress in July.

The 4-variable combination of July temperature and rainfall and August temperature and rainfall with linear trend was accepted for the soybean crop-weather model for use in subsequent 5-state analyses. The model can be written mathematically as:

$$\text{Yield} = k + a\ (\text{Jul temp}) + b\ (\text{Aug temp}) + c\ (\text{Jul rain}) + d\ (\text{Aug rain}) + e\ (\text{year})$$

where k represents the intercept value and a through e are regression weights to be determined by multiple regression. Coefficients for empirical equations for soybeans in the four Illinois areas are as follows:

	k	a	d	c	d	e
North	12.1	0.010	0.015	0.603	0.353	0.376
Central	27.8	0.017	-0.210	0.944	0.623	0.357
S. Central	32.6	-0.161	-0.116	1,016	0.636	0.291
South	57.7	-0.450	-0.200	0.864	0.404	0.312

Table 4. Significance of Partial Regression Coefficients of Soybeans for June through August Temperature and Rainfall with Linear Trend in Illinois, 1931-1969.

	Temperature			Rainfall		
	Jun	Jul	Aug	Jun	Jul	Aug
			3 Variables			
North		-	-		2	
Central		-	1		4	
S. Central		-	2		4	
South		4	3		4	
			4 Variables			
North		-	-		2	1
Central		-	1		4	2
S. Central		-	-		4	3
South		3	1		4	2
			6 Variables			
North	-	-	-	1	3	2
Central	-	-	1	-	4	2
S. Central	-	-	-	-	4	3
South	-	3	1	-	4	2

\- not significant at the 10% level, 1 significant at the 10% level, 2 significant at the 5% level, 3 significant at the 1% level, and 4 significant at the 0.1% level.

Coefficients varied from area to area in Illinois as the multiple regression system determined each set from data for historical records of each area. In this manner, the model is adjusted for application in other regions. Soybean yield deviations from trend were obtained in the same manner as previously explained for corn yield deviations (section of this report on "Corn Yield Deviations from Trend").

Crop Weather Model Extrapolations

Thus far in this report, the usual statistical tests have been performed to assess the "goodness-of-fit" of models to the data used for their determination. The validity of a model can be examined further by using it to extrapolate into a time period of independent data for comparison with the actual data. This arithmetic exercise was done for the corn-weather and soybean-weather models of each of the four Illinois areas for each year of the 6-year period 1970-1975. A graphical representation of 1) actual corn and soybean yields, 2) estimated (extrapolated) yields from the crop-weather models, and 3) expected yield curves with normal weather are shown in Figure 4.

The period from 1970 through 1975 included two years with unusual yield depressing occurrences. Severe corn leaf blight disease occurred in 1970. A combination of weather events which reduced yields severely in Illinois and much of the 5-state area, occurred in 1974. Wet weather in May and June delayed planting, July rainfall was much below normal, July temperature was above normal, and a September freeze caught the late maturing crops.

From Figure 4, it is clear that 1970 and 1974 corn yields and 1974 soybean yields were much below expected. Occasional severe crop disease

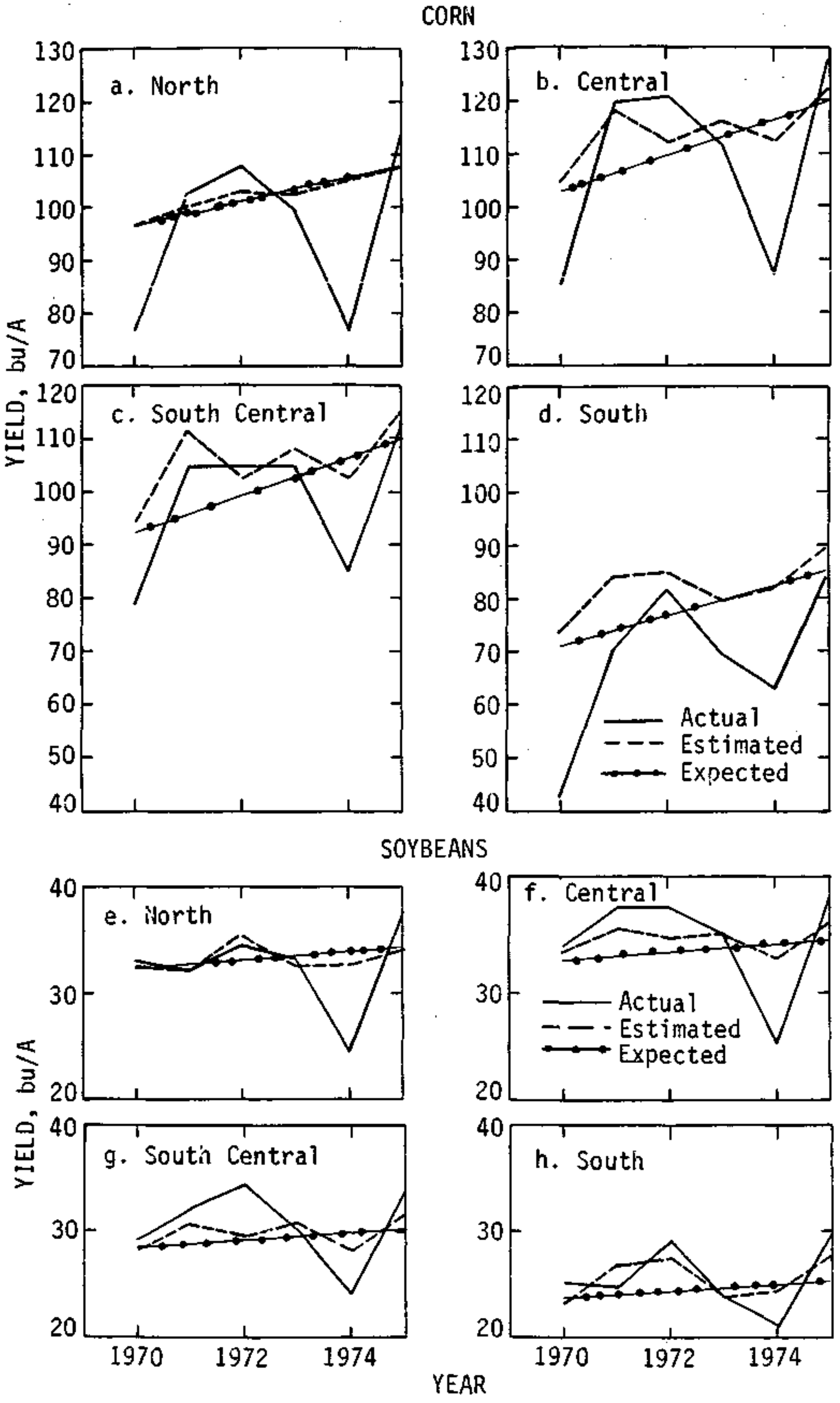


Figure 4. Actual yields, estimated yields from crop-weather models, and expected yields from technology trend for four Illinois areas, 1970-1975.

events like the corn leaf blight of 1970 and the combination of 1974 adverse weather events were not and cannot be reflected properly in crop-weather regression. This caused two (1970 and 1974) of the six corn yield estimates to be very much above actual. The 1974 soybean yield estimates were also much above actual due to the combination of unfavorable weather events that year.

A quantitative impression of model validity is obtained by an examination of Table 5 and Figure 4. For example, in 1971, July and August temperatures were below average and July rainfall was near average to above average (weather conditions favorable to corn production). In all four areas, the estimated yield from the model was above that expected with average weather and the quadratic trend (Fig. 4a-d). Actual yield was also above expected in three of four areas. Cool July and August temperatures and much above average July rainfall in central Illinois were associated with an actual corn yield of 112% (highest observed) of expected. July and August temperature and July rainfall deviations in northern and central Illinois for 1970 were favorable for near expected yields if the corn leaf blight had not occurred. Many other examples are available from Table 5. Weather deviations from average for 1972 were generally favorable to the above expected yields of that year.

Average July and August temperature deviations from 1931-1969 averages were negative for each of the four areas for the 6-year 1970-1975 period. July and August average rainfall deviations from their 1931-1969 averages were more positive than negative. These conditions are favorable for corn and soybean production. As would be expected, more than half of the observed soybean yields (17 of 24) were above trend yields. Soybean-weather models gave estimates equal to or greater than expected in 17 of 24 cases

Table 5. Deviations from July and August 1931-1969 Average Temperature and Rainfall and Ratios of Actual Yield/Expected, and Actual Yield/Estimated.

Year	Jul T	Aug T	Jul R	Aug R	Corn A/Exp	Corn A/Est	Soybeans A/Exp	Soybeans A/Est
				Northern Illinois				
1970	+0.1	+0.1	+0.46	-0.79	80	79	102	102
1971	-1.1	-1.9	-0.13	-1.21	104	102	98	100
1972	-2.0	-0.4	+1.40	+4.36	107	105	105	98
1973	+0.2	+1.3	-0.20	-1.66	96	97	99	102
1974	+1.0	-2.4	-1.20	-0.98	73	72	72	74
1975	-1.2	+0.7	-1.30	+1.35	105	105	110	111
Avg.	-0.5	-0.4	-0.16	+0.18	94	93	98	98
				Central Illinois				
1970	-0.7	-0.7	+0.28	+0.33	83	81	104	102
1971	-4.2	-2.3	+3.13	-1.47	112	101	114	106
1972	-1.9	-0.6	-0.07	+2.09	110	108	112	108
1973	-0.4	+0.3	+1.96	-0.92	99	96	103	100
1974	+1.3	-2.0	-2.08	+0.10	75	77	73	76
1975	-2.5	+1.0	+0.03	+2.84	107	105	112	107
Avg.	-1.4	-0.7	+0.54	+0.50	98	95	103	100
				South Central Illinois				
1970	-1.4	-0.9	-1.02	-0.01	74	73	102	104
1971	-4.2	-2.6	+2.33	-2.45	109	94	111	105
1972	-2.1	-1.3	-1.10	+1.51	106	102	118	116
1973	-0.7	-0.1	+2.10	+1.23	103	98	103	98
1974	+0.9	-2.4	-2.34	+2.50	80	83	81	86
1975	-2.7	+0.4	+0.21	+0.91	103	98	112	107
Avg.	-1.7	-1.2	+0.03	+0.62	96	91	105	103
				Southern Illinois				
1970	-2.0	-0.3	-1.68	-0.24	60	58	106	109
1971	-3.4	-2.8	+0.87	-0.37	94	83	103	93
1972	-2.7	-2.1	+1.41	+1.05	106	96	119	105
1973	-0.1	-0.5	-0.25	-1.00	88	87	98	100
1974	+0.4	-2.4	-2.47	+3.49	77	77	84	86
1975	-1.9	-0.4	+0.51	+2.74	98	94	118	107
Avg.	-1.6	-1.4	-0.27	+0.95	87	83	105	100

(Fig. 4e-4h) over the 4 areas. Only 11 of 24 corn yields were above trend yields, a count which included the extreme yield depressing events of 1970 and 1974. The corn-weather model, with the exception of 1974 (Fig. 4a-4d) generally indicated equal to and above expected corn yields. The expected and estimated yields for the southern Illinois corn-weather model are generally much higher than actual yields. Actual average weather departures from 1931-1969 averages do not support this. Figure 4d is indicative of an actual levelling off (cubic trend) in technological influences during this period, an occurrence which could produce overestimates from a model based on previous data with quadratic trend. Evidence for this conjecture is not available, however. Regression analysis with the cubic trend factor included for this area, based on 1931 to 1975 data, did not produce evidence that a cubic technology trend was required.

Changes (up or down) in the annual model estimates from year to year over the 1970-1975 period reflect the ability of the models to estimate year to year changes. For example, in Figure 4d, 4 of the 5 up-down changes from year to year were in the correct direction. Overall, the up-down trends for corn yield estimates were correct in 70% of the 20 district-years. Soybean up-down trends were 75% correct.

Crop-Weather Model Summary

Deviations from expected mean crop yield after adjustment for technology trend were required for the development of frequency distributions which would provide estimates of future time-space variations in crop production due to relevant weather factors. In accomplishing this task, detailed crop-weather analyses of Illinois data, described previously in this report, were made for selecting models or establishing guidelines for model selection for application in the 5-state area.

Complete separation of crop yield variation due to weather from those due to crop improvement factors is impossible with available data. However, it is believed that an optimum approximation to this problem was achieved for the Illinois data with the model development described earlier. It was also intended that the July-August temperature and July rain with quadratic trend model for corn and the July-August temperature and July-August rain with linear trend model for soybeans developed for Illinois would be applied to the computation of deviations from trends in all five states. However, some further testing was done for assurance that the two models could be applied to the 1931-1975 data period in the entire 5-state region.

Multiple regressions with August rain included as a 4th independent variable in the model for corn were done for each of the 45 districts in the 5-state area. This was done primarily to further check on the significance (or non-significance) of August rain in corn production over the whole study area. Spatial distribution over the 5-state area for the significance levels of the 4 variables is shown in Figure 5. There were only two cases (one district in northern Illinois and one in northern Indiana) of significance at the 5% level for August rain (Fig. 5d). There were 39 districts with significant July rainfall coefficients. August temperature was next with 31 significant coefficients. On the basis of this analysis check, July and August temperature and July rain were accepted as the primary relevant weather factors in corn production for the entire 5-state study. Regressions were then done for each of the 45 districts to test the three weather variables with both quadratic

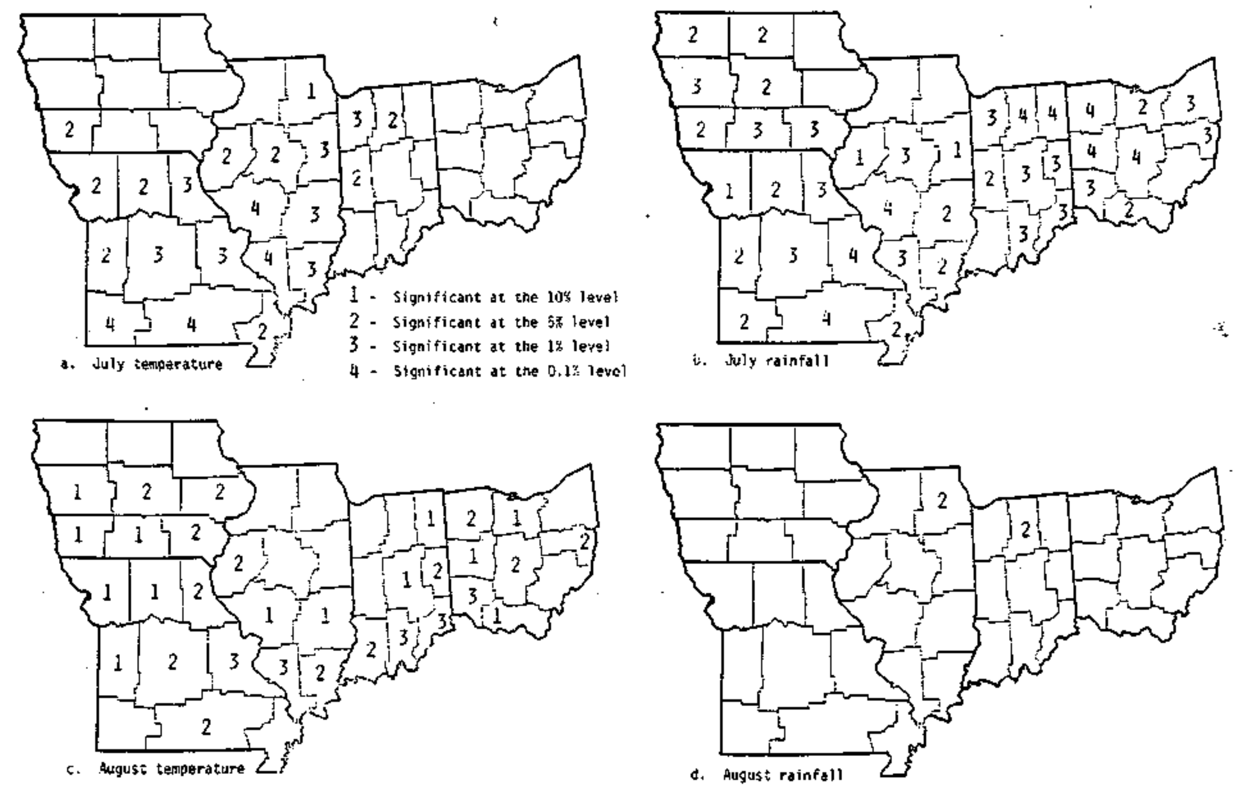


Figure 5. Areal distribution for significance levels of partial regression coefficients for corn yield on July and August mean temperatures and rainfall totals in the 5-state study area, 1931-1975.

and cubic trends to further determine the validity of the quadratic assumption for all districts. The additional yield variance explained by including the cubic trend proxy was less than 1% in 43 of the districts. The cubic explained 1.45% in southwestern Illinois and 1.75% in southwestern Missouri. Neither of these percentages was close to significance. Consequently, the quadratic trend proxy was judged statistically adequate to represent technological improvements over each of the 45 districts in the 1931-1975 period.

There was some question of the statistical significance of July and August temperatures in soybean production in the Illinois analysis for the 1931-1969 data period (Table 4). Significance for the two temperature variables was not consistent from area to area. July and August rainfall explained most of the variance attributed to weather. The July-August temperature and July-August rain with linear trend model was adjusted to data for each of the 45 districts for the 1944-1975 data period. This was the concurrent data period for soybeans in all 5 states. Figure 6 shows the spatial distribution of significance for the 4 variables in the 5-state area. There were 7 coefficients for each of the temperature variables which were significant at the 10% or higher level. July rain was the most influential weather factor in soybean production. There were 36 significant district July rainfall regression coefficients (Fig. 6c). August rain was next with 24 significant coefficients. In the interest of applying a common model for all districts, all four variables (July and August temperature and July and August rain) were retained in the model with linear trend.

The two crop-weather models:

$$y = k + a\ (\text{Jul temp}) + b\ (\text{Aug temp}) + c\ (\text{Jul rain}) + d\ (\text{year}) + e\ (\text{year}^2)$$

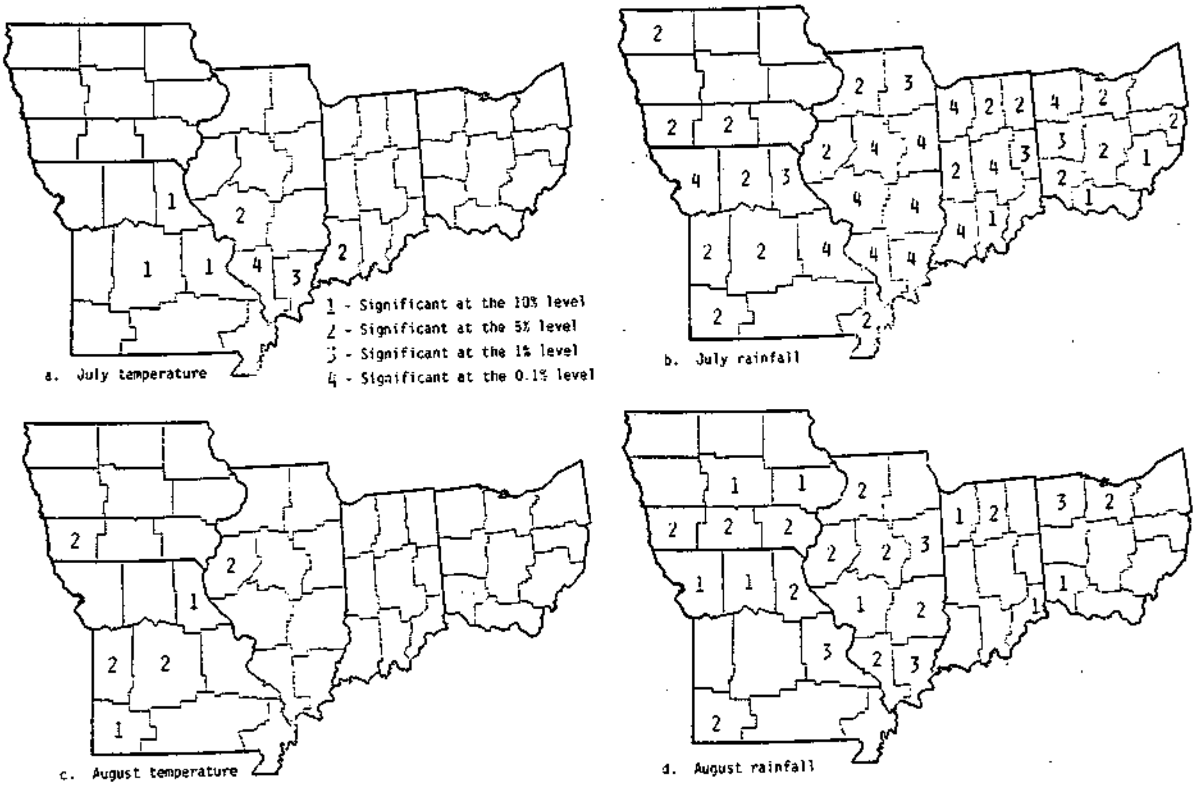


Figure 6. Areal distribution for significance levels of partial regression coefficients for soybean yield on July and August mean temperatures and rainfall totals in the 5-state study area, 1931-1975.

and

$$y = k + a\ (\text{Jul temp}) + b\ (\text{Aug temp}) + c\ (\text{Jul rain}) + d\ (\text{Aug rain}) + e\ (\text{year})$$

for corn and soybeans, respectively, were adjusted to data for each of the 45 districts. Smooth technology trend lines to represent expected yield with average weather of the form:

$$y = K + d\ (\text{year}) + e\ (\text{year}^2)$$

and

$$y = K + d\ (\text{year})$$

were determined for corn and soybeans, respectively, for each of the districts.

Yield deviations from the above curves for expected corn and soybean yield were then computed for each year in each district. These deviations are considered to be primarily due to July and August monthly temperature and rainfall fluctuations. The computed yield deviations were then used as input in the preparation of frequency distributions presented in the next section of this report.

TEMPORAL-SPATIAL DISTRIBUTION OF CROP YIELDS

Introduction

A major output from the Phase I research has been the derivation of time-space variability relations in crop yields that result from weather or weather-related factors. These have been presented in the form of frequency distributions. The variability is defined as the deviation from the expected mean yield for the crop after adjustment for technology trend. The frequency distributions were based on data for 1931-1975 for which satisfactory crop yield data were available. Such computations performed for individual areas and groups of contiguous areas provide a measure of both space and time variations in crop yields caused by natural variability in the weather. Analytical results indicate temporal-spatial probabilities of crop yields that are likely to be experienced in the future, assuming that no major changes in the natural climate take place. The information provided should be valuable in long-range planning with respect to food supplies and their short-term fluctuations due to uncontrollable variations in the time-space distribution of those weather factors which influence crop yields. Probability forecasts of the type derived here are used frequently in hydrology (and other fields) where long-range planning involving structural designs that must incorporate weather-proof safety features is required.

The probability distributions were derived from the 45-year sample of corn and soybean yields for each crop district in the five states involved in the study. District data were combined to obtain frequency distributions of crop yields for each state. This was done for annual yields and for average yields over consecutive periods of two to five years. The consecutive-year averages provide a measure of the variation in crop yields to be expected in periods exposed to relatively long dry or wet periods which are not uncommon in the Midwest. After determining the frequency distributions for each state, they were combined to obtain similar information for various groups of the 5-state area and for all five states combined. In deriving the frequency distributions, the deviation from expected mean yield in percent was used. These percentage deviations allow grouping and comparison between various combinations of districts and states. The expected mean was obtained from the district crop-weather equations which incorporate both a technology trend and weather parameters (see previous section on Crop Weather Model Development).

Distribution of Corn Yields

First, frequency distributions were determined for each of the 45 districts in the 5-state area. An example of the district probability distributions is shown in Fig. 7, which is based upon the crop-weather model for annual corn yields in District 8 in southern Illinois. Corn yield is strongly related to the July and August weather parameters in this district, especially July rainfall, because soil moisture storage is limited, so that frequent replenishment is needed for good crop yields. In computing each frequency distribution, the deviations were ranked from high negative to low negative to low positive to high positive. The curve plotted on probability paper then allows the user to determine the probability in percent of years that any selected deviation will occur, on the average. Thus, reading from the left and using the bottom scale, in 10% of the years (1 yr in 10), on the average, one can expect the crop yield in District 8 to be 30% or more (-30%) below the average or normal yield, after adjustment for existing technology. Similarly, reading from the right and using the top scale, an above-average yield of approximately 24% can be expected once

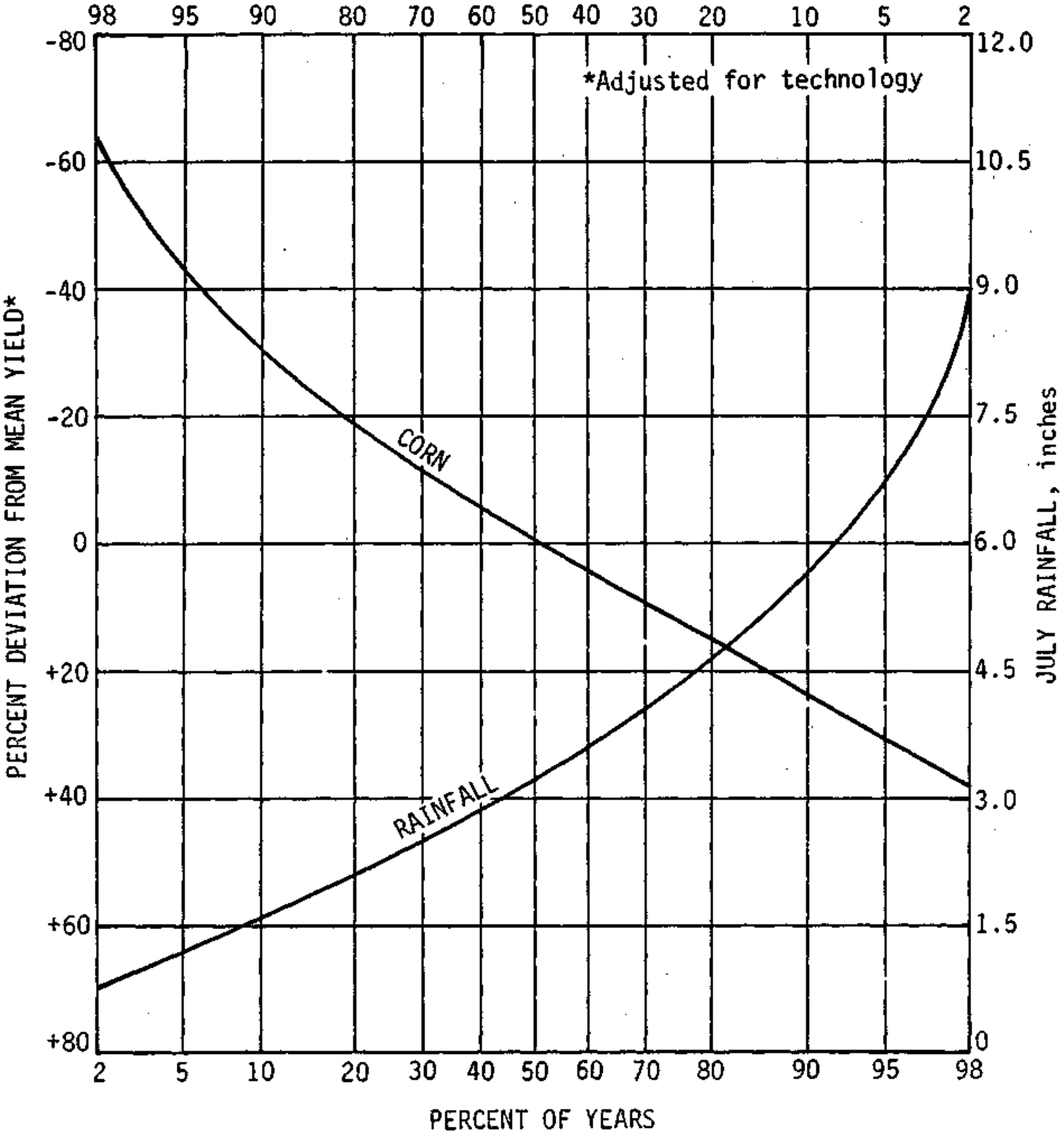


Figure 7. Frequency distribution of corn yield deviations and July rainfall in Illinois District Mo. 8.

in 10 years. The frequency distribution of July rainfall is also shown in Fig. 7 to illustrate its magnitude and large time variability. For example, the coefficient of variation for July rainfall in District 8 is 52% compared with 40% for annual corn yields and 33% for annual soybean yields.

Time distribution relationships, such as illustrated in Fig. 7, are quite useful as a guide in estimating variations in future crop yields resulting from natural climatic fluctuations. However, the areal distribution of weather-related deviations in yield resulting from climatic variability is even more useful, especially in evaluating the extent and magnitude of deficiencies in periods of unfavorable yields. Therefore, computation was made of the spatial frequency distributions of yields for each crop for each state, and for various combinations of states. This was done for annual yields and for average yields over two to five years (moving averages). An illustration of the annual distribution of negative deviations (crop deficiencies) in corn yield for the five states combined is shown in Fig. 8 which provides a family of probability curves for selected deviations ranging from 10% to 50%. For example, the 10% curve indicates that in: 20% of the years approximately 50% of the Corn Belt will have yields that are 10% or more below the average yield. Similarly, in 5% of the years there will be 20% of the area with yields that are 50% or more below average. Similar relations for positive deviations (above-normal or surplus yields) are shown in Fig. 9.

Inspection of the two families of spatial distribution curves shows that large deficiencies (negative deviations) are more likely to occur than large surpluses (positive deviations). For example, in 5% of the years (1 yr in 20) the negative deviation will equal or exceed 20% over 66% of the 5-state area compared with 39% of the area for positive deviations at the same frequency of occurrence. Comparable values for 10% of the years are 48% and 31% of the Corn Belt.

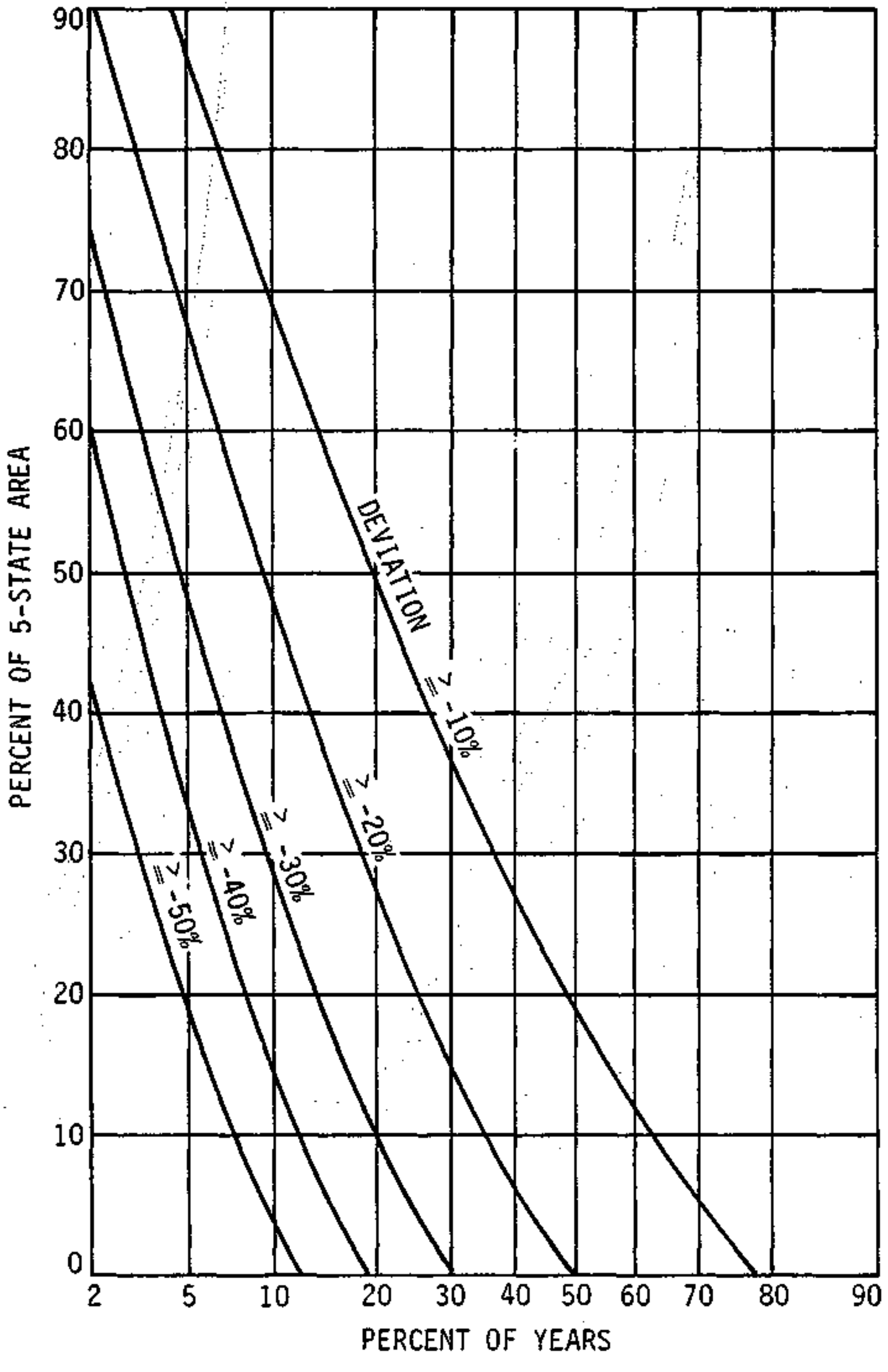


Figure 8. Spatial distribution of negative deviations from mean corn yield (adjusted for technology trend) in 5-state area.

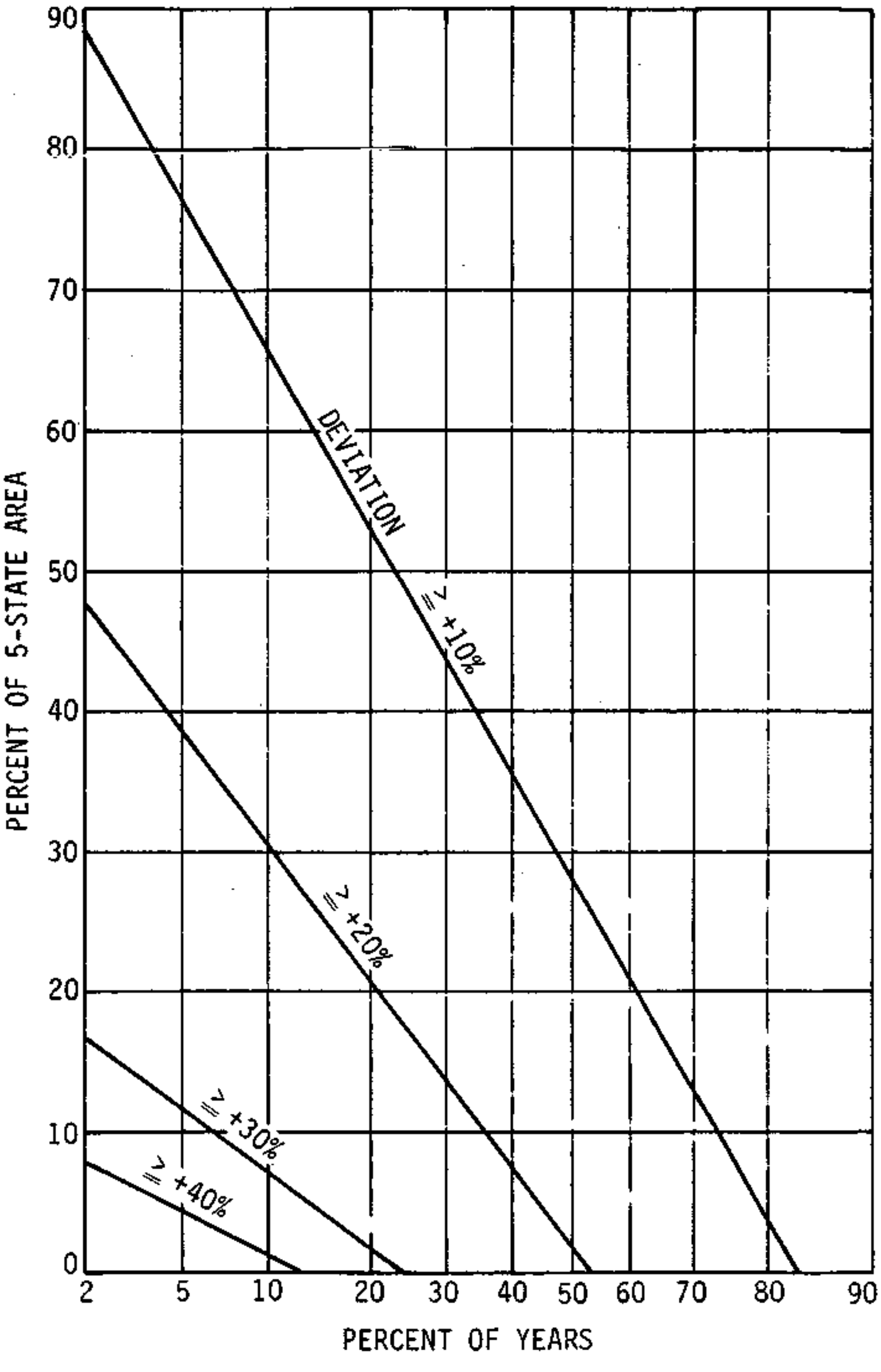


Figure 9. Spatial distribution of positive deviations from mean corn yield (adjusted for technology trend) in 5-state area.

Results of the temporal-spatial study of frequency distributions for corn are summarized in Tables 6 to 13. These tables were constructed from frequency curves derived for each state and for various combinations of states. Only the most important combinations among those analyzed have been shown. The tables show the percent of total area experiencing a given deviation (%) for a given percent of the time. Results are shown for both positive and negative deviations (above and below-normal yields) and for yields averaged over one to five consecutive years.

In general, the area encompassed by negative deviations (below-normal yields) was greater than that for positive deviations for a given location and frequency. That is, adverse weather conditions tend to be more widespread than favorable conditions. The temporal-spatial frequency distributions of annual yields (1-year values in tables) display a large amount of variability between states. The greatest variability occurs in Missouri and the least in Ohio. A general west-east decrease in the deviations is indicated, and this trend is most pronounced in the positive deviations. The west-east trend also exists to some degree when yields are averaged over two to five years. Reference to temporal-spatial distributions for individual districts (not shown) further verified the west-east trend, and also indicated a general trend for the deviations to increase from north to south. In Illinois, for example, there is a marked increase in crop yield variability, as measured by the deviations, from the northern to southern part of the state. As pointed out earlier, this is due to less desirable soil conditions in the southern part of the state, which makes the crop more sensitive to weather conditions, especially the frequency and amount of growing season rainfall.

Results in Tables 6 to 13 indicate that most of the area within a given state or combination of states seldom experiences large negative or positive

Table 6. Spatial Frequency Distribution of Deviations From Trend-Adjusted Means for Corn Yield in Illinois.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	100	86	48	23	8	--
2	100	100	80	41	14	1	--
3	100	100	78	35	11	--	
5	100	95	76	31	2	--	
			Deviation ≥ +10%				
1	94	88	79	63	46	29	6
2	89	77	64	40	21	2	--
3	79	69	59	38	19	--	
5	68	59	48	29	9	--	
			Deviation ≥ -20%				
1	100	87	63	20	2	--	
2	100	87	57	11	1		
3	100	85	55	4	--		
5	97	81	52	1	--		
			Deviation ≥ +20%				
1	58	48	34	14	--		
2	45	30	11	--			
3	34	21	8	--			
5	24	8	1	--			
			Deviation ≥ -30%				
1	89	68	34	5	--		
2	82	50	19	2	--		
3	74	47	5	--			
5	64	39	4	--			
			Deviation ≥ +30%				
1	22	11	--				
2	20	1	--				
			Deviation ≥ -40%				
1	72	48	12	--			
2	69	34	5	--			
3	50	11	--				
5	18	1	--				
			Deviation ≥ -50%				
1	63	28	2	--			
2	22	9	--				
3	12	1	--				

Table 7 . Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Corn Yields in Iowa.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	100	100	67	44	21	5
2	100	100	94	61	37	17	-
3	100	100	78	55	30	4	-
5	100	100	74	39	14	-	
			Deviation ≥ +10%				
1	100	100	90	71	53	35	17
2	100	100	87	57	36	17	-
3	100	100	82	53	33	15	-
5	100	100	73	44	25	10	-
			Deviation ≥ -20%				
1	100	89	59	23	4	-	
2	90	69	45	15	2	-	
3	88	60	34	4	-		
5	66	45	19	2	-		
			Deviation ≥ +20%				
1	81	66	50	25	4	-	
2	75	54	27	5	-		
3	48	28	4	-			
			Deviation ≥ -30%				
1	100	70	38	4			
2	59	39	21	-			
3	57	37	19	-			
5	42	20	4	-			
			Deviation ≥ +30%				
1	40	21	2	-			
2	11	1	-				
			Deviation ≥ -40%				
1	91	52	15	-			
2	39	21	-				
3	35	11	-				
5	18	2	-				
			Deviation ≥ +40%				
1	13	2					

Table 7. (Continued)

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time 2	5	10	20	30	40	50
			Deviation ≥ -50%				
1	22	9	1	-			
2	20	2	-				

Table 8 . Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Corn Yields in Indiana.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	100	89	58	35	21	10
2	100	100	85	53	30	10	3
3	100	100	70	36	16	2	-
5	100	95	63	24	2		
			Deviation ≥ +10%				
1	100	98	86	63	37	14	-
2	100	89	76	54	33	11	-
3	100	78	57	33	16	1	
5	80	69	53	29	3	-	
			Deviation ≥ -20%				
1	100	100	69	21	2	-	
2	100	71	38	5	-		
3	100	65	16	1	-		
5	100	55	14	-			
			Deviation ≥ +20%				
1	71	61	45	16	2	-	
2	28	13	-				
3	23	11	-				
5	15	2	-				
			Deviation ≥ -30%				
1	100	62	28	3	-		
2	69	28	4	-			
3	54	23	2	-			
5	16	-1	-				
			Deviation ≥ +30%				
1	23	13	1	-			
			Deviation ≥ -40%				
1	58	24	2	-			
			Deviation ≥ -50%				
1	12	1	-				

Table 9. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Corn Yields in Ohio.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
Deviation ≥ -10%							
1	100	91	74	51	34	21	8
2	87	65	48	31	20	12	4
3	100	61	33	14	5	-	
5	84	49	17	2	-		
Deviation ≥ +10%							
1	92	84	72	47	30	17	6
2	87	67	49	28	12	-	
3	80	43	24	9	2	-	
5	38	25	10	-			
Deviation ≥ -20%							
1	50	38	25	2			
2	35	17	5	-			
3	21	6	-				
Deviation ≥ +20%							
1	47	17	1				
2	22	9	-				
3	14	-	-				
Deviation ≥ -30%							
1	30	19	4	-			

Table 10. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for; Corn Yields in Missouri.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	100	100	74	47	29	15
2	100	100	100	65	27	17	9
3	100	100	100	63	24	3	-
5	100	100	95	61	22	2	-
			Deviation ≥ +10%				
1	100	100	91	80	65	42	26
2	100	100	87	67	49	31	13
3	97	88	77	60	46	28	10
5	92	84	75	58	43	26	8
			Deviation ≥ -20%				
1	100	100	88	35	19	7	-
2	100	100	85	29	11	2	-
3	100	100	83	22	2	-	
5	100	90	72	19	1	-	
			Deviation ≥ +20%				
1	90	82	69	35	18	7	-
2	68	52	37	17	3	-	
3	45	35	24	9	-		
5	27	20	13	3	-		
			Deviation ≥ -30%				
1	100	94	70	11	1	-	
2	100	91	68	9	-		
3	98	79	52	6	-		
5	87	73	43	4	-		
			Deviation ≥ +30%				
1	52	36	23	10	-		
2	26	18	11	2	-		
3	24	12	1	-			
			Deviation ≥ -40%				
1	100	87	45	10	-		
2	97	85	40	5	-		
3	88	59	26	3	-		
5	77	53	10	1	-		

Table 10. (Continued)

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
Deviation ≥ +40%							
1	35	21	3	-			
Deviation ≥ -50%							
1	95	73	14	1	-		
2	71	45	9	-			
3	60	22	3	-			
5	29	2	-				

Table 11. Spatial Frequency Distribution of Deviations From Trend-Adjusted Means for Corn Yields in Iowa-Illinois.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	100	82	54	38	25	13
2	100	100	76	47	25	15	7
3	100	97	71	42	20	8	--
5	100	92	65	37	12	1	--
			Deviation ≥ +10%				
1	94	84	75	60	48	37	26
2	92	75	63	50	30	15	2
3	79	71	61	48	28	12	--
5	70	61	53	39	22	8	--
			Deviation ≥ -20%				
1	100	76	48	22	6	--	
2	95	73	46	15	2	--	
3	91	70	38	8	--		
5	85	65	29	2	--		
			Deviation ≥ +20%				
1	56	46	36	22	12	3	--
2	43	31	20	7	--		
3	29	21	14	4	--		
5	24	15	7	--			
			Deviation ≥ -30%				
1	95	56	31	7	--		
2	69	40	19	1	--		
3	65	36	9	--			
5	57	30	4	--			
			Deviation ≥ +30%				
1	24	13	4	--			
2	11	6	--				
			Deviation ≥ -40%				
1	80	40	17	1	--		
2	50	24	7	--			
3	40	8	--				
5	15	4	--				
			Deviation ≥ +40%				
1	12	2	--				

Table 11. (Continued)

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
				Deviation ≥ -50%			
1	57	25	3	--			
2	17	7	--				
3	12	1	--				

Table 12. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Corn Yields in Illinois, Iowa, and Indiana.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	100	79	52	36	24	15
2	100	97	71	46	29	17	5
3	100	94	66	37	19	9	3
5	100	90	57	29	13	3	--
			Deviation ≥ +10%				
1	93	85	75	59	43	30	19
2	81	72	62	49	37	22	2
3	73	67	59	44	31	18	1
5	66	55	46	34	24	15	1
			Deviation ≥ -20%				
1	100	76	51	26	12	3	--
2	94	62	40	18	2	--	
3	90	54	31	5	--		
5	84	47	25	2	--		
			Deviation ≥ +20%				
1	57	45	34	21	11	3	--
2	31	24	16	5	--		
3	20	16	11	3	--		
5	16	10	5	--			
			Deviation ≥ -30%				
1	97	58	30	8	--		
2	61	37	16	--			
3	57	33	8	--			
5	36	19	4	--			
			Deviation ≥ +30%				
1	17	10	5	--			
2	12	3	--				
			Deviation ≥ -40%				
1	74	36	12	--			
2	37	19	3	--			
3	33	9	--				
5	7	2	--				
			Deviation ≥ +40%				
1	6	2	--				

Table 12. (Continued)

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time 2	5	10	20	30	40	50
	Deviation ≥ -50%						
1	39	15	1	--			
2	15	3	--				
3	12	1	--				

Table 13. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Corn Yields in 5 States Combined.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
Deviation ≥ -10%							
1	100	86	68	50	38	28	19
2	100	82	62	41	25	16	9
3	97	80	60	38	20	10	3
5	94	76	56	33	14	1	-
Deviation ≥ +10%							
1	88	76	66	53	44	36	28
2	73	68	61	48	33	20	12
3	68	60	52	39	27	17	9
5	54	48	40	31	23	14	6
Deviation ≥ -20%							
1	91	68	48	27	15	6	-
2	85	64	43	16	4	-	
3	81	62	36	4	-		
5	74	58	32	3	-		
Deviation ≥ +20%							
1	48	39	30	21	14	7	2
2	22	18	14	9	4	1	-
3	16	13	10	6	3	1	-
5	9	7	5	2	-		
Deviation ≥ -30%							
1	74	49	29	10	1	-	
2	60	40	21	2	-		
3	58	38	14	1	-		
5	49	30	9	-			
Deviation ≥ +30%							
1	17	12	8	2	-		
2	6	4	2	1	-		
3	5	2	-				
Deviation ≥ -40%							
1	60	33	14	-			
2	40	23	9	-			
3	35	16	4	-			
5	12	6	-				

Table 13. (Continued)

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time 2	5	10	20	30	40	50
			Deviation ≥ +40%				
1	8	4	2	-			
			Deviation ≥ -50%				
1	42	19	4	-			
2	22	11	2	-			
3	18	4	-				
5	5	-					

deviations from the mean yield. For example, with the exception of Missouri, the tables indicate that deviations will not be more than 20% to 30% in 80% of the years (see 20% column). When yields are averaged over a 2-year period, the deviations do not exceed 15% in 80% of the cases, except for Missouri which is not really a high corn production state compared with Illinois, Iowa, and Indiana. Eliminating Missouri, average yields for 3-year periods do not vary more than 5% from the mean yields indicated by the crop-weather equations.

Tables 6 to 13 show frequency distributions for states and the more important combinations of states. Intrastate variability in frequency distributions was investigated also. Table 14 illustrates this variability through use of Illinois district data for corn. The districts were divided into four combinations from north to south, since the crop yields (bu/acre) tend to decrease substantially in this direction. Except in the two most northern districts, percentage differences are relatively small among the district combinations. As discussed elsewhere in this report, yields in these two northern districts appear to be less sensitive to year-to-year variations in weather than are the other districts.

Table 14. Frequency Distribution of Annual Deviations from Average Corn Yield in Illinois.

	Deviation (%) from Mean Yield Equalled or Exceeded for Given Percent of Years								
Districts	10	20	30	40	50	60	70	80	90
1 + 2	-19	-9	-3	0	+2	+5	+7	+9	+15
3, 4, & 5	-24	-15	-9	-4	0	+5	+9	+13	+17
6 + 7	-28	-16	-10	-4	0	+4	+9	+14	+21
8 + 9	-28	-19	-12	-7	-2	+3	+10	+15	+24

Distribution of Soybean Yields

Results of the temporal-spatial study of soybean yields are summarized in Tables 15 to 22. These tables are equivalent to those for corn in Tables 6 to 13. Characteristics of the frequency distributions are similar to those for corn. There is again large variability between the frequency distributions of the individual states, with Missouri displaying the greatest weather-associated effects in the time distribution of crop yields and Ohio showing the least temporal variance. A general west-east increase in the stability of bean yields was indicated by the percentage deviations, similar to the corn situation. The positive deviations, similar to corn, tend to be smaller than the negative deviations for a given frequency, and this becomes more pronounced as the size of the deviations increase.

Comparison of the corn and bean frequency distributions show that the bean deviations from mean yield tend to be less severe than for corn. This is illustrated in Table 23 which shows portions of the temporal-spatial frequency distributions for corn and beans in Illinois and for the five states combined. For deviations of 20% or more, Table 23 shows larger areas consistently for a given frequency of occurrence (percent of years).

Table 15. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in Illinois.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
Deviation ≥ -10%							
1	100	97	80	50	27	8	-
2	100	83	62	36	16	5	-
3	82	72	50	27	10	1	-
5	76	57	40	19	5	-	
Deviation ≥ +10%							
1	90	72	57	40	27	16	5
2	79	62	46	28	15	3	-
3	57	43	33	20	7	1	-
5	43	35	26	13	1	-	
Deviation ≥ -20%							
1	71	58	43	16	2	-	
2	49	33	18	2			
3	38	22	5	-			
5	29	14	3	-			
Deviation ≥ +20%							
1	37	26	16	4	1	-	
2	22	9	2	-			
Deviation ≥ -30%							
1	41	26	9	-			
2	23	12	2	-			
3	19	9	1	-			
Deviation ≥ +30%							
1	11	2	-				
Deviation ≥ -40%							
1	21	9	-				
2	13	2	-				

Table 16. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in Iowa.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	97	74	50	34	20	7
2	100	81	60	37	23	11	3
3	72	52	38	24	15	7	1
5	40	30	22	14	8	2	-
			Deviation ≥ +10%				
1	91	78	65	47	32	19	7
2	90	70	52	32	17	5	-
3	81	61	44	23	8	1	-
5	43	33	23	12	5	1	-
			Deviation ≥ -20%				
1	87	63	40	9	2		
2	48	28	10	-			
3	32	11	-				
5	15	6	-				
			Deviation ≥ +20%				
1	55	40	31	20	10	3	-
2	42	29	17	5	1	-	
3	28	10	2	-			
			Deviation ≥ -30%				
1	60	25	1	-			
2	35	10	-				
3	25	2	-				
			Deviation ≥ +30%				
1	34	13	3	-			
2	14	3	-				
			Deviation ≥ -40%				
1	32	2	-				

Table 17. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in Indiana.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
				Deviation ≥ -10%			
1	100	80	62	43	31	20	11
2	76	64	52	37	26	16	4
3	47	40	34	26	19	11	2
5	45	38	32	19	8	-	
				Deviation ≥ +10%			
1	82	67	55	39	28	19	10
2	71	57	44	28	16	6	-
3	48	43	35	22	10	2	-
5	43	33	24	11	1	-	
				Deviation ≥ -20%			
1	87	35	19	2	-		
2	39	27	13	-			
3	23	15	7	-			
				Deviation ≥ +20%			
1	32	19	8	2	-		
2	15	2	-				

Table 18. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in Ohio.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	74	66	58	44	33	21	9
2	63	51	40	27	18	10	3
3	57	44	33	20	11	5	--
5	35	25	16	2	--		
			Deviation ≥ +10%				
1	82	71	60	43	30	19	8
2	75	60	45	26	11	--	
3	70	51	34	13	--		
5	27	16	6	--			
			Deviation ≥ -20%				
1	27	20	13	2	-		
			Deviation ≥ +20%				
1	34	22	8	--			

Table 19. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in Missouri.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	92	82	60	39	25	14
2	100	89	74	45	30	18	8
3	92	85	70	28	9	--	
5	84	73	58	20	--		
			Deviation ≥ +10%				
1	100	94	85	67	47	33	22
2	100	92	79	53	34	22	11
3	100	90	72	35	22	13	7
5	82	61	44	24	11	--	
			Deviation ≥ -20%				
1	91	79	61	28	10	--	
2	74	60	34	8	--		
3	70	54	30	2	--		
5	37	30	19	1	--		
			Deviation ≥ +20%				
1	75	58	44	28	17	7	--
2	49	36	21	2	--		
3	44	28	13	--			
5	28	14	2	--			
			Deviation ≥ -30%				
1	59	50	34	2	--		
2	55	29	9	--			
3	37	23	7	--			
5	21	12	2	--			
			Deviation ≥ +30%				
1	39	26	16	5	--		
2	26	15	4	--			
3	24	12	3	--			
5	20	7	--				
			Deviation ≥ -40%				
1	48	37	19	2	--		
2	28	15	3	--			
3	26	14	2	--			

Table 19. (Continued)

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ +40%				
1	24	11	--				
2	22	10	--				
3	20	9	--				
			Deviation ≥ -50%				
1	26	15	--				
2	18	4	--				
			Deviation ≥ +50%				
1	17	4	--				

Table 20. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in Illinois and Iowa.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	100	91	71	43	27	16	7
2	85	66	50	32	22	13	6
3	80	58	36	20	11	6	--
5	48	35	25	15	9	4	
			Deviation ≥ +10%				
1	83	64	51	38	29	22	10
2	71	53	40	26	18	12	3
3	45	38	31	22	14	6	--
5	35	29	23	16	6	1	--
			Deviation ≥ -20%				
1	79	56	36	17	3	--	
2	36	25	17	4	--		
3	32	19	4	--			
5	19	10	2	--			
			Deviation ≥ +20%				
1	35	26	17	8	3	--	
2	23	16	9	--			
3	15	6	--				
			Deviation ≥ -30%				
1	30	20	8	--			
2	25	15	2	--			
3	20	5	--				
			Deviation ≥ +30%				
1	17	9	2	--			
2	7	--					
			Deviation ≥ -40%				
1	21	9	--				
2	7	--					

Table 21. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in Illinois + Indiana + Iowa.

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	92	76	55	35	24	16	8
2	51	42	34	24	17	11	4
3	45	35	27	18	12	8	2
5	34	28	22	14	9	4	-
			Deviation ≥ +10%				
1	64	55	41	37	30	23	15
2	53	44	35	25	17	11	5
3	37	30	26	19	13	8	2
5	30	25	18	10	4	-	
			Deviation ≥ -20%				
1	58	41	28	15	6	-	
2	25	18	11	3	-		
3	21	11	2	-			
5	10	5	1	-			
			Deviation ≥ +20%				
1	25	19	14	8	3	-	
2	9	4	2	-			
3	6	2	-				
			Deviation ≥ -30%				
1	14	9	5	1	-		
2	11	6	3	-			
3	9	4	-				
			Deviation ≥ +30%				
1	8	3	-				
			Deviation ≥ -40%				
1	9	3	-				
2	6	1	-				

Table 22. Spatial Frequency Distribution of Deviations from Trend-Adjusted Means for Bean Yields in 5 States Combined..

Averaging Period (Years)	Percent of Total Area Equalled or Exceeded for Given Percent of Time						
	2	5	10	20	30	40	50
			Deviation ≥ -10%				
1	92	71	53	36	27	19	12
2	54	45	37	27	21	15	8
3	49	39	31	21	15	10	4
5	44	34	23	12	6	3	-
			Deviation ≥ +10%				
1	75	62	50	38	30	24	18
2	63	49	38	27	20	15	7
3	46	38	31	23	17	12	4
5	32	25	19	12	8	5	-
			Deviation ≥ -20%				
1	51	38	27	15	8	2	-
2	32	21	13	4	-		
3	28	17	9	1			
5	12	7	4	-			
			Deviation ≥ +20%				
1	25	19	14	9	6	3	-
2	13	9	5	1	-		
3	9	6	2	-			
5	5	3	-				
			Deviation ≥ -30%				
1	25	17	11	3	-		
2	18	9	3	-			
3	11	6	2	-			
5	2	1	-				
			Deviation ≥ +30%				
1	8	5	3	1	-		
2	6	3	1	-			
3	5	2	-				
5	3	1	-				
			Deviation ≥ -40%				
1	14	9	4	-			
2	9	4	1	-			
3	6	3	-				
			Deviation ≥ +40%				
1	4	2	-				
2	3	1	-				
3	2	1	-				
			Deviation ≥ -50%				
1	5	2	-				
2	3	1	-				

Table 23. Comparison of Spatial Frequency Distributions Between Corn and Beans (Based on Annual Yields, Trend-Adjusted Means, and Percentage Deviations from Mean).

ILLINOIS

	Percent of Total Area Equalled or Exceeded for Given Percent of Years					
	5	10	20	30	40	50
			Deviations ≥ -10%			
Corn	100	86	48	23	8	<1
Beans	97	80	50	27	8	<1
			Deviations ≥ +10%			
Corn	88	79	63	46	29	6
Bean	72	57	40	27	16	5
			Deviations ≥ -20%			
Corn	87	63	20	2	<1	
Beans	58	43	16	2	<1	
			Deviations ≥ +20%			
Corn	48	34	14	1		
Beans	26	16	4	1		

5 STATES COMBINED

	5	10	20	30	40	50
			Deviations ≥ -10%			
Corn	86	68	50	38	28	19
Beans	71	53	36	27	19	12
			Deviations ≥ +10%			
Corn	76	66	53	44	36	28
Beans	62	50	38	30	24	18
			Deviations ≥ -20%			
Corn	68	48	27	15	6	<1
Beans	38	27	15	8	2	<1
			Deviations ≥ +20%			
Corn	39	30	21	14	7	2
Beans	19	14	9	6	3	<1

PREDICTIVE POTENTIAL IN CROP YIELD AND WEATHER TRENDS

One objective of the research on Phase 1 has been to investigate sequences of both crop yields and weather conditions to determine whether these provide any significant predictive potential with respect to crop yields one or more years in advance. For example, how much persistence is there in the yield and weather trends displayed in the past year, two years, or longer, and is there indications provided by the immediate past trends as to when a reversal in the existing trend will occur? The predictive potential of past crop yields and weather conditions was investigated in each of the 45 districts in the 5-state study area. Both corn and soybean yields were investigated along with July rainfall, which shows the strongest relationship to crop yields. As in all other analyses, the corn and soybean yields were adjusted for technology trend prior to the computations.

District Trend Analyses

The first step consisted of determining the trend of next year's crop yield when the trend in the present year was up or down from last year's yield. This was done also for the trend averaged over the past two to five years. For evaluation purposes, this analysis was restricted initially to three districts in Illinois (1, 5, and 8) which typify yield conditions throughout the state. Results of this initial analysis are summarized for corn and bean yields in Tables 24 and 25. In these tables the probability (%) is shown for each district and each averaging condition, based upon consideration of only whether the yield in the present year was up or down from last year. Assuming strictly a random distribution of yields and knowing the present year trend (up or down)

Table 24. Trend Contingency Analysis for Corn in Selected Illinois Districts.

Present Trend	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	Probability (%) of Up and Down Trends Next Year									
	1-Year*		2-Year*		3-Year*		4-Year*		5-Year*	
District 1										
Up	24	76	38	62	48	52	58	42	72	28
Down	73	27	57	43	67	33	69	31	57	43
District 5										
Up	22	78	43	57	40	60	52	48	58	42
Down	60	40	62	38	75	25	65	35	67	33
District 8										
Up	17	83	45	55	43	57	65	35	59	41
Down	60	40	52	48	60	40	55	45	59	41

---

*Averaging Period of Present Trend

Table 25. Trend Contingency Analysis for Beans in Selected Illinois Districts.

Probability (%) of Up and Down Trends Next Year

Present Trend	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	1-Year*		2-Year*		3-Year*		4-Year*		5-Year*	
District 1										
Up	42	58	42	58	44	56	43	57	58	42
Down	74	26	61	39	52	48	63	37	50	50
District 5										
Up	25	75	41	59	53	47	50	50	50	50
Down	65	35	70	30	59	41	67	33	62	38
District 8										
Up	21	79	37	63	45	55	48	52	70	30
Down	67	33	57	43	57	43	65	35	50	50

---

*Averaging Period of Present Trend

one would expect to predict the yield trend for next year (up or down from this year) approximately 67% of the time over a long period of observation, simply by predicting the trend next year to be the opposite of that observed this year.

Results are mixed with respect to predictability. Using only the trend for the present year, Table 24 shows that when this trend is up the probability of next year's yield being less than this year's ranges from 76% to 83% among the three crop districts. When the trend for the present year is down, the trend predictability for next year is less predictable. The reversal in trend for the next year is no better, on the average, than would be expected from random distribution theory. The predictability of next year's trend, in general, decreases when the average trend over the past two to five years is used instead of that for the past year only. Of interest is the reversal in trend relationship for the "up" situations when 4-year and 5-year average trends are used as the predictor. In these cases, next year's yield is most likely to be greater than this year's. This behavior is consistent throughout the three districts, and indicates the presence of relatively long periods of general rising yields in the data sample. This is related to the relatively long period of favorable weather conditions that dominated in the late 1950's and 1960's.

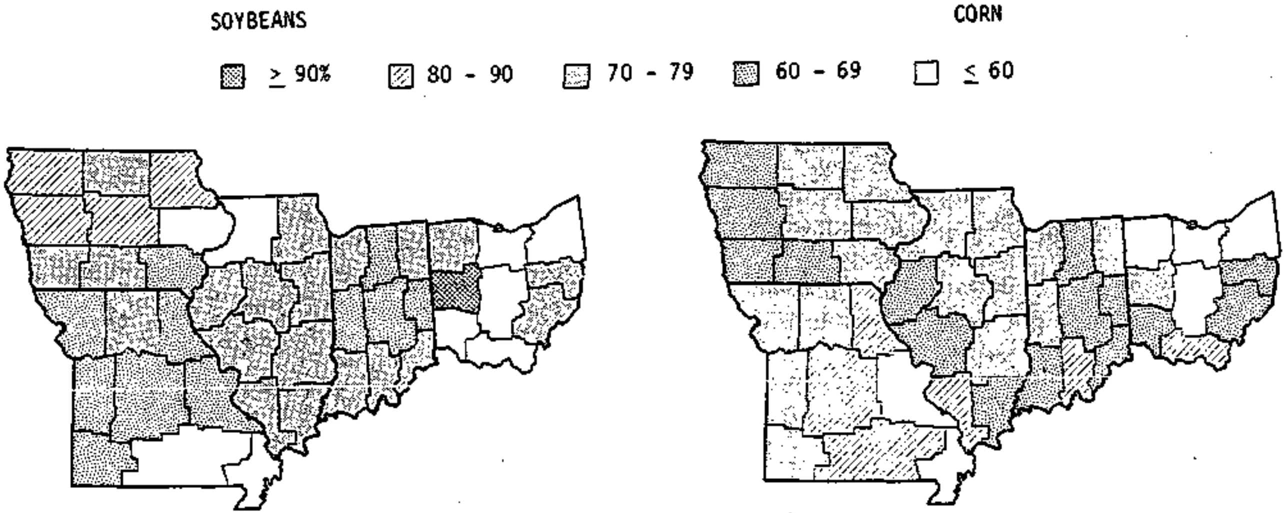
The bean summary in Table 25 shows the same general relationships as corn. The reversal in trend with 4-year averages of rising trend is not indicated, but the reversal with 5-year averages is found in two of the three districts. As pointed out elsewhere in this report, weather-related variability in soybean yields from year-to-year is not as great as that for corn.

The results summarized in Tables 24 and 25 indicate that the crop yield sequences may have some predictability beyond that expected from random distribution of up and down trends, but that most of this predictability would be provided by the trend for the past year, that is, whether the yield this year is up or down from last year's. Therefore, it was decided to extend the analyses to all 45 districts in the five states, but to consider trends only for the past year and past two years. July rainfall was also included in this second-step analysis.

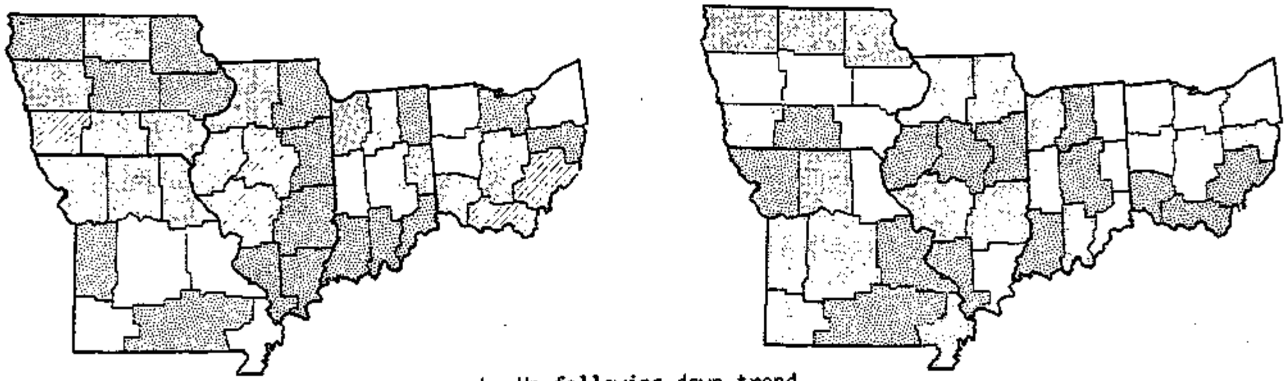
Results of the crop yield analysis are shown in Figs. 10a to 10d. These show the percent of time that next year's yield will be up or down from that observed in 1) the present year, and 2) the last two years. For the 2-year trends, maps are shown only for situations when both years had up or down trends. When the 2-year trends consisted of opposite trends (up-down or down-up), next year's trend was usually the opposite of this year's; that is, most of the predictability is provided by the trend observed in yields from last year to this year in these mixed situations.

Figure 10a shows the probability (%) that next year's corn yield will be less than this year's, when the trend from last year to this year was rising (down trend following an up trend). There is little areal consistency in the pattern. For example, there is no pronounced west-east or north-south change in the probabilities. The mean for the two highest corn production states, Illinois and Iowa, is 75% whereas the 5-state median is 70%. The Illinois-Iowa median is somewhat higher than random distribution theory would indicate.

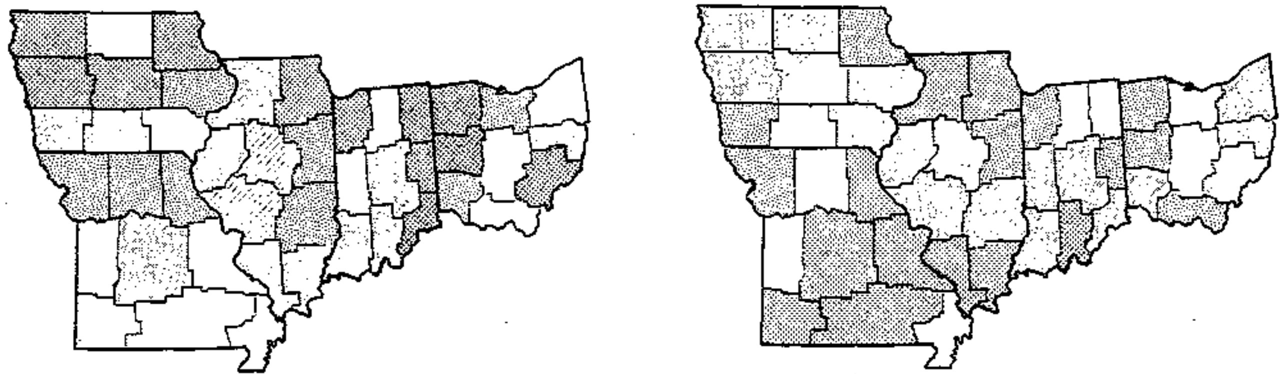
Figure 10b shows the pattern obtained when an upward trend is predicted to follow a downward trend. Medians for Illinois-Iowa and the five states combined are 66% and 68%, respectively, both very close to what would be expected from random chance. Figures 10a and 10b indicate next year's trend in corn yield can be predicted a little better when the present trend is up rather than down.



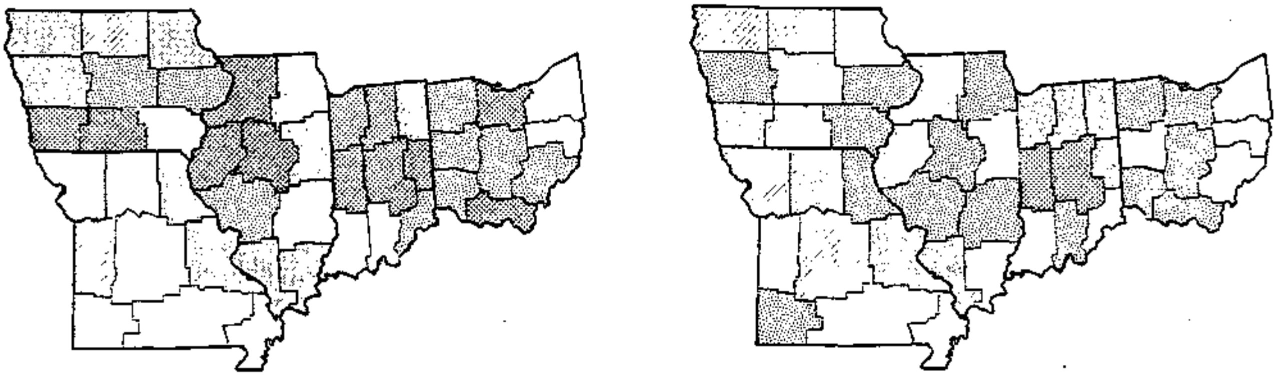
a. Down following up trend



b. Up following down trend



c. Down following 2-year up trend



d. Up following 2-year down trend

Figure 10. Percent of time next year's yield will be up or down from that for the current year and the last two years.

Figure 10c shows the probability distribution when a down trend is predicted to follow two consecutive up trends. The Illinois-Iowa median is 75% and the 5-state value is 71%. These are almost identical with those obtained using only the trend from last year to this year as the predictor. Thus, no greater predictability is indicated by the 2-year sequence than by the 1-year. Figure 10d presents the pattern associated with the prediction that an up trend will follow two consecutive years of down trend. The median for Illinois-Iowa and the five states combined are 69% and 71%, respectively. These are a little higher than the probabilities obtained with the 1-year trend, but still close to the expectancy with a random distribution of probabilities.

Figures 10a to lOd for soybeans are equivalent to those for corn discussed above. The distribution of down trends following a previous up trend are shown in Fig. 10a. The Illinois-Iowa and 5-state medians of 75% and 71%, respectively, are almost identical with those for corn in the same situation. The probability of an up following a down trend for beans is shown in Fig. 10b and the 2-state and 5-state medians of 71% and 68%, respectively, are not significantly different than those for corn in this situation, and not significantly different than the random expectancy.

Figures 10c and lOd shows the patterns of probabilities associated with two consecutive years of up and down trends. The probabilities of a down trend following two up trends is substantially larger than the random chance value (67%) for both the 2-state median (78%) and the 5-state median (75%). The same is true for the probability of an up trend following two years of down trend. In this situation, the probabilities are the same, that is, 78% for Illinois-Iowa and 75% for the 5-state area.

Assume arbitrarily that a 75% probability of identifying the trend in next year's yield is a useful prediction. Figures 10a to 10d indicate that this can be achieved only with beans and then only when the two previous years show the same trend (up or down). Except for these two situations, the trend prediction for next year's crop is little better than could be achieved from application of random distribution theory.

As indicated earlier, the potential predictability of the trend in July rainfall was investigated also. In addition to the crop yield sample for 1931-1975, analyses of July rainfall was extended to include the 1901-1975 period. Results were inconclusive, as shown by the statistics for three Illinois districts in Table 26. Reversal in trends from the past year or past two years varied from less than predicted by random theory to considerably greater than expected from a random distribution. The predictability of the trend in July rainfall also varied greatly between the three districts. In some cases, there is a district difference in the trend predictability between the 1931-1975 and 1901-1975 samples. One cause of this is the small number of samples contained in some of the classifications in the table. This problem is also present in the probabilities derived for corn and bean yields that were discussed previously.

Trend Analyses for Groups of Districts

Some of the inconsistencies in both the magnitude and areal distribution of trend probabilities are likely related to the relatively small samples available for some of the trend categories when analyzed on a district basis. Therefore, it was decided to investigate the trend probability distributions when several districts are grouped and when data from all nine crop districts are

Table 26. Analysis of Trend Predictability in July Rainfall Sequences.

	Probability (%) for Given Situation											
	District 1				District 5				District 8			
Trend	1931-75		1901-75		1931-75		1901-75		1931-75		1901-75	
Sequence	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
Up	42	58	44	56	45	55	35	65	11	89	27	73
Down	50	50	53	47	62	38	56	44	71	29	75	25
Up-Up	29	71	21	79	30	70	33	67	0	100	40	60
Down-Down	67	33	67	33	63	37	65	35	86	14	89	11
Up-Down	33	67	40	60	64	36	48	52	65	35	70	30
Down-Up	36	64	58	42	58	42	38	62	12	88	19	81

combined to obtain a single state relationship. This analysis assumes that the distribution of district trends is similar throughout the state and the combined sample of 225 observations (9 x 45) is more indicative of the true trend relationship than the individual district values.

Results of this analysis for Illinois are summarized in Tables 27 to 29 for corn, beans, and July rainfall. These tables contain analytical results for combinations of Districts 1-5 and 6-9 and for all nine districts combined. Table 27 shows that the probability of a decrease in corn yield following one or two years of rising yields is considerably greater than would be expected in a random distribution of up and down trends. For the state (9 districts combined), down trends followed an up trend in the preceding year in 74% of the cases, and this increased to 85% following two consecutive years with up trends. However, down trends were not followed as often by up trends. For the state, the frequency of an up trend was 65% when preceded by both one and two consecutive years of down trend. This is very close to the frequency to be expected with a random distribution of up and down trends. Values close to a random distribution were obtained also with the up-down and down-up trends prior to the year in question. Overall, this analysis indicates that below-average corn yields are very likely to follow two consecutive years of upward trends over the state or large portions of the state treated as unit areas. Otherwise, the probability of next year having a larger yield conforms closely to random distribution expectancies. That is, the corn yield sequences do not contain much predicative power, except in special situations.

Table 28 shows the trend contingencies for beans. For the state, the greatest probability for a reversal in trend occurs following two consecutive years with downward trends (84%). Following two consecutive upward trends, the probability of the following year having a smaller yield is 75%. Thus, the

Table 27. Trend Contingency Analysis for Corn Based on Groups of Districts and 45-Year Sample.

	Frequency Distribution of Trend for Following Year											
Present	UP		DOWN		UP		DOWN		UP		DOWN	
Trend	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
	Districts 1-5				Districts 6-9				Districts 1-9			
Up	26	26	75	74	21	27	58	73	47	26	133	74
Down	76	67	38	33	59	63	34	37	135	65	72	35
Up-Up	4	16	21	84	3	14	18	86	7	15	39	85
Down-Down	26	65	14	35	22	63	13	37	48	64	27	36
Up-Down	50	68	24	32	36	62	22	38	86	65	46	35
Down-Up	21	30	50	70	18	33	36	67	39	31	86	69

Table 28. Trend Contingency Analysis for Beans Based on Groups of Districts and 45-Year Sample.

Frequency Distribution of Trend for Following Year

Present Trend	UP Number	UP %	DOWN Number	DOWN %	UP Number	UP %	DOWN Number	DOWN %	UP Number	UP %	DOWN Number	DOWN %
	Districts 1-5				Districts 6-9				Districts 1-9			
Up	32	30	76	70	21	26	61	74	53	28	137	72
Down	77	72	30	28	63	70	27	30	140	71	57	29
Up-Up	8	25	24	75	5	24	16	76	13	25	40	75
Down-Down	27	90	3	10	20	74	7	26	47	84	10	17
Up-Down	50	66	26	34	42	69	19	31	92	67	45	33
Down-Up	24	33	48	67	15	25	44	75	39	30	92	70

Table 29. Trend Contingency Analysis for July Rainfall Based on Groups of Districts and 45-Year Sample.

Frequency Distribution of Trend for Following Year

Present	UP		DOWN		UP		DOWN		UP		DOWN	
Trend	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
	Districts 1-5				Districts 6-9				Districts 1-9			
Up	35	36	64	64	23	27	61	73	58	32	125	68
Down	65	56	51	44	62	70	25	30	127	62	77	38
Up-Up	8	24	26	76	6	26	17	74	14	25	43	75
Down-Down	29	59	20	41	20	77	6	23	49	65	26	35
Up-Down	36	55	29	45	42	69	19	31	78	62	48	38
Down-Up	25	40	37	60	16	28	42	72	41	34	79	66

probability is considerably greater than random chance that a reversal in trend will take place after two consecutive years of a given trend. In general, the probability of a reversal following a given sequence of yield trends is slightly higher with beans than with corn.

Table 29 shows trend contingencies for July rainfall. For the most part, percentage probabilities do not depart significantly from random distribution expectancies. Only one category (up-up) has a reversal probability exceeding 70%. This leads to the conclusion that the predictive power in sequences of July rainfall is insignificant.

Persistence of Inter-Annual Trends

Before proceeding further with the contingency analyses, it was decided to investigate the persistence of up and down trends in corn, beans, and July rainfall in Illinois. A major purpose was to determine how many years should be used as a trend predictor for the coming year. Results are summarized in Tables 30 and 31.

Table 30 shows the length of trends in years obtained from a summation of all occurrences in each of the nine crop districts. From this table, it is obvious that most trends last no more than two years and seldom exceed three years in duration. For example, 88% of the up trends in corn yields exceeding one year in duration persisted for only two years, and only 2% lasted three years or longer. Down trends were somewhat more persistent with 19% lasting two years or longer and 7% present for three consecutive years. No bean trends lasting more than three years were found in the 45-year sample, and the distribution of up and down trends were very similar. July rainfall showed a tendency for a few more occurrences of 2-year and 3-year trends.

Table 30. Persistence of Inter-Annual Trends in Crop Yields and July Rainfall in Illinois (Based on Trend Totals for 9 Districts).

Trend Persistence (Years)	Frequency of Up and Down Trends for Given Persistence					
	Corn		Beans		Rainfall	
	Up	Down	Up	Down	Up	Down
≥ 2	47	73	53	57	57	77
≥ 3	7	25	13	9	14	26
≥ 4	1	4	0	0	1	4
≥ 5	1	0	0	0	1	1
Total	56	102	66	66	73	108

Table 31. Probability (%) for Up and Down Trends of Various Length in Illinois.

Trend Persistence (Years)	Probability (%) for Given Condition					
	Corn		Beans		July Rainfall	
	Up	Down	Up	Down	Up	Down
≥ 2	12	19	14	15	15	20
≥ 3	2	7	3	2	4	7
≥ 4	<1	<1	<1	<1	<1	1

Table 31 shows the probability (%) for up and down trends in Illinois. The probabilities are averages obtained from combining data for each of the nine districts. Inspection of the data for individual districts indicated that trend persistence does not vary significantly throughout the state. The average district has an area of approximately 16,300 km^2 (6300 mi^2). Probabilities are shown for trends persisting for two, three, and four consecutive years.

The general conclusion from the percentages in Table 31 is that any useful predictability of the yield trends for the coming year, obtainable from the sequences of past events, must rely largely upon what has happened in the previous two years. That is, trends seldom persist for three years or longer. It is obvious from Table 31 that a reversal in trend is very likely in both corn and bean yields after two consecutive years of an up or down trend (over 80% probability). If a 3-year trend is present, the trend predictability for the coming year is very high (93% to 98% probability of reversal). Analyses were not performed for the other states, since Illinois is a typical corn belt state, and there was no reason to hypothesize any radical difference in the other four states.

INTRASEASONAL PREDICTIONS OF MONTHLY RAINFALL AND TEMPERATURE DURING GROWING SEASON

As discussed elsewhere in this report, corn and soybean yields are more strongly related to rainfall and temperature conditions in July and August, than to other weather factors tested in this research. Therefore, a study was undertaken to determine the potential predictability of weather conditions in Illinois during these two months through use of contingencies determined from sequences of temperature and rainfall preceding these months. In this study, July rainfall and monthly mean temperature were related to rainfall and temperature in June, and August weather was correlated with both June and July conditions. The analyses were performed initially on a district basis. However, small samples in some of the weather combinations made interpretation of the district results questionable. Since there was no strong tendency indicated for the intraseasonal relations to vary within the state, all district data were then combined to provide a more stable relationship applicable to districts or areas of similar size within the state.

Rainfall and temperature for each month was classified into three groups which were labeled below, near, and above normal. As a result of analyses performed in other phases of the research (discussed in Crop Weather Response Classification section), the data were separated so that 29% of the cases fell into the below-normal category, 29% were above normal, and 42% were classified as near-normal weather. Below-normal weather (cool and dry) was typed as "1"; near-normal was "2"; and, above-normal (hot and wet) was "3".

Results are summarized in Table 32. In this table, the probability (%) of below-normal, near-normal, and above-normal rainfall or temperature for a given month is related to weather conditions in the previous month. For example, the first relationship shown is between June and July rainfall. With dry conditions in June (below-normal), the 1931-1975 data indicate the probability is 37% that July will continue dry, 36% that rainfall will increase to near normal, and 27% that a reversal from dry to wet conditions will prevail. If no relationship existed between June and July rainfall, the probability of each of the three July conditions would be 33%, on the average. In the above example, the probabilities indicate very little predictability of July rainfall from June rainfall. The highest July probability (37%) does not significantly exceed the average "guess" value of 33%.

Table 32. Relation Between Rainfall and Temperature in Successive Months.

June	Probability (%) for July Rainfall		
Rainfall	Dry	Near-Normal	Wet
Dry	37	36	27
Near-Normal	25	47	28
Wet	25	43	32

June	Probability (%) for July Temperature		
Temperature	Cool	Near-Normal	Hot
Cool	46	30	24
Near-Normal	31	56	13
Hot	11	32	57

June	Probability (%) for July Rainfall		
Temp.-Rain	Dry	Near-Normal	Wet
Cool-Dry	33	42	25
Cool-Normal	39	28	33
Cool-Wet	28	37	35
Normal-Dry	30	36	34
Normal-Normal	18	54	28
Normal-Wet	16	53	31
Hot-Dry	43	35	22
Hot-Normal	24	51	25
Hot-Wet	62	25	13

July	Probability (%) for August Rainfall		
Rainfall	Dry	Near-Normal	Wet
Dry	21	46	33
Near-Normal	31	37	32
Wet	34	47	19

July	Probability (%) for August Temperature		
Temperature	Cool	Near-Normal	Hot
Cool	41	42	17
Near-Normal	31	43	26
Hot	17	40	43

Table 32. (Continued)

June-July Rainfall	Probability (%) for August Rainfall		
	Dry	Near-Normal	Wet
Dry-Dry	14	52	34
Dry-Normal	29	29	42
Dry-Wet	34	44	22
Normal-Dry	19	43	38
Normal-Normal	31	38	31
Normal-Wet	37	46	17
Wet-Dry	33	40	27
Wet-Normal	35	41	24
Wet-Wet	30	51	19

July Temp.-Rain	Probability (%) for August Rainfall		
	Dry	Near-Normal	Wet
Cool-Dry	24	56	20
Cool-Normal	21	35	44
Cool-Wet	28	47	25
Normal-Dry	33	38	29
Normal-Normal	30	38	32
Normal-Wet	43	45	12
Hot-Dry	22	41	37
Hot-Normal	43	37	20
Hot-Wet	17	58	25

June-July Temperature	Probability for August Temperature		
	Cool	Near-Normal	Hot
Cool-Cool	27	55	18
Cool-Normal	25	44	31
Cool-Hot	29	13	58
Normal-Cool	49	32	19
Normal-Normal	34	45	21
Normal-Hot	27	32	41
Hot-Cool	67	25	8
Hot-Normal	26	33	41
Hot-Hot	8	60	32

The highest probability in each classification in Table 32 has been underlined. Reference to the underlined values indicates they range most frequently between 40% and 50%, which is somewhat higher than expected from pure chance occurrences, but not high enough to qualify as a single, valid predictor of rainfall or temperature in the coming month. However, when used in combination with other predictors, the contingencies in Table 32 might be very useful.

In Table 32, use has been made of both single and double predictors. It was hypothesized that the double predictors might improve the predictability substantially. Overall, this did not occur. This is evident from reference to the probabilities for August rainfall using 1) only July rainfall, 2) June and July rainfall, and 3) July rainfall and temperature. The maximum probabilities among the various predictor groups remains in the same general range (mostly 40%-50%) when two predictors are used instead of July rainfall only.

The predictability of temperature appears to be somewhat better than rainfall. This can be deduced from reference to the maximum probability in each classification for August rainfall and temperature, based on June-July rainfall and temperature. In nearly every case, the August maximum probability is greater for temperature than rainfall.

The type of rainfall conditions occurring in August following two consecutive dry or wet months is of interest. Thus, if both June and July are dry, a reversal to near-normal or wet conditions is highly likely in August. That is, the probability is 86% (over 4 chances in 5) that August will be near to above normal. This has implications with regard to crops which have a substantial dependency on August rainfall. For example, initiation of a weather modification program in August following dry conditions in June and July would be highly questionable. The probability of August being dry to near normal after two wet months is 81%

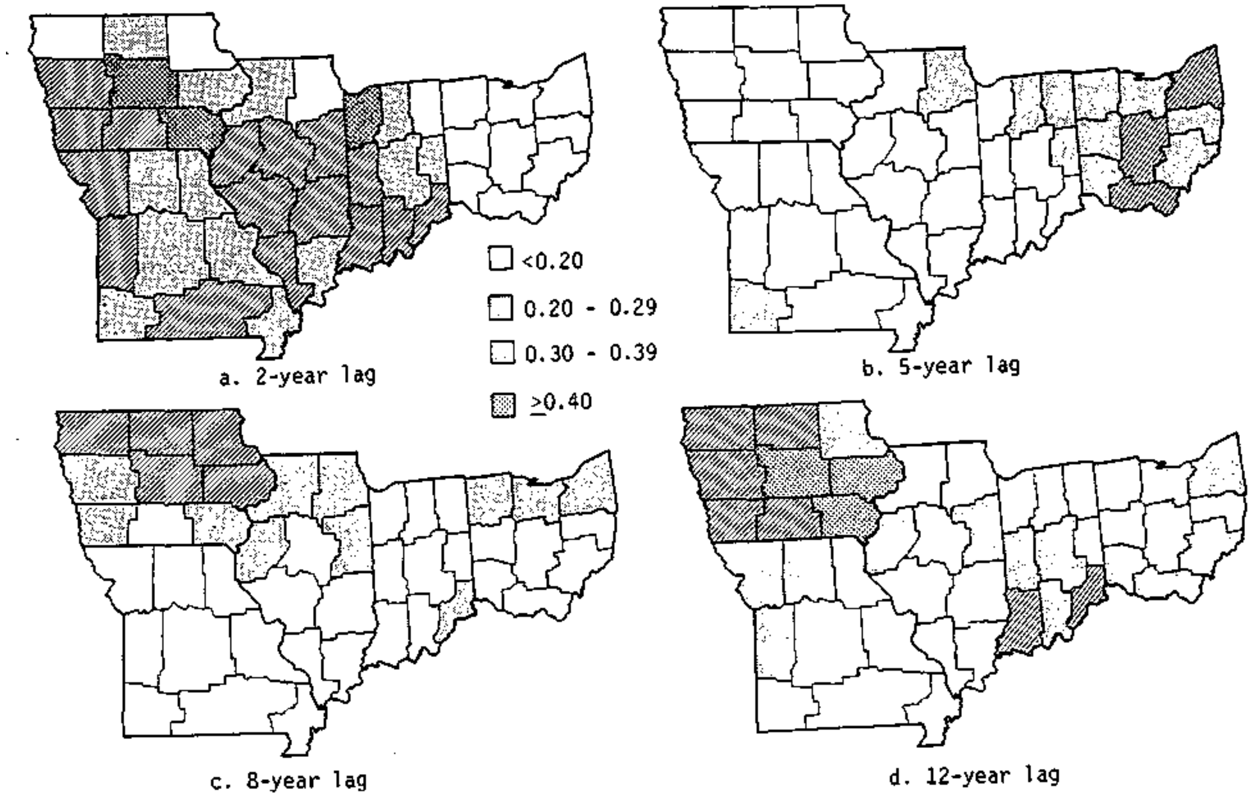
according to Table 32. Thus, three successive dry or wet months seldom occur in summer in Illinois, which is a typical midwestern state with respect to precipitation climate.

LAG CORRELATION ANALYSIS OF CORN YIELDS

In another effort to evaluate the time distribution characteristics of crop yields and the potential statistical predictability contained in their yield sequences, lag correlation analysis was performed for each of the 45 districts within the 5-state Corn Belt. This analysis was first made for corn. The correlations were performed on percent deviations from mean yield adjusted for technology trend. Computations were made for lags of 1 to 15 years.

Most lag correlation coefficients were less than 0.3 and none exceeded 0.5. The best lag varied in different parts of the 5-state area. Thus, in northern Illinois the highest correlation coefficients were obtained with an 8-year lag, for which values of -0.28 and -0.29 were obtained for Districts 1 and 2. In the rest of Illinois, the best correlations were obtained with a 2-year lag. The best lag in Iowa, in general, was 12 years with values ranging from -0.27 to -0.44. In Indiana, 2-year lags were also best, but ranged only from 0.2 to 0.4. In Missouri, lag coefficients were between 0.2 and 0.4 with the best lag periods, 2 and 14 years. In Ohio, a 5-year lag was best with coefficients ranging from 0.2 to about 0.4. Correlation patterns for lags of 2, 5, 8, and 12 years are shown in Figs. 11a to 11d.

Overall, the 2-year lag was best for the five states combined. However, the median coefficient was 0.29 which explains only 8% of the variance. Therefore, the general conclusion from this analysis is that there is very



a. 2-year lag

b. 5-year lag

c. 8-year lag

d. 12-year lag

Figure 11. Correlation patterns for lags of 2, 5, 8, and 12 years.

little of a cyclical or oscillatory nature in corn yields from year-to-year that provides a basis for the prediction of future yields. In view of the relatively low correlations obtained with corn, no effort was made to do the same analysis for beans.

FREQUENCY DISTRIBUTION OF JULY RAINFALL AND TEMPERATURE

July rainfall and temperature were found to be the weather factors most strongly associated with crop yields in the Corn Belt, especially corn yields. Therefore, an analysis was made of the spatial and temporal distribution characteristics of these important parameters in the crop yield-weather relationship. Frequency distributions were computed first for each of the 45 districts in the 5-state area through use of the 1931-1975 sample. These were then combined to obtain state and multi-state relationships. Frequency distributions were computed for 1-year to 5-year moving averages. The distributions for each state and state group were based upon the median deviations from July mean values for the incorporated districts.

July Rainfall

The rainfall frequency distributions were determined from the deviations expressed as a percent of the monthly mean rainfall. Distributions for each state and selected group of states are summarized in Table 33, based upon annual values of July rainfall. Similar relationships between areas were obtained when 2-year to 5-year moving averages were used, although as expected, the deviations become smaller as the averaging period increases. Consequently, only annual relations are presented here to illustrate areal variations in the characteristics of the frequency distributions.

Table 33. Frequency Distribution of Yearly Deviations from July Mean Rainfall.

	Deviation (%) for Given Percent of Years										
Region	5	10	20	30	40	50	60	70	80	90	95
Illinois	-61	-53	-40	-26	-14	-2	+10	+20	+32	+48	+60
Iowa	-66	-52	-36	-24	-14	-2	+9	+22	+38	+62	+85
Indiana	-58	-46	-32	-21	-12	-4	+4	+14	+42	+38	+51
Ohio	-46	-37	-26	-18	-8	-2	+4	+10	+18	+31	+44
Missouri	-69	-58	-42	-30	-20	-10	+1	+14	+30	+53	+77
Illinois-Iowa	-61	-50	-35	-24	-15	-5	+4	+14	+28	+49	+70
Illinois-Indiana	-60	-48	-32	-22	-12	-5	+3	+12	+22	+38	+58
Indiana-Ohio	-53	-40	-26	-16	-9	-3	+6	+12	+20	+34	+47
5 State Combined	-54	-44	-30	-21	-3	+4	+1	+8	+17	+31	+48

Table 34. Frequency Distribution of Yearly Deviations (°F) from July Mean Temperature.

Region	5	10	20	30	40	50	60	70	80	90	95
Illinois	-3.5	-3.0	-2.2	-1.5	-0.8	-0.3	+0.3	+1.0	+1.9	+3.3	+4.8
Iowa	-4.3	-3.4	-2.4	-1.6	-0.9	-0.3	+0.4	+1.2	+2.1	+3.4	+4.8
Indiana	-3.5	-2.8	-2.0	-1.4	-0.8	-0.4	+0.2	+0.9	+1.8	+3.2	+4.6
Ohio	-3.2	-2.6	-1.9	-1.4	-0.9	-0.4	+0.2	+0.7	+1.4	+2.6	+3.8
Missouri	-4.2	-3.4	-2.4	-1.7	-1.0	-0.4	+0.4	+1.2	+2.3	+3.8	+5.2
Illinois-Iowa	-3.6	-2.9	-2.1	-1.5	-1.0	-0.5	+0.2	+1.1	+2.1	+3.3	+4.4
Illinois-Indiana	-3.5	-3.0	-2.2	-1.5	-0.8	-0.3	+0.4	+1.1	+2.0	+3.1	+4.2
Indiana-Ohio	-3.2	-2.6	-1.9	-1.3	-0.8	-0.3	+0.3	+1.0	+1.8	+3.0	+4.2
5 States Combined	-3.4	-2.9	-2.1	-1.4	-0.8	-0.3	+0.4	+1.0	+1.9	+3.2	+4.5

Comparison of the five states shows a general decreasing trend in the size of the deviations from west to east across the 5-state area, and this agrees with the trend for corn and bean yields discussed earlier in this report. For example, at the 20-percent level, the median deviation decreases from -40% in Iowa, to -26% in Ohio. At the 80-percent level, a decrease from +32% in Iowa to +18% in Ohio is indicated. Similar to findings for crop yields, the largest yearly deviations from the mean occur in Missouri and the smallest deviations in Ohio. The similarity in time-space distribution characteristics between crop yields and July rainfall reflects the relatively strong dependency of yields on natural fluctuations in weather from year-to-year.

July Temperature

The temperature frequency distributions were determined from the deviations (°F) from July mean temperature. They were computed for the same combinations of states as the rainfall distributions. Results for the frequency distribution of annual deviations are presented in Table 34.

Similar to rainfall, there is a decreasing trend from west to east in the temperature deviations. Iowa and Missouri have similar distributions and show the most extreme deviations with a range from -4°F to +5°F between the 5-percent and 95-percent probability levels. Of the year-to-year values, Ohio exhibits the smallest deviations with a range from approximately -3° to +4°. The west-east trend was maintained when frequency distributions were determined from 2-year to 5-year moving averages, but, of course, the magnitude of the deviations decreased with increasing averaging period.

REGIONAL DIFFERENCES IN TEMPORAL RELATIVE VARIABILITY OF CROP YIELDS AND WEATHER FACTORS IN ILLINOIS

The intrastate variability in weather and crop yields was investigated through use of data from the nine crop districts in Illinois. For this purpose, the districts were divided into four groups. These included Districts 1 and 2, 3, 4, and 5; 6 and 7; and, 8 plus 9. Corn yield, bean yield, July rainfall, and July temperature were analyzed. Frequency distributions were calculated for each group. For corn and beans, the frequency distributions were based on percent deviation from mean yield, after adjustment for technology trend. Distributions were computed for percent deviation from the mean for July rainfall and deviation from mean monthly temperature in °F.

Results of the investigation are summarized in Table 35. Corn and bean yields show a definite trend for the temporal relative variability to increase southward in the state. This increase is related to the greater weather dependency of the crops in southern Illinois compared with the northern part of the state. The percentage frequency distributions for July rainfall show only relatively minor fluctuations within the state. There is no significant differences indicated among the district groups for monthly temperature deviations.

Table 35. Percentage Frequency Distribution of Crop Yields and Weather Factors in Illinois.

Deviation [%) Equalled or Exceeded for Given Percent of Years

District Group	10	20	30	40	50	60	70	80	90
Corn									
1 & 2	-19	-9	-3	0	2	5	7	9	15
3,4, & 5	-24	-15	-9	-4	0	5	9	13	17
6 & 7	-28	-16	-10	-4	0	4	9	14	21
8 & 9	-28	-19	-12	-7	-2	3	9	15	24
Beans									
1 & 2	-12	-7	-3	-1	1	3	5	7	10
3,4 & 5	-22	-16	-9	-5	-2	2	4	7	13
6 & 7	-18	-11	-6	-2	1	4	8	10	14
8 & 9	-25	-15	-8	-3	1	5	9	14	19
July Rainfall									
1 & 2	-50	-32	-20	-9	0	10	21	34	51
3,4 & 5	-59	-43	-26	-13	-1	10	24	38	59
6 & 7	-54	-39	-28	-18	-8	4	18	37	66
8 & 9	-50	-37	-28	-19	-9	2	14	30	55
July Temperature (°F)									
1 & 2	-2.8	-2.0	-1.3	-0.7	-0.1	+0.5	1.2	1.9	3.1
3,4, & 5	-3.1	2,3	-1.5	-0.8	-0.2	+0.4	1.1	1.9	3.2
6 & 7	-3.2	-2.3	-1.5	-0.9	-0.3	+0.4	1.1	2.0	3.5
8 & 9	-3.0	2.1	-1.4	-0.8	-0.2	+0.4	1.1	1.9	3.1

CROP WEATHER RESPONSE CLASSIFICATION

Introduction

Crop-weather regression models (discussed previously in the model development section) require temperature and rainfall values for extrapolation or prediction of crop yields. However, the capability of predicting accurate monthly and seasonal temperature and rainfall values for use in crop-weather regression models and other purposes is not a reality. Prediction of weather trends such as wet, normal, dry, hot, or cool is nearer to being possible. These are the first steps toward achieving more accurate quantitative predictions. Consequently, crop-weather models that can utilize less precise quantitative data are needed. Prediction models that accept weather-trend estimates such as near-normal, above-normal, and below-normal could be used to obtain crop yield trends. To serve this prediction purpose, crop-weather models based on below-, near-, and above-normal weather classes or types were developed.

Data Used

Three sets of data were used in the classification study. The first consisted of July and August monthly average temperatures plus July and August monthly rainfall totals. These were the most significant variables found in the crop-weather regression modelling. The second data set were the annual corn yield deviations from the corn-weather trend model (see previous section of this report). The third data set were annual soybean yield deviations from the previously determined soybean-weather trend model. These data from each of the 45 crop reporting districts for 1931 through 1975 were used to achieve corn-weather classifications. Data for 1944-1975 were used to obtain 5-state soybean-weather classifications.

Crop-Weather Classification Development

Many arbitrary choices can be made in classifying crop-weather types, i.e., the number of classes and the class boundaries. For example, Changnon (1969) determined seasonal weather types based on a grouping of historical values into three equal parts: above-normal (upper 1/3 of the values), normal (middle 1/3), and below-normal (lower 1/3).

The number of sets (combinations) increases rapidly with an increase in the number of classes and the number of variables analyzed. The number of combinations (categories) can be expressed as N^n, where N is the number of classes and n is the number of variables. Consequently, 4 variables classified simultaneously into 3 classes (below-, near-, and above-normal) generates 81 combinations. It is evident that a very long data record (at least 100 years for example) is needed in order for each weather combination to occur at least once. Since we had only 45-year records for crop reporting districts, the alternative was to limit the number of classes and the number of variables analyzed simultaneously.

Three classes were adopted for the study as the first step in holding the number of combinations to a workable and yet meaningful limit. A computer program was prepared to separate the 45 years of each crop reporting district into three classes with options for setting class boundaries.

A choice of boundaries for the three classes can be arrived at in a number of ways. In the statistical (frequency) distribution sense, a greater number of crop yield deviations from technology trend, July and August temperatures and rainfall totals tend to cluster in the vicinity of their respective means. That is, the majority of crop yields are associated with a group (class) of similar weather conditions. Likewise, it is the more extreme weather conditions (favorable and unfavorable) that contribute to food surpluses and deficiencies.

With this reasoning in mind, the authors chose class boundaries that would place a greater number of yields in the near-normal class and a lesser number in each of the above- and below-normal classes. For the initial classification analysis for corn, boundaries were fixed so 13 of each 45-district yield set would be placed in each of the below- and above-normal classes and 19 would be in the near-normal class. This produced an approximate 29, 42, 29% grouping for below-, near-, and above-normal, respectively.

The classification described above was accomplished in the following manner: 1) the computer program ranked (ordered) each column of the time series data (yield deviations, July temperature, etc.,) matrix from low to high in preparation for computerized setting and use of class boundaries, and 2) computer instructions were set to use the values of the 13th and 32nd rows (lines) of the ranked data matrix as upper and lower boundaries, respectively, of the near-normal (middle) class. That is, values in each of the unranked matrix columns which were equal to or less than the corresponding value of the 13th row of the ranked matrix were counted as belonging in the below-normal class. Those greater than the value located in the 32nd row were counted as belonging in the above-normal class. Remaining values were in the near-normal class.

The classification procedure is illustrated in Table 36 for corn yield deviations, July temperature and rainfall, and August temperature from Illinois district 3 (west-central Illinois). The unranked (time series) data matrix is shown on the left side of the table and the ranked values are on the right. Data for the year 1947 are underlined in the ranked matrix to illustrate the classification determined for that year. Corn yield was below-normal. Corresponding July temperature and July rainfall, and August temperature were below-, below-, and above-normal, respectively. In this case, the computer would add 1 to the frequency count for the below-, below-, below-, above-normal category.

Table 36. An Illustration of Class Boundary Determination and Application to Data Classification for District 3 in West-Central Illinois (1931-1975).

	Unranked Data Matrix				Ranked Data Matrix				
Year	Corn Yield Dev. %	Jul Temp.	Aug Temp.	Jul Rain	Corn Yield Dev. %	Jul Temp.	Aug Temp.	Jul Rain	Row No
					Below-Normal				
31	-9.70	79.90	74.20	3.54	-60.60	72.00	69.10	0.58	1
32	5.90	77.80	74.50	4.99	-58.70	72.30	69.70	0.94	2
33	-24.30	78.10	73.60	1.72	-35.60*	72.40	70.30	1.35	3
34	-60.60	84.30	77.40	2.08	-24.30	72.60	71.50	1.72	4
35	-20.90	80.20	76.20	5.02	-20.90	73.50*	71.70	1.78	5
36	-58.70	85.60	82.50	0.58	-19.80	74.00	72.30	1.84	6
37	22.10	77.00	78.70	4.39	-18.70	74.00	72.50	1.91	7
38	-1.70	77.80	78.00	4.15	-15.00	74.20	72.60	1.92	8
39	15.70	76.80	72.60	3.58	-12.90	74.30	72.80	1.93*	9
40	-0.10	77.30	73.60	1.84	-9.70	74.30	73.00	2.03	10
41	12.60	76.60	77.00	2.07	-8.50	74.70	73.20	2.07	11
42	17.70	76.40	73.50	4.53	-5.90	74.90	73.50	2.08	12
43	7.50	77.20	76.60	4.26	-3.80	75.00	73.50	2.26	13
					Near-Normal				
44	1.20	75.70	74.90	1.91	-3.00	75.00	73.60	2.64	14
45	-18.70	74.00	75.30	0.94	-2.60	75.30	73.60	2.91	15
46	16.50	76.90	70.30	1.35	-1.80	75.30	74.00	3.00	16
47	-35.60	73.50	82.90	1.93	-1.70	75.60	74,00	3.05	17
48	24.00	75.60	75.20	8.62	-0.50	75.70	74.00	3.10	18
49	-1.80	73.70	75.00	4.15	-0.20	75.90	74.10	3.29	19
50	-0.50	72.40	69.70	5.26	-0.10	75.90	74.20	3.41	20
51	1.60	75.30	73.50	5.07	0.50	76.10	74.30	3.49	21
52	4.40	77.60	73.00	2.91	1.20	76.40	74.50	3.54	22
53	-12.90	77.90	76.10	2.64	1.60	76.60	74.70	3.58	23
54	-5.90	79.90	75.10	2.03	2.30	76.80	74.80	3.65	24
55	-3.80	81.10	77.90	1.78	3.20	76.90	74.90	3.65	25
56	3.20	75.30	75.30	5.97	3.20	77.00	75.00	4.01	26
57	-3.00	78.90	75.70	3.10	3.40	77.20	75.00	4.15	27
58	10.90	72.60	74.80	8.41	4.40	77.30	75.10	4.15	28
59	-0.20	74.90	78.10	3.29	5.90	77.40	75.10	4.26	29
60	-15.00	74.00	75.10	3.65	7.50	77.60	75.20	4.28	30
61	8.00	74.70	74.30	8.90	8.00	77.60	75.30	4.39	31
62	9.00	74.20	74.70	4.28	8.40	77.80	75.30	4.45	32
					Above-Normal				
63	8.40	76.10	72.80	6.02	9.00	77.80	75.40	4.53	33
64	2.30	77.40	73.20	3.00	9.60	77.90	75.70	4.99	34
65	13.50	74.30	72.50	4.45	10.90	78.00	76.10	5.02	35
66	-2.60	79.60	71.50	1.92	12.60	78.10	76.20	5.07	36

Table 36. (Continued)

	Unranked Data Matrix				Ranked Data Matrix				
Year	Corn Yield Dev. %	Jul Temp.	Aug Temp.	Jul Rain	Corn Yield Dev. %	Jul Temp.	Aug Temp.	Jul Rain	Row No
67	14.30	72.30	59.10	6.51	13.50	78.70	76.60	5.26	37
68	3.40	74.30	74.00	3.65	14.30	78.90	77.00	5.39	38
69	0.50	77.60	74.00	6.59	14.80	79.60	77.40	5.97	39
70	-19.80	75.90	74.00	3.49	15.70	79.90	77.90	6.02	40
71	14.80	72.00	72.30	4.01	16.50	79.90	78.00	6.51	41
72	16.70	75.00	74.10	3.41	16.70	80.20	78.10	6.59	42
73	3.20	75.90	75.00	5.39	17.70	81.10	78.70	8.41	43
74	-8.50	78.00	71.70	3.05	22.10	84.30	82.50	8.62	44
75	9.60	75.00	75.40	2.26	24.00	85.60	82.90*	8.90	45

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*Values for 1947

Classification of 4 variables (as illustrated above) produces 81 possible categories. Only 33 of the 81 were represented (occurred) during the 45-year record in west-central Illinois. The number of occurrences of each of the possible categories was also too small to establish a frequency distribution. This emphases the necessity of limiting the number of variables to be analyzed. Therefore, much of the analysis was done with three variables (crop yield and two weather variables) which limited the number of possible categories to 27. Weather variables chosen were the most important (July-August temperature and rainfall) in explaining corn and soybean yields.

Further discussion of the classification procedure is illustrated with soybean yield deviations. They were classified with July temperature and rainfall to relate soybean yield categories with July weather classifications for 1931-1975 in Illinois and Iowa (only states with 45-year soybean yield records). A series of four maps (Fig. 12) is shown for Illinois and Iowa to illustrate the results of classifying crop yield deviations with July weather. In the four maps,

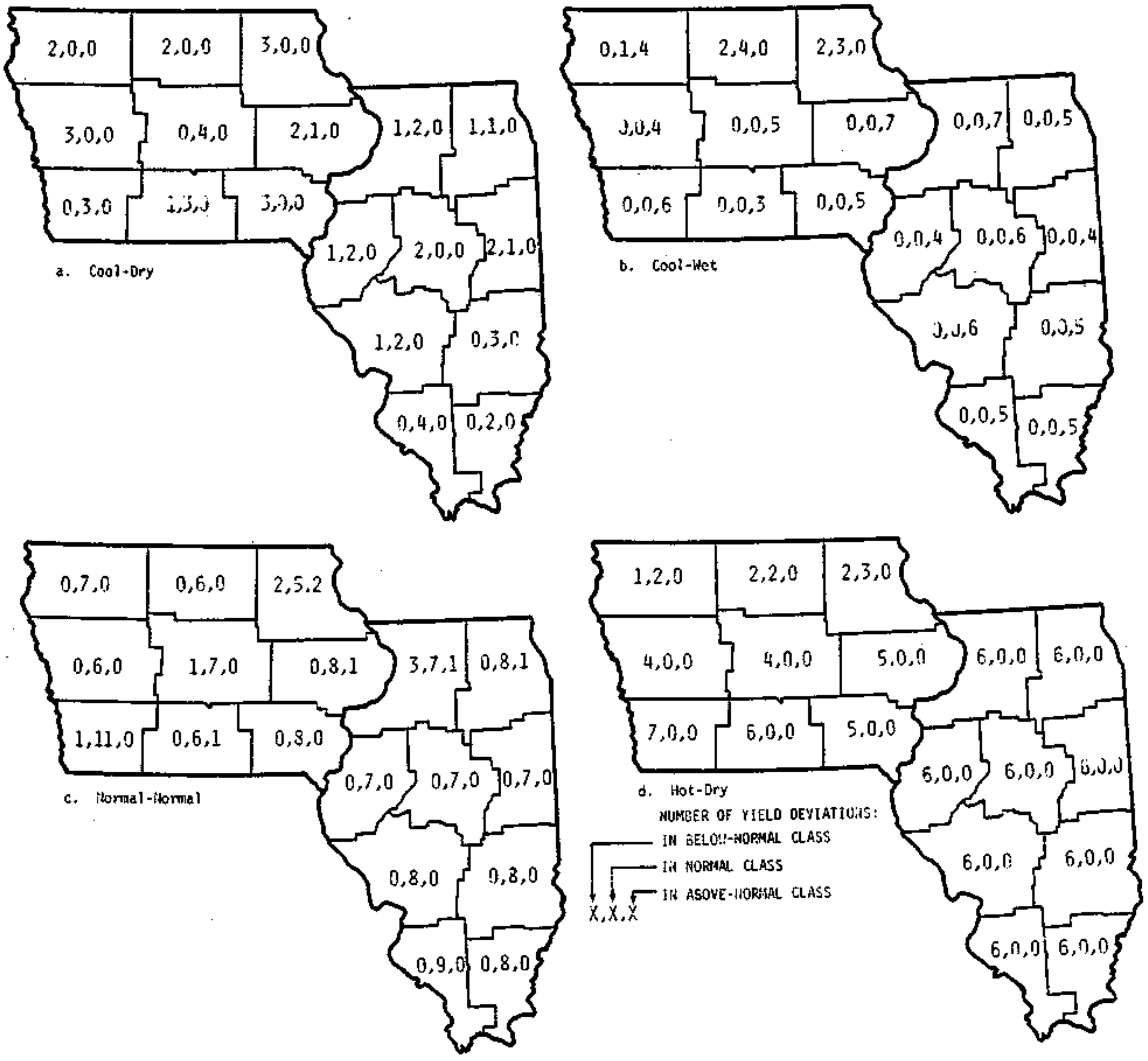

Figure 12. Soybean yield response to July temperature and rainfall, Illinois and Iowa, 1931-1975.

"cool-dry" refers to below-normal for both July temperature and rainfall; "cool-wet" is below-normal temperature and above-normal rainfall; "hot-dry" is above-normal for temperature and below-normal for rainfall; and "normal-normal" is near-normal (near-normal will be called normal hereafter) for both July variables. Soybean yield response to July weather in Illinois and Iowa is very evident (Fig. 12). Below-normal and normal yields occurred with cool-dry Julys. Predominately above-normal yields were associated with cool temperature and above-normal rainfall. The central (normal) and greater percentage of occurrence class experienced predominately normal yields. There were no above-normal yield deviation occurrences associated with the hot-dry July weather type. Only northern Iowa districts experienced some yields in the normal class with their hot-dry Julys. Conditions classified as hot-dry in northern Iowa may not produce as much moisture stress for crops as they do in more southerly latitudes of Iowa and Illinois.

District yield occurrences, as shown in Figure 12, for below-, normal, and above-normal were accumulated (counted) over all 18 districts. District-year counts are tabulated in Table 37. This table is a tabular summary of the soybean yield relationships shown in Figure 12. Tabular (contingency table) summaries will be used to depict the results of subsequent classification analyses. The distribution of counts in Table 37 and subsequent tables is a function of crop-weather relationships and the class boundaries used in each analysis.

Five-State Crop-Weather Classification

Corn Yield and July Weather (29, 42, 29% Classification).

The procedure outlined above was done for corn yield deviations with July temperature and rainfall for each of the 45 crop reporting districts involved in the 1931-1975 study. The 29, 42, 29% class grouping was used. Frequency counts of the 2025 district-years are tabulated in Table 38 for this time-space association of corn yield with July weather. The number of yield deviations below-normal (B), normal (N), and above-normal (A) for each of the nine July temperature and rainfall pairs is indicated in the table. Percent of the total number of district-years for each category is also shown in the table. The table is arranged in temperature blocks to aid visualizing the effect of the rainfall increasing from below- to above-normal. It is clear (as expected) that the number of yield deviations shifts from the below-normal class toward the normal- and above-normal classes as rainfall increases from below- to above-normal. Over the five-state area for 1931 through 1975, the second largest number of occurrences (182) for the 27 categories was associated with hot-dry Julys (yield depressing conditions). Hot-dry Julys totaled 247 or 12.2 percent of the 2025 district-years in this time-space study. Thus, seventy-four percent (182/247) of the hot-dry district-years experienced below-normal corn production.

Table 37. Number of Below-, Normal-, and Above-Normal Soybean Yield Deviations from Technology Trend Related to Four July Weather Types (Illinois and Iowa, 1931-1975).

July Weather Types*	Number of Yield Deviations (District-Years) B	N	A	Totals
Cool-Dry (BB)	24	28	0	52
Cool-Wet (BA)	4	8	81	93
Normal-Normal (NN)	7	133	6	146
Hot-Dry (A,B)	90	7	0	97

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* B, N, A represent below-, normal-, and above-normal, respectively. Class boundaries were determined so approximately 29, 42, and 29% of the values were grouped into B, N, A, respectively.

The beneficial effect of above-normal rainfall can be assessed by an inspection of the number of yield deviations associated with the three above-normal July rainfall types (cool-wet, normal-wet, and hot-wet). These occurrences total 270 (114 + 131 + 25) or 13.3 percent of the district years. Results show that 46.5 percent (131/270) of the above-normal yields were associated with normal-wet district-years, compared to 9.3 percent (25/270) for hot-wet, and 42.2 percent (114/270) for cool-wet Julys.

The two columns (totals) on the right hand side of Table 38 show frequency data for the nine July weather types independent of any association with corn yield. Hot-wet Julys occurred least frequently of the nine types. Cool-dry also occurred less often than most types. Normal-normal occurred the greater number of times (16.9%), etc.

Corn Yield and July Weather Classification with Class Boundaries Set at ±10% for Yield Deviations. Classification results presented in the previous section were determined with class boundaries set to provide a 29, 42, 29% grouping for the classes (same for all districts). An alternative to a fixed class boundary is one determined by a certain crop yield deviation percent of technology trend. Class boundaries of this type are directly associated with crop yield deviations from technological trend in each district. The percentage of district-years in each class will vary from district to district, as dictated by yield variation about the technological trend line for each district. For this alternative class separation, below- and above-normal were set at ≤ 10 and > 10 percent, respectively. This class boundary selection will increase the range of the normal class as compared to the previous classification (see Table 36) and put the more extreme yield cases into the upper and lower groups.

Table 38. Corn Yield, Deviations from Trend, Response to July Temperature and Rainfall Classified into 3 Groups* for the 5-State Area, 1931-1975.

July Weather Types*		Number of Yield Deviations (District-Years) and Percent of Total District Years							
		B		N		A		Totals	
		No	%	No	%	No	%	No	%
Cool-Dry	(BB)	51	2.5	48	2.4	15	0.7	114	5.6
Cool-Normal	(BN)	44	2.2	119	5.9	108	5.3	271	13.4
Cool-Wet	(BA)	27	1.3	74	3.7	114	5.6	215	10.6
Subtotals and %		122	6.0	241	11.9	237	11.7	600	29.6
Normal-Dry	(NB)	110	5.4	84	4.1	33	1.6	227	11.2
Normal-Normal	(NN)	47	2.3	186	9.2	110	5.4	343	16.9
Normal-Wet	(NA)	22	1.1	132	6.5	131	6.5	285	14.1
Subtotals and %		179	8.8	402	19.9	274	13.5	855	42.2
Hot-Dry	(AB)	182	9.0	57	2.8	8	0.4	247	12.2
Hot-Normal	(AN)	82	4.0	121	6.0	37	1.8	240	11.9
Hot-Wet	(AA)	22	1.1	36	1.8	25	0.1	83	4.1
Subtotals and %		286	14.1	214	10.6	70	3.5	570	28.1
Totals and %		587	29.0	857	42.3	581	28.7	2025	100.0

* B, N, A represent below-normal, normal, and above-normal, respectively. Class boundaries for each of the 45 crop reporting districts were determined so approximately 29, 42, and 29% of the values were grouped into B, N. A classes, respectively.

Table 39. Corn Yield Deviations from Trend Response to July Temperature and Rainfall Classifications* for the 5-State Area, 1931-1975.

July Weather Types*		Number of Yield Deviations (District-Years) and Percent of Total, 2025 District Years							
		B		N		A		Totals	
		No	%	No		No	%	No	%
Cool-Dry	(BB)	35	1.7	40	2.0	8	0.4	83	4.1
Cool-Normal	(BN)	39	1.9	128	6.3	84	4.1	251	12.4
Cool-Wet	(BA)	15	0.7	57	2.8	116	5.7	188	9.3
Subtotals and %		89	4.4	225	11.1	208	10.3	522	25.8
Normal-Dry	(NB)	92	4.5	80	3.9	23	1.1	195	9.6
Normal-Normal	(NN)	46	2.3	245	12.1	130	6.4	421	21.0
Normal-Wet	(NA)	13	0.6	138	6.8	143	7.1	290	15.0
Subtotals and %		151	7.5	463	22.9	296	14.6	910	45.0
Hot-Dry	(AB)	167	8.2	54	2.7	5	0.2	226	11.0
Hot-Normal	(AN)	77	3.8	150	7.4	39	1.9	266	13.0
Hot-Wet	(AA)	18	0.9	49	2.4	34	1.7	101	5.0
Subtotals and %		262	12.9	253	12.5	78	3.9	593	29.0
Totals and %		502	24.8	941	46.5	582	28.7	2025	100.0

* B, N, A represent below-normal, normal, and above-normal, respectively. B, N, A class boundaries for each of the 45 crop reporting districts were determined by the crop yield deviation which was set at 510% for the below-normal boundary and at ≥10% for the above-normal boundary.

The computer program was adjusted for computing the new class boundaries and the analysis procedure of the previous section was repeated for corn yield deviations from trend with July temperature and rainfall. Frequency tabulations for this analysis are presented in Table 39. This table does show a greater number of occurrences in the normal temperature class and in the hot temperature class than is shown in Table 38. The below-normal (B) yield categories contain lower counts since the -10 percent class boundary is set farther from the median deviation (Table 36). Other category adjustments from Table 38 to Table 39 are not as obvious. The relationship between corn yield and July weather is apparent in Table 39 (as it was in Table 38). For example, increasing rainfall while the temperature class is held constant is associated with a decrease in below-normal yields.

Soybean Yield Deviation Classification with July Weather and August Weather. The 5-state (45-district) classification analysis for soybean yield was reduced to a 32-year period, 1944 through 1975, to establish a common yield record for all districts. Upper and lower class boundaries for the normal band were set to include 12 values of each district record. This left 10 values in each of the below- and above-normal classes for an approximate 31, 38, 31% grouping of 1440 district-years.

Frequency counts for each of the 27 categories are presented in Tables 40 and 41 for soybean yield related to 1) July temperature and rainfall, and 2) August temperature and rainfall. There is a dramatic increase in the number of district-years with above-normal yields as the July rainfall advances from dry to the wet classification with both cool and normal temperature classes (Table 40). July rainfall influence appears to have been least influential in

Table 40. Classification of Soybean Yield Deviations from Linear Technology Trend and July Weather Types.

Number of Yield Deviations (District Years) and Percent of Total (1440) District Years

July Weather Types*		B		N		A		Totals	
		No	%	No	%	No	%	No	%
Cool-Dry	(BB)	69	4.8	35	2.4	9	0.6	113	7.8
Cool-Normal	(BN)	54	3.7	95	6.6	52	3.6	201	14.0
Cool-Wet	(BA)	16	1.1	54	3.7	83	5.8	153	10.6
Subtotals and %		139	9.7	184	12.8	144	10.0	467	32.4
Normal-Dry	(NB)	57	4.0	53	3.7	41	2.8	151	10.5
Normal-Normal	(NN)	47	3.3	81	5.6	57	4.0	185	12.8
Normal-Wet	(NA)	22	1.5	77	5.3	97	6.7	196	13.6
Subtotals and %		126	8.8	211	14.7	195	13.5	532	36.9
Hot-Dry	(AB)	115	8.0	54	3.7	19	1.3	188	13.1
Hot-Normal	(AN)	54	3.7	60	4.2	43	3.0	157	10.9
Hot-Wet	(AA)	19	1.3	30	2.1	47	3.3	96	6.7
Subtotals and %		188	13.1	144	10.0	109	7.6	441	30.6
Totals and %		453	31.5	539	37.4	448	31.1	1440	100.0

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* B, N, A represent below-normal, normal, and above-normal, respectively. Class boundaries for each of the crop reporting districts were determined so an approximate 31, 38, 31% class grouping would be achieved.

Table 41. Classification of Soybean Yield Deviations from Linear Technology Trend and August Weather Types.

Number of Yield Deviations (District Years)
and Percent of Total (1440) District Years

August Weather Types*		B		N		A		Totals	
		No	%	No	%	No	%	No	%
Cool-Dry	(BB)	51	3.5	50	3.5	28	1.9	129	9.0
Cool-Normal	(BN)	51	3.5	51	3.5	68	4.7	170	11.8
Cool-Wet	(BA)	37	2.6	58	4.0	64	4.4	159	11.0
Subtotals and %		139	9.7	159	11.0	160	11.1	458	31.8
Normal-Dry	(NB)	52	3.6	84	5.8	45	3.1	181	12.6
Normal-Normal	(NN)	38	2.6	87	6.0	93	6.5	218	15.1
Normal-Wet	(NA)	25	2.7	64	4.4	58	4.0	147	10.2
Subtotals and %		115	8.0	235	16.3	196	13.6	546	37.9
Hot-Dry	(AB)	98	6.8	40	2.8	6	0.4	144	10.0
Hot-Normal	(AN)	54	3.8	58	4.0	38	2.6	150	10.4
Hot-Wet	(AA)	47	13	48	3.3	47	3.3	142	9.9
Subtotals and %		19S	13.8	146	10.1	91	6.3	436	30.3
Totals and %		453	31.5	540	37.5	447	31.0	1440	100.0

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* B, N, A represent below-normal, normal, and above-normal, respectively. B, N, A class boundaries for each of the 45 crop reporting districts were determined so an approximate 31, 38, 31% class grouping would be achieved.

producing normal- and above-normal yield with hot temperatures. However, there was a relatively small number of occurrence of district-years (96) with the hot-wet classification. In general, both tables document the favorable influence on soybean yields of cool and normal July and August temperatures and normal- to above-normal July-August rainfall.

Classification of Corn Yield with July and August Weather Factors. It was noted previously that difficulties arise when more than 3 variables are classified simultaneously. A very large sample is required before an entry can be expected for each category. Also, questions arise regarding how to handle those categories with a single observation or no occurrences in developing a prediction scheme.

Classifying a crop yield with four weather variables (July and August temperature and rainfall) would generate 3° or 243 categories (an unwieldy number). In this case, a weighting procedure is needed to reduce the number of categories and at the same time to retain the influence of each of the 4 weather variables in the analysis. Partial regression coefficients were used for this weighting purpose in the 5-state study. A July temperature factor was computed by multiplying the regression coefficient for corn yield on July temperature times the July temperature. This produced a July temperature weighted according to its' influence on corn yield. Similar products were determined for July rainfall, August temperature, and August rainfall. A single July weather influence on corn yield for each year was obtained by adding the regression-weighted July temperature and rainfall. An August weather factor was computed in the same manner. This adjustment reduced the classification of corn yield according to July and August weather to 3 variables and 27 categories. This weighting procedure was considered appropriate since it incorporated the crop production experience with the weather.

Class boundaries were dictated by the corn yield deviations from trend in each district. A criterion of 10% or more above or below normal was used to set the class boundaries. July and August weather factors (indices) were entered in the analysis procedure as new variables and classified in the same manner as observed values. The number of yield deviations and their percent of the total (2025) district-years are recorded in Table 42.

Yield deviation frequencies summarized in Table 42 depict the influence of the critical July-August weather season on corn production in the 5-state area. The 3-class separation procedure, with ≤10 and ≥ 10 percent yield deviations for class boundary criteria, produced an approximate 25, 46, 29 percent grouping of the yield deviations. The arrangement of Table 42 in sections which hold the July weather index at a constant class level while the August index is varied, tends to emphasize an August influence following a prior July index. For example, below-normal July and August (BB) seasons were associated with a relatively high number (154) of below-normal (B) yields. Varying the August index from B to N to A decreased the number of below-normal yields prominently. A low number of district-year above-normal yields (19) were associated with below-normal (B) July district-year indices. It is also apparent that above-normal August occurrences (95) following below-normal July indices were relatively infrequent. The most unfavorable (BB) July-August season occurred in 9.8 percent of the 2025 district years.

The remainder (middle and lower sections) of Table 42 shows a definite increase in the number of above-normal corn yields as the July index class goes from B to N to A. Improvement in the August district-year index was generally associated with a greater number of above-normal district-year yield deviations.

Table 42. Classification of Corn Yield Deviations from Quadratic Technology Trend with July and August Weather Indices.

Corn-Weather Index*		Number of Yield Deviations (District-Years) and Percent of Total (2025) District-Years							
		B		N		A		Totals	
Jul	Aug	No	%	No	%	No	%	No	%
B	B	154	7.6	40	2.0	4	0.2	198	9.8
B	N	119	5.9	85	4.2	5	0.2	209	10.3
B	A	32	1.6	53	2.6	10	0.5	95	4.7
Subtotals and %		305	15.1	178	8.8	19	0.9	502	24.8
N	B	45	2.2	128	6.3	34	1.7	207	10.2
N	N	72	3.6	280	13.8	119	5.9	471	23.3
N	A	20	1.0	137	6.8	107	5.3	264	13.0
Subtotals and %		137	6.8	545	26.9	260	12.8	942	46.5
A	B	19	0.9	52	2.6	24	1.2	95	4.7
A	N	25	1.2	112	5.5	127	6.3	264	13.0
A	A	20	1.0	55	2.7	147	7.3	222	11.0
Subtotals and %		64	3.2	219	10.8	298	14.7	581	28.7
Totals and %		506	25.0	942	46.5	577	28.5	2025	100.0

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[*] B, N, A represent below-normal, normal, and above-normal classes, respectively. Class boundaries were at ≤10 percent yield deviation and ≥10 percent yield deviation for below-normal and above-normal, respectively.

The percent of district-years experiencing each of the nine types of July-August seasons is presented in the right hand column of Table 42. Below-normal (B) July district-years were more frequently followed by (B) and (N) August corn-weather factors (9.8 and 10.3%, respectively) than by (A) August factors (4.7%). An (N) index for August is more likely to follow an (N) index for July than an (A) or a (B) August index. The (B) type August corn-weather index followed the (A) type July in 4.7% of the district-years as compared to 13.0% and 11.0% for (N) and (A) type Augusts, respectively.

A number of conditional probabilities or general predictions for a district in the 5-state area can be determined from the data of Table 42: 1) given that a (B) July has occurred, the conditional probability of a negative yield deviation from "expected" (trend) of 10% or more at harvest time is 305/502 or 0.61, 2) the probability of a yield deviation between ±10% of expected is 178/502 or 0.35 after the occurrence of (B) July, and 3) the probability of a yield deviation > than 10% of trend is only 0.04 following a (B) July. Probabilities for yields following (N) and (A) Julys can be determined from the table in the same manner. Also, yield probabilities can be determined as soon as July and August indices are both known. For example, the probability of a below-normal (B) yield is 154/198 or 0.78 following a (B) July and a (B) August season.

Prospective Application of Crop-Heather Models with Seasonal Trend Predictions as Input

It was noted previously (introduction to crop weather response classification) that crop-weather models that could accept weather-trend estimates as input were needed. The purpose of the crop-weather classification analyses has been the development of such a model or models.

Above-normal, normal, and below-normal weather trend estimates can serve as input into Table 42 to obtain conditional probabilities of below-, normal-, and above-normal yields. Thus, with the capability of making a (B) July and (8) August seasonal trend prediction, for example, the resulting probability of a below-normal corn yield is 154/198 or 0.78. The capability of making seasonal weather trend precitions is addressed in the final report for Phase II under NSF Grant ATM76-11379.

SUMMARY AND CONCLUSIONS

Purpose and Scope

The research discussed in this report involved a 3-year program whose major objective has been to provide useful estimates of future variations in crop production due to weather. Research was centered on the 5-state Corn Belt, including Iowa, Illinois, Missouri, Indiana, and Ohio, and on the two major crops in this region, corn and soybeans.

Crop-Weather Model Development

The search for an optimum model or models to represent corn and soybean-weather relationships was performed basically on Illinois data. Illinois is centrally located in the 5-state study area and crop-weather relationships were expected to be similar to that of the other four states. Data used for model development consisted of 1) monthly average temperature and monthly total rainfall and 2) annual corn and soybean yield averages. These were determined for each of the nine crop reporting districts for 1931 through 1975.

Any study involving the effects of weather fluctuations on crop production during 1931 through 1975 must deal with the problem of separating weather and technological influences. Since technological factors (e.g., planting density fertilizer application, hybrid seed) are not documented over areas the size of crop reporting districts or counties, it was necessary to select a "proxy" to represent the technology complex in the crop weather model development. The year of observation was tested as a linear, a quadratic, and a cubic factor to represent the expected yield increase over the study period resulting from the introduction of crop improvement and production factors.

The initial crop-weather analyses (Illinois data) involved regression with crop yield as the dependent variable. June, July, and August mean temperature, and rainfall totals, pre-season precipitation, plus the year of observation (1, 2, 3, —) were used as the independent variables. These weather factors were included in the early regressions because of their generally accepted importance in corn and soybean growth and development in Illinois and the Midwest. The initial Illinois data analysis involved a 39-year period from 1931-1969. The last six years of the 45-year period, 1970-1975, were reserved for testing the validity of the selected models.

Extensive model testing on the 39-year Illinois data sample indicated the following 1) July and August temperature, July rainfall, and the year of observation as a quadratic technology trend proxy were the optimum "independent" variables included in a corn-weather relationship, and 2) an optimum independent variable set for a soybean weather model included July and August temperature, July and August rainfall, and a linear trend proxy. Other weather factors included in the testing were not statistically significant as predictors in regression analysis.

The models selected above were used to obtain extrapolated (estimated) yields for each of six years, 1970-1975, for comparison with actual yields for this period in Illinois. Seventy percent of the yield trends (annual up-down yield changes) were predicted correctly for corn. For soybeans, 75% of the yield trend predictions were correct.

The model selections for corn and soybeans were subjected to further regression testing on data for each of the 45 districts of the 5-state area for the 45-year sample, 1931 through 1975. Statistical tests of significance confirmed the hypothesis that the models selected from a study of the 39-year (1931-1969) Illinois sample were applicable over the 5-state area for the longer 45-year record.

Partitioning of weather and technological influences on crop yield involved a 2-step process: 1) equations for "expected" yields with the selected technology proxy and average weather were determined for corn and for soybeans in each of the 45 districts (accomplished by a substitution of average July and August temperature and rainfall for 1931-1975 into each district model, followed by an adjustment of the intercept value); and 2) annual district crop-yield deviations from the trend lines were determined. The deviations were assumed to be due to July and August temperature and rainfall fluctuations. These yield deviations, expressed as a percent of trend, were the basic data for subsequent analyses.

Temporal-Spatial Distribution of Crop Yields

A major output from the Phase I research has been the derivation of time-space variability relations in crop yields that result from weather or weather-related factors. The variability was defined as the deviation from the expected mean yield after adjustment for technology trend. The results provide a measure of the temporal-spatial probabilities of crop yields that are likely to be experienced in the future. The probability distributions were derived from the 45-year sample of corn and soybeans for each district in the five states involved in the research. District data were combined to obtain frequency distributions for states and various combinations of states. This was done for annual yields and for yields over consecutive two to five years. The information provided by this investigation should be valuable in long-range planning with respect to food supplies and their short-term fluctuations due to uncontrollable variations in the time-space distributions of weather factors which influence crop yields.

In general, results of this research indicated that the variability in annual yields varies considerably among states. Of the area studied, the greatest variability occurs in Missouri and the least in Ohio. A general west to east decreasing trend in variability was noted, and the trend was most pronounced with positive deviations from the annual mean yield. Corn deviations tend to be larger than those for beans.

Negative deviations (crop deficiences) tend to be larger than positive deviations (surpluses) in both corn and soybeans. However, most of the area within a state or combination of states seldom experiences large deviations from the mean yield. Except for Missouri, deviations in the past have not been more than 20% to 30% in 80% of the years. Averages for 2-year periods show that deviations have not exceeded 15% in 80% of the cases, except for Missouri. Similarly, except for Missouri, average yields for 3-year periods have not varied more than 5% from the mean yield indicated by the crop-weather models.

Persistence and Predictability in Crop Yield Sequences

Most crop yield trends (up or down) last no more than two successive years, and seldom exceed three years in duration. Down trends appear to be somewhat more persistent than up trends. In general, predictability of yield trends for the coming year, based upon sequences of past events, must rely largely upon what has happened in the past two years. A high probability of trend reversal occurs after two consecutive years of up- or down-trends in yields (over 80% probability). With an existing 3-year trend, the probability of reversal next year is over 90%. Although the above findings are based on Illinois experience, similar probabilities should exist in the other Corn Belt States.

Overall, the present year experience is the best predictor of next year's trend. The Illinois analyses indicate that the crop yield sequences have some predictability beyond that expected from a random distribution of trends, but the prediction verification becomes high only when a trend has existed for two or more years, as indicated above.

Intraseasonal Prediction of Rainfall and Temperature Conditions

Illinois data were used to investigate the intraseasonal predictability of monthly total rainfall and mean temperature in the Corn Belt. The study was restricted to the three summer months. Results indicate very little predictability of July and August rainfall and temperature from rainfall and temperature conditions in the preceding one or two months. The predictability exceeds that obtained from considering the month-to-month weather conditions randomly distributed, but the gain is relatively small. Grouping monthly rainfall and temperature into three classes (near, below, and above normal), the probability of predicting the correct class for the following month from conditions in the past one to two months is usually less than 50%, compared with a "guess" probability of 33%. In approximately 30% of the possible combinations of temperature and rainfall conditions, the probability exceeds 50%, but only in 6% of the situations did the data indicate a prediction capability exceeding 60%.

Lag Correlation of Corn Yields

Lag correlation analyses were performed on corn yield data for the five states on a district basis. This was employed as one means of evaluating the time distribution characteristics of crop yields and the potential statistical predictability contained in the yield sequences.

Most district lag correlation coefficients were less than 0.3 and none exceeded 0.5. The best lag varied within the five states. Overall, a 2-year lag was best for the five states combined. However, the median coefficient was 0.29 which explains only 8% of the total variance. The lag correlation results indicate there is very little of a cyclical or oscillatory nature in corn yields that may provide a means for predicting future yields consistently and accurately. However, oscillations could, perhaps, serve as one of several inputs into a useful statistical prediction formula.

Frequency Distribution of July Rainfall and Temperature (5 States)

July monthly rainfall and temperature were found to be the weather factors most strongly associated with corn and soybean yields. Frequency distributions were derived for each state and selected groups of states. Distributions were determined for consecutive periods of 1 to 5 years.

A general decreasing trend in the deviations from mean monthly rainfall was found from west to east across the 5-state area, similar to the trend found with corn and soybean yields. Overall, a strong similarity was noted in the time-space characteristics between crop yields and July rainfall. Similar relations were found for the deviations from monthly mean temperature for July.

Regional Differences in Temporal Relative Variability of Crop Yield and Weather Factors in Illinois

Analyses were performed for nine crop districts in Illinois to investigate the degree of intrastate variability in crop yields and weather. Corn and soybean yields showed a definite trend for the temporal relative variability to increase southward in the state. This trend was not apparent in the July relative variability for rainfall or in the deviations from July mean temperature The southward increase in crop yield variability is linked to differences in soils which make the southern yields more dependent upon weather conditions than the northern and central yields. Thus, there is greater agricultural risk in southern Illinois than there is in central and northern Illinois.

Crop-Weather Response Classification

Crop-weather regression models require temperature and rainfall values for prediction of yields. However, predictions of accurate monthly and seasonal temperature and rainfall values are not yet available with high reliability. Prediction of weather trends such as near-, above-, and below-average temperature and precipitation is nearer to being possible. Consequently, crop-weather models that can utilize trend information rather than trend and magnitudes are needed.

To serve this purpose, crop-weather models based on below-, near-, and above-normal classifications for weather variables and associated crop-yield deviations from technology trend were developed.

Three classes (groups) and three variables (crop yield and two weather factors) were used in the analysis. Using only 3 classes and 3 variables yields 27 possible categories, a manageable and meaningful number. Crop yields (corn and soybeans) were classified with July temperature and rainfall and with August temperature and rainfall, the most relevant weather parameters. To classify crop yield with July-August temperature and rainfall influences simultaneously and still limit the number of categories to 27, it was necessary to weight and combine temperature and rainfall. This was accomplished as follows: 1) July temperatures were multiplied by the regression coefficient for crop yield on July temperature; 2) July rainfall was weighted in the same manner; 3) weighted July temperature and rainfall were added to obtain a single July weather factor; 4) the same steps were repeated to determine an August factor. The weighting procedure was considered appropriate since it incorporated the crop growth experience with the weather. These July and August weather indices were classified with crop yield in the same manner as observed values.

Results of the crop-weather classification analyses were presented in contingency table form. These tables depict the influence of the critical July-August weather factors, temperature and rainfall.

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