

AREAL VARIATIONS IN CORN-WEATHER RELATIONS IN ILLINOIS

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ABSTRACT.— Various statistical measures of the relations between weather factors and corn yields were derived for all counties in Illinois. These were used to ascertain the existence of areal variations and to develop regional patterns. Historical monthly weather data and annual yield data for the 102 Illinois counties were the basis of the research that included several single and multiple regression analyses. Technology was treated as a time trend in the analysis.

July rainfall was found to be the single most important weather factor although in portions of southern and eastern Illinois either July temperature or August temperature achieved higher correlations with yields. Weather factors together explained more than 80% of the variability in yields in southern Illinois, but only 45% of the yield variability in northern Illinois. Regressions of both technology and weather factors with yields produced correlations greater than $+0.88$ in all counties.

Regional patterns developed from the weather-yield analysis compared favorably with patterns of soil types, droughts, and high temperatures. One such pattern delineating five areas of different weather-yield relations was chosen to define risk regions for crop-weather insurance. Other regions were delineated as having essentially different rainfall-yield relations and were used in a study to determine irrigation potential.

A desire for statistical measures of the areal variability in corn yields due to weather factors in Illinois led to a study of corn-weather relations and how they varied within the state. Parameters measuring this areal variation were used 1) to es-

tablish weather-crop insurance risk areas, and 2) to delineate areas with different irrigation potentials.

A key problem in this study of areal variability was identifying a suitable analytical technique and a source of data appropriate for use with the technique. Selected for much of the analysis was a procedure (Thompson, 1963) using multiple curvilinear regressions based on seasonal and monthly temperatures and precipitation, and technology as represented by time-trend analysis. Thus, the research was based on the assumption that corn yields are dependent on weather-soil interactions which can be considered the 'natural factors', on technology or the man-made factors, and on certain unmeasured and random factors. County weather-yield data were used in the Illinois analysis, whereas Thompson (1963) used data from larger areas, states and crop-reporting districts.

Data for the study consisted of 34 years of corn yield data and monthly and seasonal weather data determined for each of the 102 counties in Illinois. Yields from each county were individually correlated with each of the weather variables and with time for technology. In addition, multiple regressions were performed for all weather variables and

technology to produce patterns expressing corn-weather relations.

The varying degrees of statistical association between weather and corn yields were used to define regions of different weather risk for insurance applications. These regions were compared with more commonly available patterns, such as July rainfall, to find which pattern correlated best, and thus could be used to provide the areal patterns of weather-yield risk in other Corn Belt states. A pattern based on the county coefficients of variation of yields was found to compare best with the risk map developed from corn yields in Illinois.

Areal variation in the relationships between corn yields and July-August rainfall amounts was also investigated. The results of regression analyses indicated the existence of 12 regions within Illinois, each with essentially different July-August rainfall-yield relationships. These findings were used in a study to determine potential water needs for future irrigation in Illinois.

DATA AND ANALYSIS

Yield data used in the study consisted of annual county corn yields for the 1930-1963 period reported by the Illinois Crop Reporting Service. Weather data used for each county represented the following eight variables: preseason precipitation (September through May), May mean temperature, June rainfall, June mean temperature, July rainfall, July mean temperature, August rainfall, and August mean temperature. Each seasonal and monthly weather value was an average of the data from all the weather stations within each county. When no data were available within a county, estimations were made using data from all weather stations surrounding the county.

Each county weather variable and technology were individually regressed

with yields. Simple linear correlation coefficients were determined for temperature variables and technology. Curvilinear correlation indices were calculated for precipitation variables. Maps of the county coefficients and indices were made to delineate areal variations of these relationships.

Multiple regression analyses of yield versus weather variables and technology were performed. In these analyses, a technology effect was determined in a manner recently suggested by Thompson (1966). To develop a measure of the effect of technology on yields and the changes in corn yields due to technological advances, two sets of 'dummy numbers' were employed. The first set represented the general trend of technology in the 1930-1957 period, and the second set expressed an accelerated technology effect since 1958. These dummy variables were scaled to known large advances or changes in technological practices and were included as linear terms in the regression equations.

Statistical techniques using results from the multiple regression analyses were employed to determine values that would provide a measure of the county yield variation explained by all eight weather variables or by technology. For instance, regression and analysis of variance techniques were used to separate the variance (standard deviation squared) of the county corn yields into a portion primarily explained by weather values and an unexplained portion associated with technological and random factors. A county index of variation was obtained by taking the square root of the variance explained by regression for each county, dividing by the county mean yield, and expressing the resulting ratio as a percentage. The index can perhaps be visualized more directly as the product of the correlation coefficient and the coefficient of variation. This type of index was used to compare corn yield response to weather variables and to technology among counties and to derive regional patterns.

RELATIONS BETWEEN YIELDS AND INDIVIDUAL FACTORS

July rainfall and yields. For each county, the mathematical relationship of corn yield to July rainfall was examined by comparing the fit of equations of linear, quadratic, and cubic forms with

the July rainfall and corn yield data. Interestingly, the 102 best-fit curves assumed many different shapes, but each could be classed generally as being in one of seven different basic types. The seven types of best-fit curves are illustrated in FIGURE 1 by curves from specific counties.

The most common form of best-fit curve was the quadratic, which is shown for Stark County and was found for 42 counties. Maximum yields occurred with July rainfall totals ranging from 6.0 to 8.5 inches, and low yields occurred with either too much or too little rainfall.

Other versions of quadratic relationships are represented by the curves for Calhoun and Jackson Counties. Counties with these types of curves occurred in distinct geographical regions with similar soil conditions suggesting that each type was the result of specific soil-water relations. The counties with a cubic fit, as illustrated by the curve for Mason County, all had large amounts of sandy soils.

The curves illustrated by Williamson,

Adams, and Lawrence (FIG. 1) were obtained in counties where the 34-year sample of July rainfall was considered inadequate. The cubic relations with double peaks illustrated by Lawrence and Adams Counties were found for counties where one very high July amount had occurred but where the second highest amount was relatively low which produced a cubic fit rather than a quadratic. Similarly, the linear curves, illustrated by Williamson County, may have resulted because these counties had not experienced an extremely high July rain.

These curves of FIGURE 1 were presented to illustrate that areal variations in the July rainfall-yield relations do exist. However, certain curves also reveal that inadequate sampling in some areas can produce apparently erroneous results. In general, the data indicate that the relationship between corn yields and July rainfall is quadratic, but that geographic areas within the state exhibit identifiably different forms of this relationship.

Patterns of association. Shown on

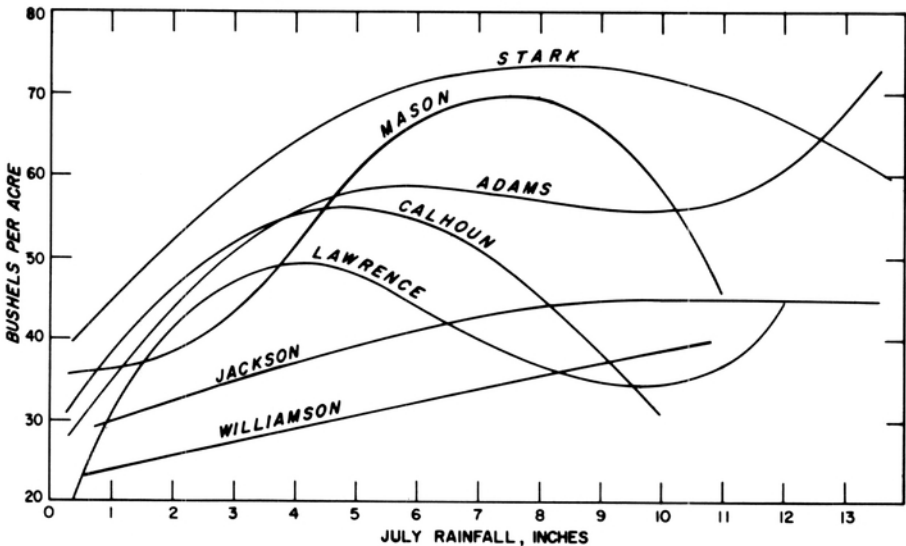
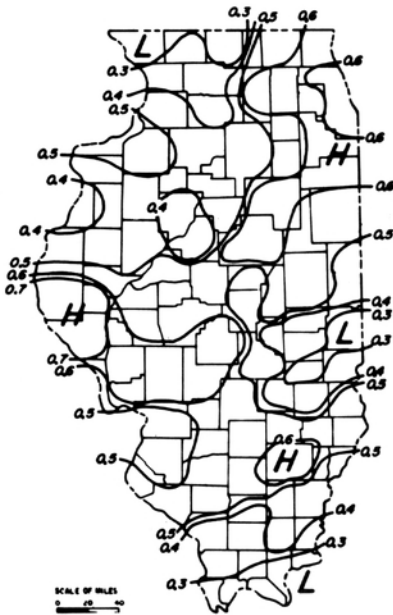
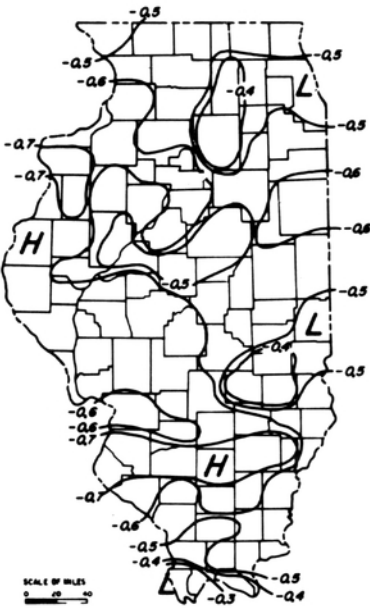


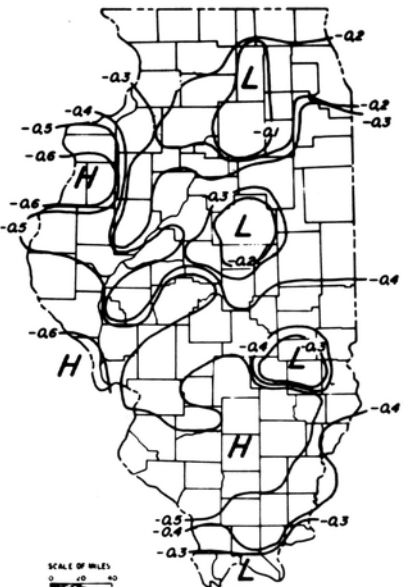
FIGURE 1.—Seven types of best-fit curves for corn yields and July rainfall illustrated by selected counties.



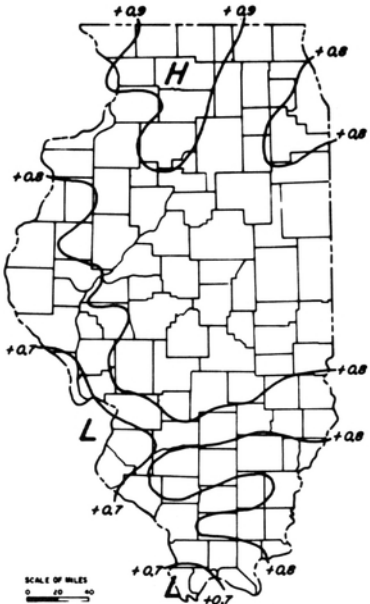
A. CORRELATION INDICES FROM JULY RAINFALL



B. CORRELATION COEFFICIENTS FROM JULY MEAN TEMPERATURE



C. CORRELATION COEFFICIENTS FROM AUGUST MEAN TEMPERATURE



D. CORRELATION COEFFICIENTS FROM TECHNOLOGY

FIGURE 2.—Iso-coefficient patterns based on correlations between corn yields and various county factors.

FIGURE 2 are the correlation patterns for the three monthly weather variables found to be most important in explaining yields: July rainfall, July temperature, and August temperature. Since July rainfall has a curvilinear association with yields, correlation indices were calculated for a quadratic form of relationship. The resulting pattern of indices appears on FIGURE 2A. These indices ranged from a low of 0.25 in three areas to a high of 0.71 in western Illinois. Thus, July rainfall values considered alone explained between 80% and 50% of the variation in corn yields in Illinois. Throughout much of Illinois July rainfall totals account for more than 25% of the variability in yields.

The correlation coefficients derived from linear regressions of yields with July temperatures and with August temperatures were used to construct the patterns in FIGURES 2B and 2C. July temperature is well correlated negatively with corn yields in western and south-central Illinois where July rainfall was also well correlated with yields, which is to be expected because of the frequent inverse relationship between rainfall and temperature. However, there are several areas, such as northwestern Illinois, where July temperature is correlated to a much higher degree with yields than is July rainfall. Linear correlations for August temperature and yields were also negative, but the magnitudes of the associations were not as large as those obtained for either July temperature or rainfall.

Technology values, as determined from a linear time-trend analysis, were correlated with the county corn yields. Simple linear correlation coefficients ranged from +0.65 to +0.92 indicating that technology defined in this manner explained between 42% and 85% of the variability in county corn yields. A pattern created from a plot of the county correlations of technology with yields is presented in FIGURE 2D.

REGIONAL PATTERNS DERIVED FROM MULTIPLE REGRESSIONS

For each county, multiple curvilinear regressions were performed for all eight weather variables and corn yields. The pattern based on the county multiple correlation coefficients is shown in FIGURE 3. The coefficients ranged from 0.65 in extreme northern Illinois counties to 0.93 in several counties in south-

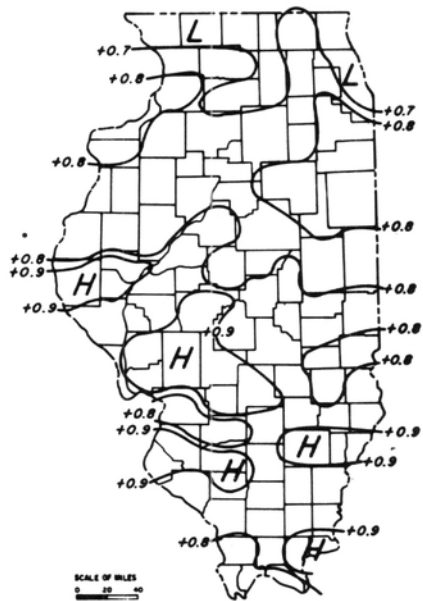


FIGURE 3.—Isocoefficient pattern for multiple regressions of weather and corn yields.

central and extreme southern Illinois. Thus, the eight weather variables explained between 42% and 86% of the variability in corn yields. Most counties in the southern half of the state had correlations above 0.80 indicating that the weather factors explained more than 65% of the variability.

Regressions of both the technology and weather factors with corn yields produced correlation coefficients above 0.88 in all counties. In 70% of the counties these factors explained more than 88% of the variability in yields. The unexplained variation can be attributed to random factors, or to weather-soil and technology factors not included in the equation.

For the purpose of identifying regions of different crop-weather risk, a county statistic which combined the association (multiple correlation) of yield and weather with a measure of the variation in county yields was preferred. The index of variation described in the data analysis section was chosen. This index of variation provides a measure of county yield variability due to the eight

weather factors expressed as a percent of county mean yields.

These county indices ranged from a low of 8% to a high of 38% of the county mean yields. The indices were sorted into five groups with approximately equal numbers of counties in each group, and the resulting pattern appears on FIGURE 4. Group 1 comprises counties in which weather factors explained between 29 and 38 percent of the mean yields. Comparison of the location of these counties with a map of Illinois soil types (FIG. 5A) revealed that the soils in these counties are mostly slowly permeable and thin (Wascher, et al., 1950). As shown in FIGURES 5B and 5C, these counties are also in the area of the state where 6-month precipitation droughts are most frequent and severe (Huff and Changnon, 1963). The average annual number of days with temperatures of 90 degrees or higher is greatest in this same area (FIG. 5D). Yields in an area having soils of low moisture holding capacity and frequent severe droughts and extreme temperatures should be quite affected by weather,

and the results substantiate this.

At the other end of the variability scale are the counties of group 5 in which weather conditions explained only 8% to 14% of the variability in corn yields. Most of these counties are in northwestern Illinois (FIG. 4) and have thick, moderately permeable soils that are generally drought resistant. Most of the counties in groups 4 and 5, which reflect the least effect of weather on yields, are located in northern Illinois where high temperatures are least frequent (FIG. 5D) and droughts are not as frequent nor as severe.

Certain regional anomalies appear on FIGURE 4. One of these is a 3-county area in northeastern-central Illinois classed in group 2, a group with a relatively strong weather-yield response. The soils (FIG. 5A) in these three counties are either permeable, droughty sands, or are thin and slowly permeable clayloams. Both soils are generally incapable of providing adequate soil moisture during dry periods. Drought characteristics and temperature extremes in these three counties are no more severe or frequent than in surrounding counties, so the stronger weather-yield relationship in this area is largely a result of the soil conditions.

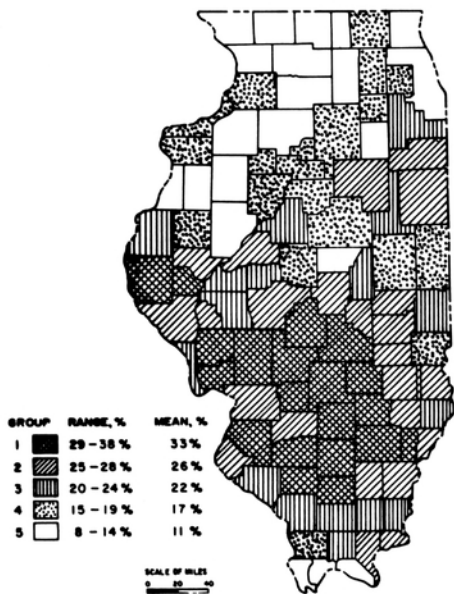


FIGURE 4.—Variability of corn yields attributed to weather (soil) factors expressed as a percent of county mean yields.

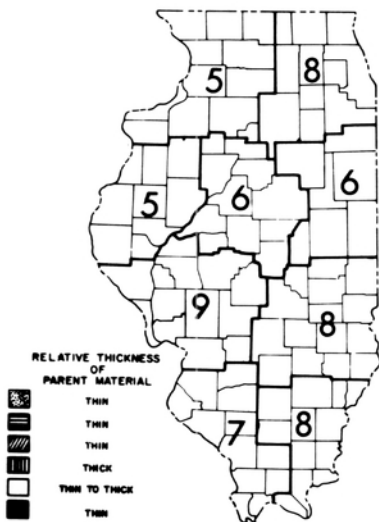
USES OF WEATHER-YIELD PATTERNS

This research concerning the areal variation in weather-yield relations was initiated to provide answers for two specific problems. One of these concerned development of risk regions for crop-weather insurance applications (Changnon, 1966). The other problem concerned identifying regions with differing potentials for corn irrigation as reflected by different rainfall-yield relations.

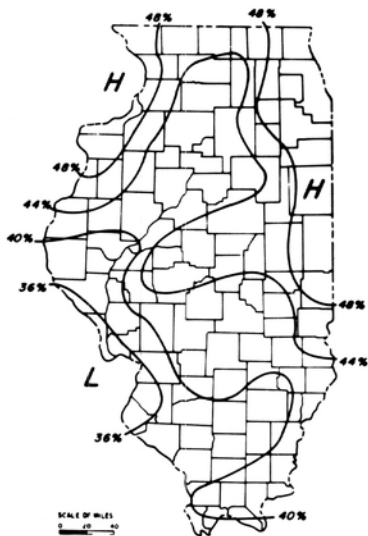
Insurance applications. The research concerning insurance applications had two objectives. The first was to identify regions of essentially different crop-weather relations with the goal of using these as a measure of risk due to weather. The numerical differences between these regions also might serve as measures of the differences in possible rate values. The second objective was to establish, through comparisons with other more readily available weather or crop patterns, a pattern that would correlate well with the regional risk map. If a well-correlated pattern could be found, then that type of pattern could



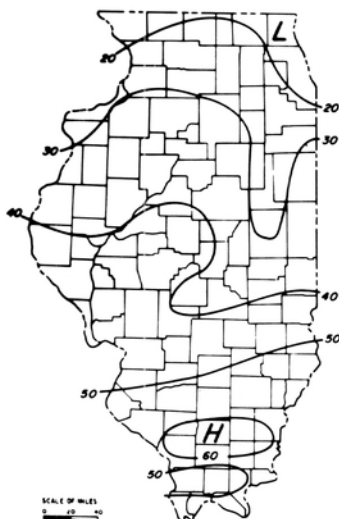
A. GENERALIZED SOIL TYPE AREAS IN ILLINOIS



B. NUMBER OF TIMES A 6-MONTH DROUGHT CENTERED IN EACH CROP-REPORTING DISTRICT, 1906-1965



C. PERCENT OF NORMAL 6-MONTH PRECIPITATION EXPECTED ONCE IN 25 YEARS



D. ANNUAL AVERAGE NUMBER OF DAYS WITH MAXIMUM TEMPERATURE OF 90 DEGREES OR HIGHER

FIGURE 5.—Patterns of soils, droughts, and high temperatures.

be used to delineate risk regions in other Corn Belt states without repeating the time-consuming analysis pursued in Illinois.

The regional pattern shown on FIGURE 4 was chosen as a best measure of risk regions in Illinois. Each of the five groups was identified as a different risk region. Thus, all counties in group 1 would have the same insurance risk since their risk due to weather is comparable. Differences in the mean percentages (Fig. 4) calculated for each of the five groups were used to provide a possible measure of rate differences between the regions. Group 5 (lowest risk) was assigned a value of 1.0 for risk rating ($1.0 = 11\%$), and the means were compared to this base value. The risk value for counties in group 4 is 1.55 times as great; that for group 3 is 2.0; that for group 2 is 2.36; and that for group 1 is 3.0 times as great.

The risk map (FIG. 4) was compared with several other patterns including those for individual weather conditions and yield maps. These comparisons revealed that a pattern based on the coefficient of variation of corn yields (Swanson, 1957) was in good agreement with the risk pattern. The pattern based on the coefficient of variation of corn yields shown on FIGURE 6 is very similar to the pattern in FIGURE 4. This suggests that crop-weather risk regions in other Corn Belt states could be established using similar maps of the coefficient of variation of corn yields.

Irrigation applications. To provide answers on the water requirements related to the potential development of corn irrigation in Illinois, a method was devised using the county weather-yield regression results and the growing season weather as determined from long-term records. The objective in this case was to provide an estimate of annual irrigation water needs for maximum corn yields expressed as a frequency of occurrence for all crop-land in the state. Such an engineering expression of specific yield increases related to water needs was considered an essential input in the current statewide planning for future water resources.

The data used in most methods for estimating irrigation water needs are usually measurements of radiation, evapotranspiration, and soil moisture. Unfortunately, such data are not available for most areas, and hence an empirical approach using the widely available precipitation and temperature data was

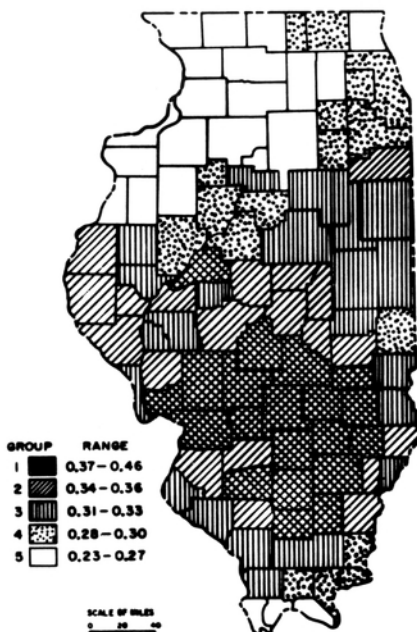


FIGURE 6.—Coefficient of variation of corn yields.

devised. The first phase of the research was to determine for each of the 102 counties the response between yields and the July and August rainfall which are the most critical rainfall amounts in corn production. A regression using July plus August rainfall was performed, and indices of variation were derived in the manner previously described. These indices suggested 12 regions (Fig. 7) of specifically different rainfall-yield relations. Although some of the regions had indices of similar magnitude, such as regions labeled 1 and 3, they were considered as separate entities because of their geographical separation and known areal differences in the variability of July-August rainfall.

The second phase of the irrigation research was the calculation of weather-yield regression equations for each of the 12 regions. Data used in these regressions included the eight weather factors, technology factors, and yields. In the third phase, long-term weather records in each region were summarized to ascertain the basic types of growing season weather that occurred over the past 65 years. The number of basic weather



FIGURE 7.—Regions of July and August rainfall-yield relations used in irrigation calculations.

types ranged from a low of 12 in one region to a high of 20 in a few regions. The number of years that experienced each of the identified seasonal weather types was expressed as a frequency of occurrence for the total period of record. The actual weather data for the years classed in each weather type were averaged to produce numerical values of temperature and rainfall representative of each weather type.

In the final phase of the irrigation research, these average seasonal weather values were inserted in the regional regression equation to calculate the yields that would result from each. Then for each weather type, the July rainfall total entered in the equation was systematically increased, while holding all other variables constant at their average value, to calculate the maximum yield. The August totals were also increased in the equation but with the optimum July rainfall previously calculated. The difference between the average July-August rainfall and that needed for maximization of yields was then calculated for each seasonal weather

type. Since the frequency of the weather types had been established, the frequency of water differences, or demands, was also known for each region.

The results obtained for regions 10 and 11 (FIG. 7) are shown in TABLE I. Region 10 in northern Illinois is in the area that has been shown to have yields with relatively little variation due to weather (FIGS. 1 and 4). In this region, increases of 7% to 8% are possible with 4.2 inches of added water in the July-August period in 5 years out of 20, whereas in region 11, 4.2 inches of added water will increase yields anywhere from 25% to 31% in 4 of 20 years.

TABLE I.—Frequency of Water Demands and Related Percentage Increases Associated with Maximum Corn Yields During an Average 20-Year Period.

Frequency, years	Yield Increase, percent	Water required, inches
Region 10 (North)		
5	7-8	4.2
1	6	3.8
2	4	3.1
6	1-2	1.8
6	0	0
Region 11 (South-Central)		
4	37-49	4.8
4	25-31	4.2
4	13-20	3.5
3	8-10	2.8
1	1-5	1.0
4	0	0

CONCLUSIONS

This research has identified and measured the areal variations of practical importance in weather-yield relations in Illinois. An expression employed to measure these areal variations in yield due to

weather factors produced results that compared favorably with data on soils, droughts, and temperature extremes.

When yields were correlated with technology based on time trends, it was found that technological factors alone explained between 50% and 80% of the variability in corn yields. However, weather factors analyzed separately also were shown to explain between 50% and 80% of the yield variations. Thus, there is considerable interaction between technological factors and the weather factors. Multiple correlations of technology plus weather factors with corn yields indicated that together they explained more than 80% of the yield variations in all counties.

Yields in south-central Illinois were found to have a stronger relationship with weather than those elsewhere. The weakest weather-yield relations were found in northern Illinois. July rainfall and July temperature were found to be more highly correlated with corn yields than any of the other six weather variables.

The pattern of yield variability attributable to weather factors was used to identify possible risk regions for crop insurance applications. Numerical differences in the variability indicated that counties in south-central Illinois had weather-yield risk values that were three times as great as those for counties in northern Illinois. This risk pattern for Illinois was found to be well correlated with a pattern based on the county coefficients of variation of corn yields. Hence, coefficient of variation patterns, which can be determined more easily than the risk pattern, could

be used to map risk regions in other states.

The country measures of yield variability due to July-August rainfall were used as input into a method developed to determine water requirements for future corn irrigation in Illinois. These measures, or variability indices, indicated there were 12 regions in Illinois with different yield-rainfall characteristics.

ACKNOWLEDGMENTS

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