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State Water Survey Division

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Research Report to the Crop—Hail Insurance
Actuarial Association

WEATHER-CROP YIELD-CROP PRACTICE RELATIONSHIPS IN CENTRAL ILLINOIS, 1979-1980

By

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Introduction

This report covers research utilizing data on weather, crop yield, and crop practices collected in central Illinois during 1979 and 1980. The State Water Survey, with state and federal funding, operated a weather network of 1800 square miles in the Macon, DeWitt, McLean, and Piatt County area in 1979 and one of 500 square miles in 1980. These networks provided rainfall and temperature data on a dense grid (stations every 3 miles). Questionnaires about yields and farm practices on fields immediately adjacent to the weather stations were prepared and sent to farmers. These questionnaires for 1979 and 1980 appear in the Appendix.

Various studies were made of the relationships between weather, yields, and farm practices. A scientific paper prepared and presented at a conference (and to be published in the Journal of Applied Meteorology) appears in the Appendix. It reports on many of the findings of the 2-year research effort.

This report presents the highlights of the research findings in four areas.

Summary of 1979 Results

In 1979, 94 East-Central Illinois farmers agreed to cooperate in a study on the effects of weather on corn production. These farm cooperators provided detailed information on yields and technical practices followed on their corn field nearest the site of an Illinois State Water Survey monitor weather instrument. The location of these 94 respondents was well dispersed with farmers from eight counties in East-Central Illinois participating. The fields for which data were provided ranged in size from eight to 245 acres. The average sized field contained 62 acres.

Figure 1 presents the pattern of summer (June-August) rainfall for the area of data collection.

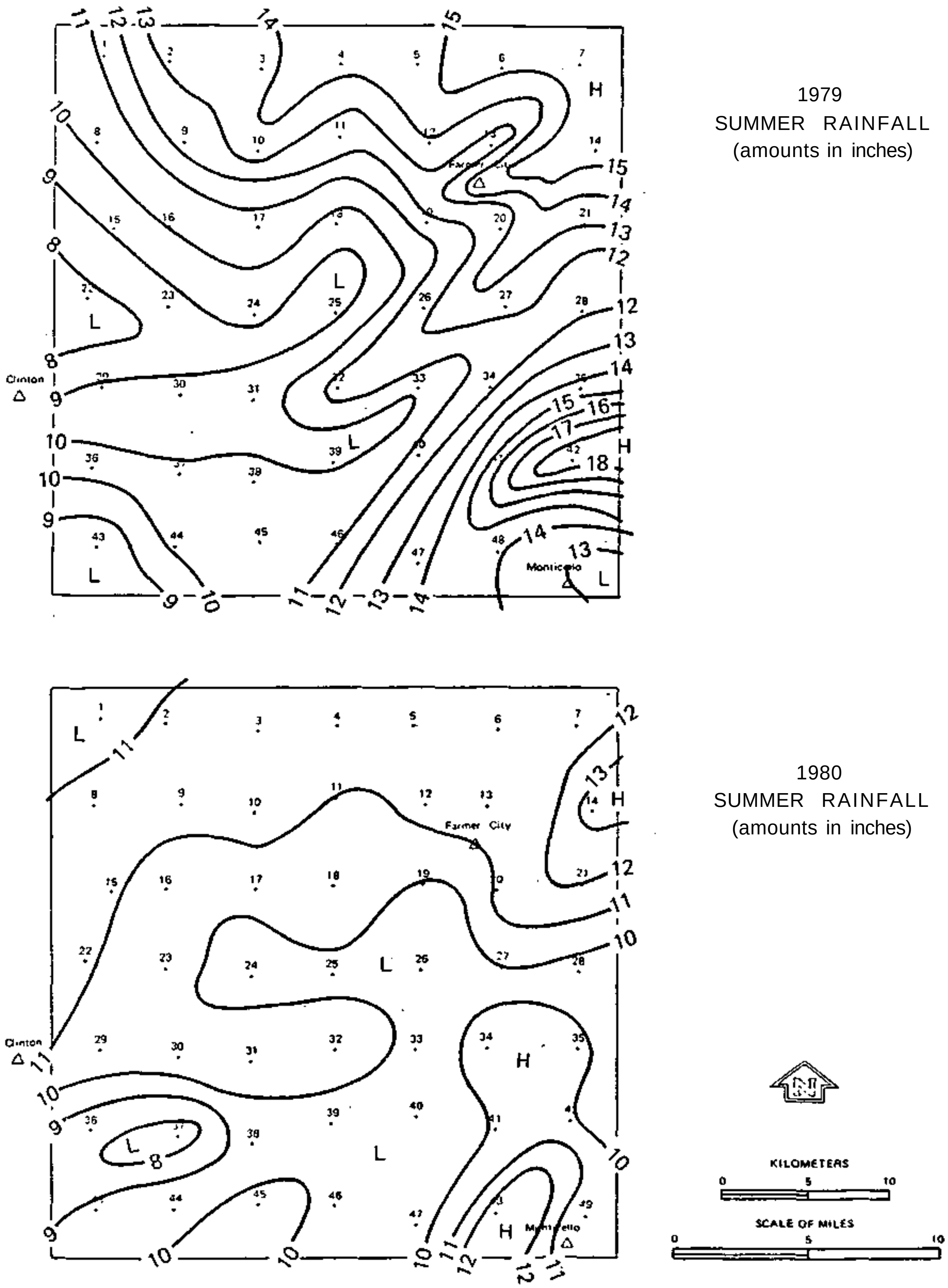

Figure 1. Summer rainfall patterns in central Illinois study areas

Since 9 to 10 inches of rain is normal for summer, one notes in Figure 1 that most of the area received normal or above normal rain. Average corn yields of the respondents were almost 150 bu/acre with some yields exceeding 2 00 bu/acre. (These are average yields for the cornfield nearest the network raingage and are not per-farm averages). Considerable information on tillage and cultural practices utilized by farmers were also detailed. An additional set of weather information is contained in Table 4 which describes the farmers' responses as to their perceptions of the seriousness of weather events as a hazard for corn production. These replies are interesting with respect to the question of all-peril crop insurance as a significant portion of the farmers did regard weather events as a moderate or severe problem in the production of corn. In particular, moisture related problems were generally cited as having a more severe impact than were temperature problems. These moisture problems included excess moisture in the spring and dryness in July and August.

As can be seen from Table 1, the corn yields reported varied widely throughout this region. The average yield for all farms responding was 148 bushels per acre. However, the maximum yield reported was more than twice the minimum yield of 100 bushels per acre. Further research efforts are underway to attempt to at least partially explain these yield fluctuations. Both fluctuations in weather events and differing technical practices will undoubtedly contribute to the explanation of these yield differences.

The information in Table 2 and 3 illustrate that cultural practices do vary among farm operators in this region. The average farmer responding applied 44 pounds of nitrogen in the fall and 112 pounds in the spring. The application patterns for potassium and phosphorus were the reverse of the nitrogen pattern with over 70 percent of these two nutrients being applied in the fall.

The zero fertilizer application rates noted in the fall and spring periods are for farmers who applied all of their fertilizer material in one season and none in the other. Slightly more than 10 percent of these farmers applied 200 or more pounds of nitrogen to the 1979 corn crop. One farmer applied a total of more than 200 pounds of potassium and three applied in excess of 200 pounds of phosphorus.

Preliminary analysis of these data indicated that a higher planting rate tended to be associated with higher yields. The average planting rate was almost 24,500 kernels per acre. The minimum rate planted was 24,000 kernels per acre, only 500 kernels less than the average. However, over 20 percent of the cooperating farmers planted at a rate of 27,000 or more kernels per acre.

Both skyrocketing diesel fuel prices and concern about soil erosion have made tillage practices an important issue. As noted in Table 2, one-third of the participating farmers reported using a moldboard plow, with the vast majority of them plowing in the fall. Almost two-thirds of the cooperating farmers practice chisel plowing. Six farmers reported that they used neither a chisel or a moldboard plow on the field in question.

The number of trips required for land preparation and planting of the crop varies considerably. Fifteen percent of these farmers needed less than four trips for both fall and spring operations whereas an identical 15 percent undertook more than six trips. The most common response was four trips with 34 percent of the respondents citing that number. All cooperating farmers cultivated their corn crop at least once, with 31 percent applying a second cultivation.

Because weather events in the 1970's have received considerable attention, the cooperating farmers were asked to indicate the severity of specific weather

Table 1. CORN YIELDS REPORTED BY FARMERS PARTICIPATING (All Yields are in Bushels of No. 2 Corn Per Acre)

	Average Yield	Minimum Yield	Maximum Yield
All farms in raingauge network	148	100	203
Farms in Macon County	145	100	182
Farms in Piatt County	150	117	175
Farms in DeWitt County	137	113	161
Farms in Champaign County	152	119	177
Farms in McLean County	167	146	203
Farms in Douglas County	140	125	160
Farms in Moultrie County	153	143	172
Farms in Logan County	147	106	196

Table 2. SOIL FERTILITY AND PLANTING RATES

	Average	Minimum	Maximum
Pounds/acre of fertilizer applied in Fall			
Nitrogen	44	0.0	239
Potassium	69	0.0	125
Phosphorus	89	0.0	225
Pounds of fertilizer applied in Spring			
nitrogen	112	0.0	250
Potassium	21	0.0	250
Phosphorus	23	0.0	250
Planting rate (kernels per acre)	24,460	24,000	28,000

Table 3. TILLAGE PRACTICES REPORTED

Operation	% of farmers who:
Fall moldboard plow	29
Spring moldboard plow	3
Fall chisel plow	53
Spring chisel plow	10
Number of trips required for land preparation and planting (fall and spring)	
Less than 4 trips	15
4 trips	34
5 trips	17
6 trips	20
More than 6 trips	15
Cultivations of growing crop	
Once	69
Twice	31

Table 4. FARMER'S PERCEPTIONS OF THE SERIOUSNESS OF SPECIFIC WEATHER EVENTS AS A HAZARD FOR CORN PRODUCTION

Weather Event	% of fanners who view the specific weather event as: Insignificant	A moderate problem	A severe problem
Too cold in spring	53.5	32.6	14.0
Too wet in spring	23.9	48.9	27.3
Too dry in spring	58.6	29.9	11.5
Too dry to activate herbicides	56.8	30.7	12.5
Too hot during July and August	51.1	45.3	3.5
Too dry during July and August	39.5	40.7	19.8
Too wet during July and August	84.6	14.3	1.2
Early frost in fall	78.6 .	10.7	10.7
Wet and cold weather during harvest	46.6	37.2	16.3
Too wet and cold to conduct fall tillage	62.8	30.2	7.0

events for corn production in their area. Moisture-related problems were generally cited as having a more severe impact than were temperature problems. Too much moisture was felt to be a severe problem in the spring, but dryness in July and August was also felt to be a critical concern. Wet and cold weather in the fall was noted as a moderate to severe problem by over one-half of the cooperating farmers.

Value of Weather Forecast Information

Although the 1979 data were interesting because of the unusually favorable weather conditions, these conditions posed problems relative to the original intents of the research. In particular, an objective of the research proposal had been to attempt to estimate relationships between corn yields and weather events. However with generally favorable weather conditions many of the expected relationships were not discernible with the 1979 data. However, as is often the case in research, what is a disadvantage for one purpose turns out to be a positive attribute for another. Indeed, the incidence of these favorable conditions in 1979 led us to examine the question, "What economic benefits would have resulted if we had known these favorable weather conditions were going to occur?" A study was initiated to discern if the particular data set which was available from the central Illinois raingage network would be appropriate for addressing this question.

Two papers have resulted from this research effort. The first is a paper which was given at the 61st Annual Meetings of the American Meteorological Society, January 1981. This paper was entitled "Can Seasonal Forecasts be Valuable for Crop Producers: A Case Study for East Central Illinois." The authors of the paper are Steven T. Sonka, Peter J. Lamb, Stanley A. Changnon, Jr., and Aree Wiboonpongse.

The paper was well received at those meetings and formed the basis of a scientific article which was prepared (and accepted) for publication in the Journal of Applied Meteorology. That article is entitled "Can Climate Forecasts for the Growing Season be Valuable to Crop Producers? Some General Considerations and an Illinois Pilot Study." A copy is attached in the Appendix as Exhibit 3. This particular paper demonstrates (in a pilot study sense) that prior knowledge of pronounced fluctuations in weather events could be of considerable value to farm producers. The results indicate that Midwestern corn production could be a sector containing sufficient flexibility to utilize climate forecasts. The paper also describes additional research needed before weather forecasts could be usable by crop producers. An important implication of this research is that technological practices (in particular seed population and level of fertilization), which were extremely beneficial under the weather conditions of 1979, may have been detrimental in the summer of 1980.

Results from the 1980 Raingage Network

In 1980 the raingage network in central Illinois was greatly reduced in terms of number of raingages and size. Thus, even though a limited questionnaire was mailed to farmers in that area (Appendix, Exhibit 2), only a small set of responses was received. Table 5 lists the 1980 yields for the 13 farmers from whom we received responses in both 1979 and 1980. Included with these 1980 yields are their 1979 yields and volunteered information as to wind damage which occurred for several of the farmers in this area in 1980.

Table 5 documents the severity of the 1980 summer for corn producers in east central Illinois. Whereas the range of yields in 1979 for these 13 farmers was from 107 to 164 bushels, the range in 1980 was from 38 to 111.4 bushels per acre. On the average, yields were reduced by 52 bu/acre from their 1979 level.

Table 5. Farmers reporting yields in both 1979 and 1980. Yields are for one field which may not have been the same in 1980. All yields are reported on 15.5% moisture basis.

Farmer	1979 Yield	1980 Yield	% Wind Damage Reported (1980)*	Yield Difference (1979-1980)
A	149.5	101.6	—	-47.9
B	164	38.1	75%	-125.9
C	129	59.8	30%	-69.2
D	111.8	99.5	13%	-12.3
E	151.2	106.0	—	-45.2
F	143.2	83.2	—	-60.0
G	135.3	86.4	—	-48.9
H	124.6	69.7	—	-54.9
I	107.3	78.5	33%	-28.8
J	150.1	103.0	30%	-47.1
K	139.3	111.4	—	-29.9
L	148.8	99.4	—	-49.4
M	137.6	84.1	—	-53.5

* Data volunteered by farmer respondents.

The 1980 summer rainfall pattern (Fig. 1) shows near normal rains, but July was hot (temperatures were 4°F above normal) and very dry. Figure 2 shows the plot of the 13 yields and their associated corn yields. No relationship is shown, generally because the July rains everywhere were so deficient.

An interesting feature of these data is that inspection of the farmer responses indicates that tillage and cultural practices followed by individual farmers did not greatly differ between the two years. Thus, it may be presumed that these massive yield declines are caused by differences in weather events of the two years.

With respect to all-risk crop insurance these data have some interesting messages. In particular, farmers noted as Farmer A, E, J, and L all received yields in 1980 which were near or exceeded 100 bu/acre. These yields were roughly two-thirds of the yields the farmers had received in 1979. (County yields average between 75 and 85 bu/acre in this area). Even though these farmers received yields in 1980 which were considerably above their county yield in that year, these yield levels undoubtedly were significantly below the yields which these farmers expected. Thus, even above average yields (relative to their area) may be disastrous for individual farmers.

Methods of Estimating Crop-Yield Weather Relationships

The remaining study effort, which directly evolved from the raingage network data, is nearing completion. This is an attempt to make a methodological contribution relative to weather/crop yield modeling. With respect to the 1979 raingage network data, we were fortunate in having paired data of yields and weather events. These data were paired in the sense that they were generated from essentially the same location.

The more general case is to have individual farm yield observations, but to use weather data which is from a larger network, or not adjacent to the farm. For example, the Urbana Morrow Plots weather station is being used as a proxy for a 2- and 3-county area around Champaign County. In this research effort we are attempting to determine what difference it would make if we had tried to accomplish the same research investigation, but had not had the extensive raingage data on weather events available to us in 1979. When this effort is completed in the near future, a special short report and a scientific paper will be prepared discussing these results.

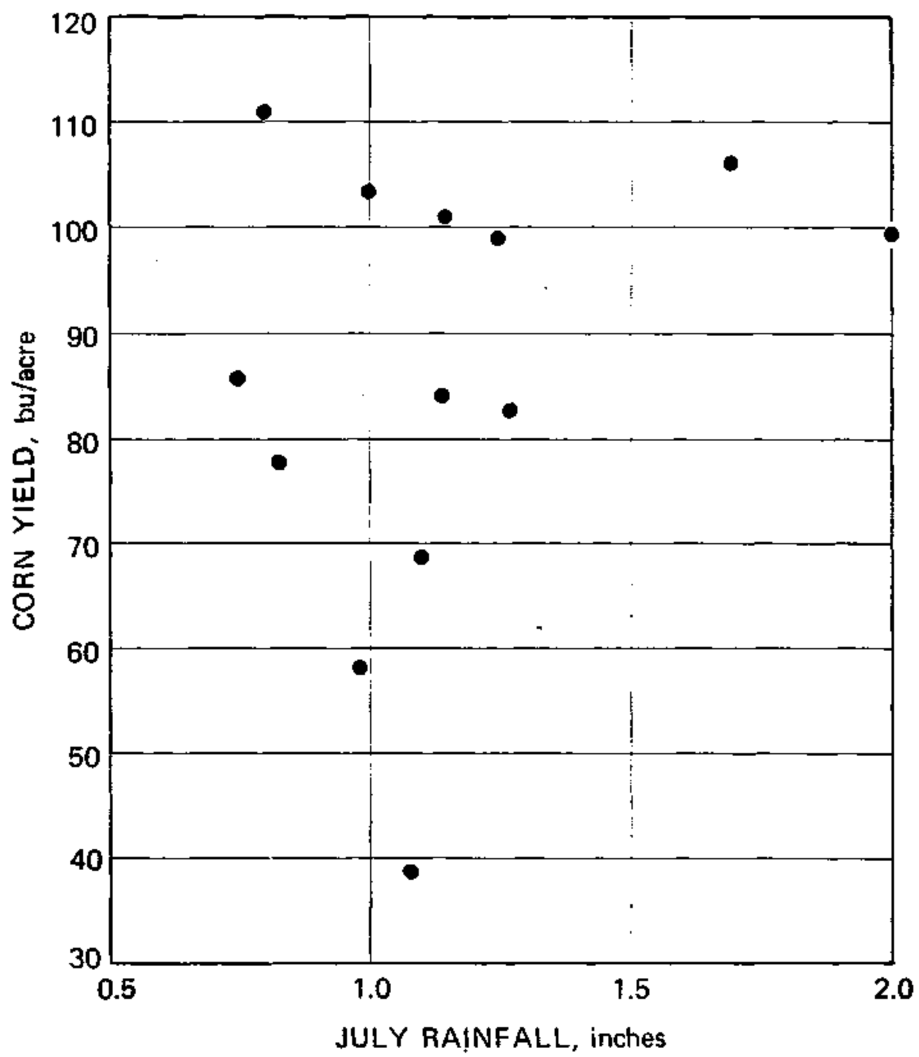

Figure 2. Central Illinois Yields versus July Rain in 1980

Appendix

(Exhibit 1)

1979 Questionnaire

- Please choose the corn field closest to the raingage site and report information for that field only.
- If you do not know the answer to a question, just enter "don't know."

1. How large is this field? ____________ acres

2. Where is this field located in relation to the ISWS raingage?

____

____

5. What is the predominate soil type in this field? ________________________

4. When was this field planted? (check which period is correct: if planting occurred in more than one period, indicate the number of acres planted in each period.)

________ Prior to April 15	_______ May 16 to May 31
________ April 15 to April 20	_______ May 31 to June 15
________ May 1 to May 15	_______ After June 15

5. Fertilizer is, of course, an important factor in determining corn yields. Please indicate either the actual pounds of nutrients applied in Section 5a or the pounds of specific plant food materials applied in Section 5b. (Please answer 5a or 5b).

5a. What amount of plant nutrients was applied in this field?

	Fall, 1978			*Spring, 1979*		
	N	P_2O_5	K_2O	*N*	P_2O_5	K_2O
Lbs. of nutrients per acre	____ -	____ -	____	____ -	____ -	____

5b. What amount of fertilizer materials was applied on this field? (For example, 200 pounds of 18-46-0 or 150 pounds of 0-0-G0.)

Fall, 1978			*Spring, 1979*		
material	*Lbs. of applied*	*Chemical Analysis*	*material*	*Lbs. of applied*	*Chemical Analysis*
____________		___ - ___ - ___	____________		___ - ___ - ___
____________		___ - ___ - ___	____________		___ - ___ - ___
____________		___ - ___ - ___	____________		___ - ___ - ___

Please continue on back.

6. What was the planting Tate for this field?________Kernels per acre.

7. What specific variety (or varieties) of corn did you plant in this field? (For example, DeKalb XL-72AA or Pioneer 3541.)

Manufacturer	*Variety*	*Number of acres*
________	________	________
________	________	________
________	________	________
________	________	________

8. What- crop was grown on this field last year? (If more than one crop was grown, please indicate the number of acres of each crop grown.)

____

____

9. What herbicides were applied to the field for this year's crop?

			Quantity Used before diluting			*Method of Application (check one)*	
Herbicide brand name	*Acres treated*	*Granular product per acre (lbs.)*	*Liquid concentrate per acre (qts.)*	*Wet table powder per acre (lbs.)*	*Surface applied*	*Incorporated into soil*	*Band*

10. How many cultivations did the growing crop on this field receive this year? ______________________________

11. Did this field experience unusually severe weed control problems this year? ______________________________

If so, what specific types of weeds were a problem? ____________

12a. What insecticides were applied to the field for this year's crop?

Insecticide brand name	Acres treated	Quantity Used (before diluting): Granular product per acre (lbs.)	Liquid concentrate per acre (qts.)	Wet table powder per acre (lbs.)	Method of Application (check one): Broad cost	Band

12b. Did you notice unusually severe insect activity in this field this year? ______

If so, what insects? ______

13. What tillage operations did you perform to prepare the field for this year's crop?

Fall, 1978

Field Operation	Total trips number of over field	Number of trips to incorporate herbicide
Chop stalks		
Disking		
Moldboard plowing		
Chisel plowing		
Other operations (please specify by name)		

Please continue on next page

	Spring, 1979	
Field Operation	*Total number of trips over field*	*Number of trips to incorporate herbicide*
Chop stalks		
Disking		
- Harrowing		
Field cultivator		
Moldboard plowing		
Chisel plowing		
Field cultivate and plant (tandem hitch)		
Planting (as separate operation)		
Other operations (please specify by name)		

14. Did this field experience serious flooding or ponding this summer? ______

If so, how many acres were affected?___________acres
About, how many days did water stand in that area?________days

15. Did this field experience any hail loss this year? ______________________

If so, when and how many acres were damaged?

_____________(approximate or exact date)___________________________acres

How severe was the damage (as a percent of potential yield)?_____percent

16. Based on your farming experience in growing corn over several years, please indicate your feelings as to the severity of the weather events listed below over the past years (not just 1979), and the frequency with which they occurred.

	(Please indicate with a check mark)					
	Weather event is a:			*Weather event occurs:*		
Weather event	*Major problem*	*Moderate problem*	*Minor problem*	*Frequently*	*Occasionally*	*Almost never*
Too cold in spring						
Too wet in spring						
Too dry in spring						
Too dry to activate herbicides						
Too hot during July and August						
Too dry during July. and August						
Too wet during July and August						
Early frost in fall						
Wet and cold weather during harvest						
Too wet and cold to conduct fall tillage						

17. How long have you been farming?__________years

Appendix (Exhibit 2)
1980 Questionnaire

Input information about the corn field on which you will report yields.

1. How large is this field?__________acres

2. Vhere is this field located in relation to the ISWS rainguage?

____

____

3. What is the predominate soil type in this field?____________________

4. When vas this field planted? (Check which period is correct: if planting occurred in more than one period, indicate the number of acres planted in each period.)

_____ Prior to April 15 _____ May l6 to May 31

_____ April 15 to April 30 _____ May 31 to June 15

_____ May 1 to May 15 _____ After June 15

5. Fertilizer is, of course, an. important factor in determining corn yields. Please indicate wither the actual pounds of nutrients applied in Section 5a or the pounds of specific plant food materials supplied in Section 5b. (Please answer 5a or 5b.)

5a. What amount of plant nutrients was applied in this field?

	Fall, 1979			Spring, 1980		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Lbs. of nutrients per acre	_____ -	_____ -	_____ -	_____ -	_____	

5b. What amount of fertilizer materials was applied on this field? (For example, 200 pounds of 18-46-0 or 150 pounds of 0-0-60.)

Fall, 1979		Spring, 1980	
Lbs. of material applied	Chemical analysis-	Lbs. of material applied	Chemical analysis
__________	___ - ___ - ___	__________	___ - ___ - ___
__________	___ - ___ - ___	__________	___ - ___ - ___
__________	___ - ___ - ___	__________	___ - ___ - ___
__________	___ - ___ - ___	__________	___ - ___ - ___
__________	___ - ___ - ___	__________	___ - ___ - ___

6. What tillage operations did you perform to prepare the field for this year's crop?

Fall, 1979

Field Operation	Total number of trips over field	Number of trips to incorporate herbicide
Chop stalks		
Disking		
Moldboard plowing		
Chisel plowing		
Other operations (please specify by name)		

Spring, 1980

Field operations	Total number of trips over field	Number of trips to incorporate herbicide
Chop stalks		
Disking		
Harrowing		
Field cultivator		
Moldboard plowing		
Chisel plowing		
Field cultivate and plant (tandem hitch)		
Planting (as separate operation)		
Other operations (please specify by name)		

7. What vas the planting rate for this field?_________Kernels per acre.

8. What specific variety (or varieties) of corn did you plant in this field? (For example, DeKalb XL-72AA or Pioneer 3541.)

Manufacturer	*Variety*	*Number of acres*
____________	________________	_______________
____________	________________	_______________
____________	________________	_______________
____________	________________	_______________

9. What crop vas grown on this field last year? (If more than one crop was grown, please indicate the number of acres of each crop grown.)

____

____

10. How many cultivations did the growing crop on this field receive this year?____

11. Did this field experience serious flooding or ponding this summer? ______

If so, how many acres were severely affected? __________acres
About, how many days did water stand in that area? _________days

12. Did this field experience any hail loss this year? ____________________

If so, when and how many acres were damaged?

________________ (approximate or exact date) ___________________ acres

How severe was the damage (as a percent of potential yield)? _________Percent

13. Did you apply insecticides on this field? _________________________

14. How long have you been farming? _________________ years

Appendix

Exhibit 3

CAN CLIMATE FORECASTS FOR THE GROWING SEASON BE VALUABLE TO CROP PRODUCERS: SOME GENERAL CONSIDERATIONS AND AN ILLINOIS PILOT STUDY

by

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ABSTRACT

A three step process is proposed to be most efficient for generating skillfull climate forecasts which could reduce the adverse socioeconomic effects of climatic variability. These steps involve identifying weather sensitive economic sectors, documenting the flexibility of these sectors with respect to likely forecast information, and the development of accordingly focused forecast capabilities. An illustration of the types of information needed to identify sector flexibility is provided for Midwest crop production. Finally, a pilot study using actual farmer data for east central Illinois suggests that increased corn yields could have resulted if producers had been forewarned of the benign weather conditions experienced during the 1979 growing season. This implies that skillful, properly structured climate forecasts may be useful to Midwest crop producers.

1. Introduction

Since about 1968 there has "been a tremendous upsurge of scientific and popular interest in the variability of the world's climate. Several factors have contributed to this development. First, during this period the atmosphere-ocean-earth system provided an abundance of striking weather extremes and climatic fluctuations. Secondly, the ever-increasing capabilities of the news media ensured wide publicity of these episodes, leading to a much greater general awareness than when similar extremes occurred in the past. This publicity invariably extended to the graphic documentation of unfavorable socioeconomic consequences, such as the Sahel famine, Russian crop failures, water shortages in England, and the snow-produced paralysis of Chicago's transport system. Thirdly, because of increased world trade, climate-caused adversity is now readily transmitted between nations, especially those of the "developed" world. As a result, emphasis has recently been placed on the need to devise means to minimize the stresses climatic variability imposes on society (e.g., Australian Academy of Science, 1976; Priestley, 1973; Lamb, 1979).

In response to this situation, the atmospheric sciences community has initiated several large and ambitious climate programs to investigate both the physical causes and socioeconomic consequences of climatic variability. These include the World Climate Program (World Meteorological Organization, 1978; Mason, 1978), the United States Climate Program (National Academy of Sciences, 1980; U.S. Department of Commerce, 1980), and the Climate Dynamics Program of the National Science Foundation (Hecht, 1977). Implicit in these programs is the belief that the development of climate forecasting skill constitutes one method of reducing the adverse social and economic impacts of climatic variability. For example, the Climate Dynamics Program has the dual objectives of developing "... a basis for predicting climate variation and for assessing some of the impacts of these variations on human affairs" (Hecht, 1977). Furthermore, the National Climate Program Act, the legislation (PL 95-367, September, 1978) establishing the United States National Climate Program, actually goes so far as to mandate the establishment of experimental climate forecast centers. This activity is now being initiated.

Before climate forecasts can be used to minimize the adverse socioeconomic consequences of climatic variability, however, it seems that three reasonably sequential prerequisites must be satisfied. These are proposed in Lamb (1981) and reproduced here to provide part of the framework for the present discussion. First, the human activities most severely impacted by climatic fluctuations must be identified by geographical region, along with the time this occurs during the year and the weather parameters responsible. The second prerequisite is the determination of which of the most affected regional economic sectors possess the flexibility to adjust or change to an extent that would permit substantial capitalization on the availability of skillful climate forecasts. The satisfying of these first two prerequisites should then permit the optimum attack on the third prerequisite for reducing the stresses climatic variability imposes on society — the actual development of skillful climate forecast schemes — for it will provide the focus these schemes need to be useful.

The foregoing sequence of prerequisites is only one view of the technology development process. An alternative approach would be to generate those climate forecast schemes for which, at the outset, the greatest skill seems attainable, and then attempt to find socially and economically beneficial uses for them. We contend, however, that the development phase of technological discovery is most cost effective when "both the physical capabilities and the potential socioeconomic value of the technology are considered. A pertinent issue in this regard for climate forecasts concerns their required precision (Dillon and Officer, 1971). Some potential forecast users may have very specific needs. Having an awareness of such requirements during the development process may result in forecast schemes that can be most readily implemented to minimize the adverse effects of particular climatic vagaries.

The present paper first discusses the problems of generating information about whether a particular economic production sector (Midwest corn cultivation) possesses the flexibility to allow climate forecasts to be incorporated into the decision making process. This is followed by the presentation of results for a specific agricultural setting (east central Illinois) that suggest increased 1979 corn yields could have been obtained had producers been forewarned of this summer's benign weather conditions.

2. Crop production as an economic activity to utilize climate forecasts

Several of the social concerns relating to climatic variability have been prompted by the unfavorable growing conditions for feed grains experienced in recent years. Corn is a widely used feed grain both for domestic and export purposes. The sensitivity of its production to weather events is illustrated by the Illinois yield data of Table 1, which clearly reflect both the benign weather conditions of 1975 and 1979 and the unfavorable circumstances of 1974 and 1980. Indeed, a repetition of the 1980 summer in the Midwest would have profound consequences for the supply and cost of food, both in the United States and much of the rest of the world. For example, the United States Department of Agriculture (1980) recently estimated that the domestic carryin of corn inventories prior to the 19Sl harvest will be equivalent to less than one month's normal use of this product.

Although the recent past has amply documented the sensitivity of Midwest corn production to climatic fluctuations, it does not necessarily follow that this sector possesses sufficient flexibility to utilize skillful forecasts of climatic fluctuations. In order to determine this, it is necessary to consider the decision making processes involved in the planning of crop production in the Midwest. Table 2 illustrates the major decision points and questions which might be affected by the availability of climate forecasts. These decisions commence in the early fall of the year prior to the crop production season in question, and extend late into the subsequent spring. The decision process is clearly sequential in nature, with the result that certain early choices may restrict an operator's later options. Furthermore, the potential yield impact of the choices available at several of Table 2's decision points is affected by unknown future weather conditions. For example, although late maturing (i.e., full season) corn varieties are potentially higher yielding than their short season counterparts, they may be undesirable if the autumn drying and harvest periods are unusually wet and/or cold.

A further implication of Table 2 is that the decisions presented are made within the context of a farm firm. Thus, even though expectations of prices and climate may point to corn being slightly more profitable than soybeans, for example, individual farmers may still choose to plant a considerable fraction of their acreage in soybeans. This seemingly odd behavior may be dictated by physical constraints (e.g., size of available machinery or concerns about insect infestations) or result from a risk mitigating strategy. Farmers will evaluate the utility of climate forecasts within this farm firm context, and so the forecast schemes should be compatible with such a framework.

In order for farmers to effectively use skillful climate forecasts they will need guidance on what actions to take when different conditions are forecast. It is doubtful that adequate relevant information can be directly extracted from existing agronomic experimental data, despite the considerable number of experiments conducted. This is due, first, to the very limited experimental designs typically employed. So that the impact of a certain production practice (e.g., level of fertilizer applied) can be fully documented, agronomic researchers vary only a small number of production factors in any one experiment. In contrast, the key question relating to the utilization of climate forecasts can be paraphrased as, "How should the entire mix of inputs be combined to take advantage of increased knowledge of future climatic fluctuations?" A second problem with the results of agronomic experiments is that they are not conducted in the context of the firm environment. They are instead performed on extremely small land areas, and utilize relatively large amounts of mechanical and labor input as a further means of ensuring that the effects of other production practices are excluded from impacting on the experimental yields. Such experimental situations are vastly different than the farm environment, where operators seek to minimize the machinery and labor use necessary to obtain satisfactory yields on relatively large acreages.

An alternative source of information relating to what actions a farmer should take when different climatic conditions are forecast could be derived from historical data on actual farm operations (cultural practices and yields) and the coincident climate (Changnon and Weill, 1968). However, this approach is far from problem free. Farm operation data, for example, are generally reported on a whole-farm basis, which can mask important intra-farm variations in soil productivity and cultural practices. In addition, weather data specific to each firm are frequentlv not available.

By a fortunate combination of circumstances, however, the above limitations did not apply to a set of data pertaining to a small area of east central Illinois for the 1979 growing season. The availability of this data set has permitted a preliminary investigation of the potential for the use of climate forecasts by corn producers. Details are presented in the next section.

3. The Illinois pilot study: analysis of actual farmer data

a. Background

The operation of a meso-scale meteorological network in east central Illinois during the 1979 growing season provided the required farm-specific weather data. This network, which was part of a major investigation of low-level convergence and convective rainfall , covered 6,309 km immediately west of Champaign-Urbana and contained 260 recording raingages and about 70 stations measuring additional meteorological parameters (e.g., temperature, pressure, wind). Information on the farm operation (e.g., production and tillage practices, and resulting yields) conducted in the cornfield nearest to each raingage was solicited from the farmers concerned by means of a questionnaire survey. Almost 100 responses were received. We recognize that farm operation data obtained by this procedure are probably not as accurate as those used in experimental settings and that there may be a discrepancy between what the farmer reported and what actually happened. However, since corn yields and cultural practices are items of extreme importance to the farmer, we expect to have reasonable estimates of these parameters.

The 1379 growing season weather experienced in the study region was highly unusual. During the all-important July-August tasseling and silking period, rainfall was above the long term average at all but 3 of the 260 raingage sites, and often substantially so (Table 3). Furthermore, days of extremely high temperatures and low humiditities were fathei limited (Table 3). Similar conditions produced record corn yields across Illinois (Table 1) and much of the rest of the Midwest.

b. Crop Production Results

Although 1979 was a year of record corn yields for Illinois as a whole (Table 1), reported yields on individual study area fields varied from a low of 100 bushels per acre to a high of 203 bushels. The average of the yields reported was approximately 150 bushels per acre. This diversity of yields raises the question of whether these differences are related to mesoscale convective rainfall patterns, or if they can be attributed to cultural practices which are particularly attractive if climatic conditions are favorable. If the latter is true, there would seem to be some potential for the effective utilization of skillful climate foreast by this economic sector.

Table 4 presents linear multiple regression estimates for corn yields based on responses of 65 farmers selected because each raised soybeans on the survey field in the previous year. The average yield for this sample was 150.2 bushels per acre (on a 15.5 percent moisture basis). Only two of the rainfall periods, June 5 - June 12 and July 7 - July 14, were found to have significantly affected corn yields. The lack of deficient or below normal rainfall in 1979 may have caused the result that several of the rainfall periods were estimated to be insignificant. If rainfall was uniformly adequate throughout the raingage network in a particular period, that rainfall may have been critical to the record yields reported, but the estimation procedure could not have reflected that importance. Changnon and Neill (1963) used yield and weather data from 1955-1963 from this same area to study weekly weather and yield relationships. They too found the rainfall in the weeks of June 8—14 and July 6-13 to be positively related to yields with quadratic correlations of 0.27 and 0.1+8, respectively. Negative coefficients were estimated for two 1979 periods, June 29 - July 6 and July 23 - July 30. Both coefficients were not statistically significant, however. (In the second of those periods, the average 'measured rainfall exceeded 4 inches). The 1955-1963 results showed a strong positive correlation for rain in June 29 - July 5 and a weak positive correlation for July 20-26.

Several cultural practices can be expected to influence corn yields. A factor commonly felt to be important is planting date (Illinois Cooperative Extension Service, 1980). Typically, earlier planting dates are expected to result in higher yields. However, in 1979 the early planting period was characterized by unusually wet, cold conditions throughout the area which prevented any farmers in the region from planting at this time.

This inclement weather was fortunately followed immediately by a period of very favorable planting conditions throughout the study area. Therefore, given the extensive mechanization of corn producers in this region, all of the corn planted by the participating farmers was planted within a 2 week period. It was thus not possible to discern either the effect of planting date on yields, or any implications for the potential of climate forecasts in altering planting date decisions.

Two cultural practice variables were found to have substantially affected reported 1979 yields. These were the amount of nitrogen fertilizer applied and the number of kernels of seed planted. This agrees with 1955-1963 area results which provided linear correlation coefficients of +0.65 for corn yields and plant population and +0.65 for nitrogen fertilizer and corn yield (Changnon and Neill, 1968). In the 1979 study the average application rates for these two inputs were 151 pounds and 24,200 kernels per acre, respectively. It is interesting that these reported application rates are almost equal to those suggested to produce maximum yields under "normal" weather conditions (Illinois Cooperative Extension Service, 1980).

The results in Table 4 can be used to crudely estimate what the potential benefits of a perfect climate forecast for 1979 would have been. Extension recommednations suggest that in "normal" years nitrogen applications and plant population densities in excess of the average reported (in this study) would not be expected to increase yields. However, the present regression estimates indicate that higher application levels of these inputs in 1979 resulted in substantially increased yields. Based on the results of Table 4, it seems that an application rate of 200 pounds of nitrogen and

28,000 kernels of seed per acre would have increased yields by almost 21 bushels per acre over the average application rates. Although estimated in a very crude fashion, these results suggest that the potential existed for even higher yields than the actual record yields of 1979 -- if knowledge of 1979's summer weather conditions had existed and had been used prior to corn planting that year.[2]

Although heavy application of fertilizer and a large plant population appear to have been "good" practices in 1979, these may not be appropriate practices to follow every year. Indeed, limited data from this area for 1980 suggest that large plant populations may be undesirable if weather conditions are hot and dry during the growing season. A smaller version of the weather station network was operated in the summer of 1980 and provided this limited data set. In 1980, lack of moisture and intense heat in July acted to severely restrain corn production in this area. Data from only 13 cornfields were available and strong winds in July rendered three of these observations unusable. Corn yields for the 10 remaining fields averaged only 89 bushels per acre (on a 15.5 percent basis).

Lack of sufficient numbers of observations makes any statistical analysis from these data inconclusive. It is interesting, however, that the lowest yield (60 bushels per acre) was reported by the farmer who applied the most kernels of seed (27,500 per acre) and a heavy application of nitrogen (l80 pounds). The highest yield, 111 bushels, was reported for a field with a 24,500 seeding rate and 165 pounds of nitrogen, substantially lower rates than had been advantageous in 1979.

4. Conclusions

Although weather conditions clearly impact on corn production, the existence of this impact, by itself, does not guarantee that skillful climate forecasts could be utilized to enhance corn production. Rather the corn production sector must possess sufficient flexibility to accommodate additional forecast information in a manner which alters the production practices adopted by the farm operator. The results reported here suggest that accurate climate forecasts for the 1979 growing season could have allowed for a substantial increase in corn yields in east central Illinois. Further the very limited data for 1980 indicate that production strategies which were beneficial in the summer of 1979 may have been detrimental in conjunction with the adverse weather conditions of 1980.

Thus, it appears that Midwestern corn production may be a sector containing sufficient flexibility to utilize climate forecasts. Before such potential can be realized, however, much more needs to be known about the required design of the forecasts. Insights as to necessary lead time and the precision of predicting specific weather parameters are examples of such critical information needs. In addition, evaluation of these impacts must be conducted within a framework that reflects the decision setting of the farm producer. Considerable sums are invested by the farmer in order to produce a crop. Thus, it will be necessary to understand the farmer's decision process and the variables which impact on it, before skillful climate forecasts are truly able to alter the production behavior of that decision maker.

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FOOTNOTES

This research endeavor is outlined in the "News and Notes" section of the 5ull. Amer. Meteor. Soc., 60, 8l3-814.

2 Yield increases of this magnitude if repeated on a large number of farms would result in a lowered market price for corn, thereby making it difficult to estimate the revenue impacts of these yield increases. Valuing corn at a conservative $2 per bushel implies an increase in net returns of $31.50 per acre after deducting the marginal costs of the additional inputs.

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Table 1. Illinois average corn yields, 1972-80 (Source: Illinois Cooperative Crop Reporting Service.)

Year	Yield per acre (bushels)
1972	110
1973	103
1974	82
1975	116
1976	107
1977	105
1978	111
1979	128
1980	98

Table 2. Schematic of time frame of decision process for a Midwestern crop producer

TIME	DECISIONS
Fall, year t-1	1. What crop to plan to produce in year t?
	2. Whether to perform fall tillage operations?
	3. Whether to apply fertilizer and how much to apply?
Spring, year t	1. What crop to plan to produce in year t?
	2. Which tillage practices to perforin?
	3. Which pesticides to apply?
	4. What variety of seed to plant and at what rate?
	5. Whether to shift choice of crop?
	6. How much fertilizer to apply?

Table 3. Comparison of east central Illinois weather statistics for the period 10 July through 20 August 1979 with long term averages. Network rainfall values were computed from totals for 260 gages (see text); the Urbana temperature and humidity data were recorded at the eastern edge of the network. Long term Urbana averages are for 1889-1980 (rainfall and temperature) and 1916-1980 (saturation vapor deficit). The saturation vapor deficits given were computed using mean daily maximum temperatures and mean daily 1400 CDT relative humidities.

Average 1979 rainfall for network	Standard deviation of 1979 rainfall across network	Long term average rainfall for Urbana	Average Urbana daily maximum temperature for 1979	Long term average daily maximum temperature for Urbana
216 mm	48 mm	110 mm	28.2°C	29.8°C

# of 1979 days Urbana maximum temperature ≥ 32.3°C (91°F)	Long term average # of days Urbana maximum temperature ≥32.8°C (91°F)	Average 1979 saturation vapor pressure deficit for Urbana	Long term average saturation vapor pressure deficit for Urbana
1	9	13.5 mb	19.5 mb

Table 4. Multiple regression estimates for corn yields for 65 corn producers in east central Illinois, 1979. All farmers reported raising soybeans in the previous year on the field for which data were obtained. Corn yields were expressed in bushels per acre, nitrogen in pounds of actual N per acre, plant population in hundreds of kernels per acre, hail damage in percent of loss, and rainfall in hundredths of an inch. Asterisk denotes statistical significance at 10% level. Correlation coefficient was 0.64.

Variable	Estimated Coefficient	Standard Error
Constant	34.66	40.35
Nitrogen	0.124*	0.054
Plant Population	0.368*	.176
Hail Damage	-3.89	8.82
Summer Rainfall (8 day periods)		
June 5 - June 12	.094*	.038
June 13 - June 20	.029	..062
June 29 - July 6	-.043	.063
July T - July 14	.060*	.036
July 23 - July 30	-.012	.192
August 16 - August 23	.002	.031