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Illinois State Water Survey

EVALUATION OF POTENTIAL BENEFITS OF WEATHER MODIFICATION ON AGRICULTURE

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A report of activities is hereby submitted for the 6-month period indicated above, along with plans for the next period and a list of active personnel and their assignments. During this report period, efforts have been concentrated on analyses of the potential effects of weather modification on corn yields in Illinois. It is anticipated that the soybean analyses will be initiated in the next period.

REPORT PERIOD ACTIVITIES

Research in this report period has been devoted to analyses involved in determining the potential effects of cloud seeding on corn yields. Work has involved two major activities. Computation of daily rainfall models for July and August in each year in the 38-year sampling period, 1931-1968, has been completed for eight of the regions used in the corn yield study, and three others are nearing completion. Also, computations have been made of the modification in monthly rainfall during July and August of each year resulting from application of each of seven hypothetical seeding models to these daily rainfall distributions. The above computations provide basic input for computer analyses of the effects of rain modification in corn yields. Location of the regions being used in the corn yield study is shown on the Illinois county map on the following page.

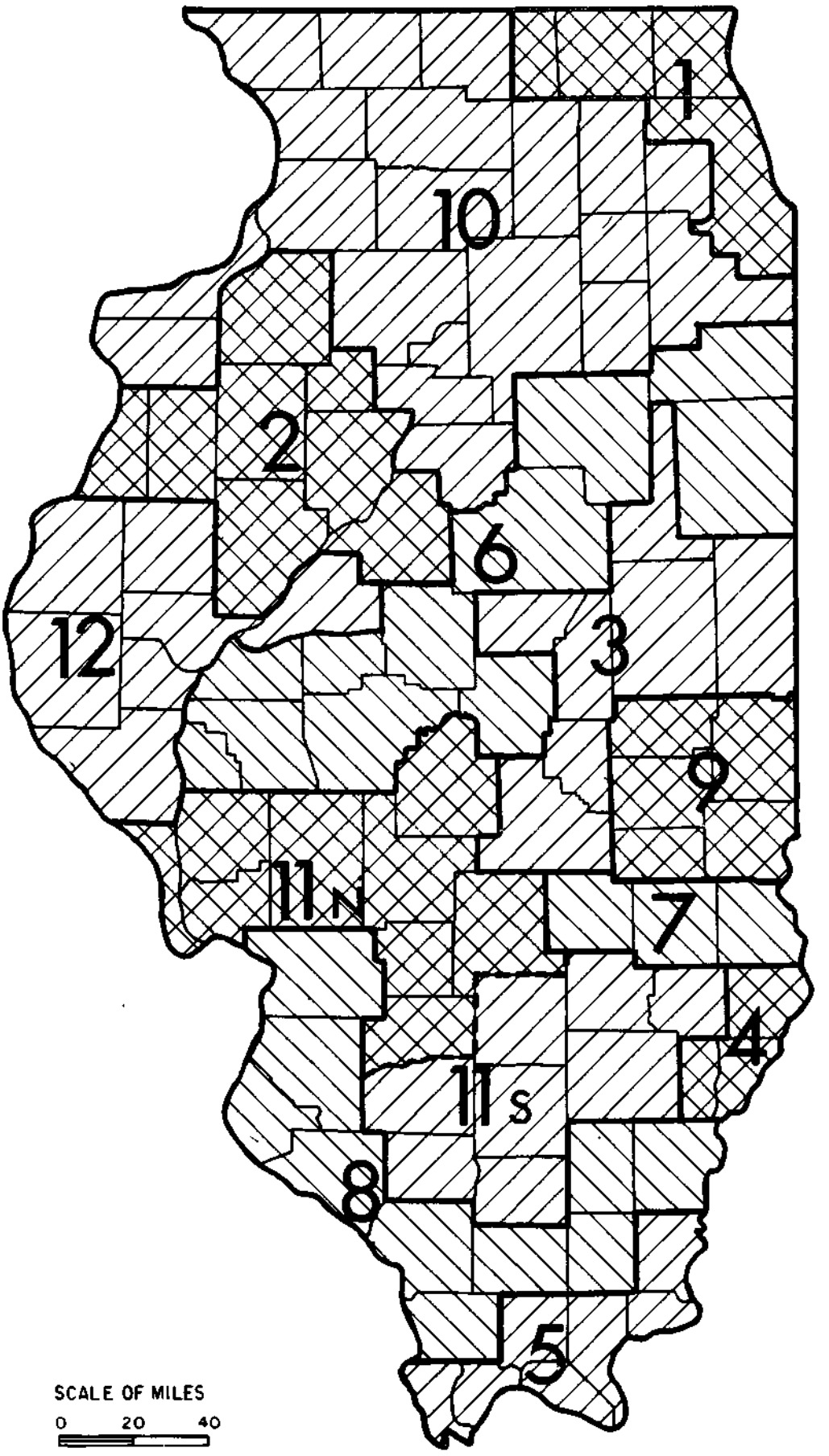
The second major activity during the report period has involved development of optimum regional prediction equations for estimating yield effects from application of the various hypothetical seeding models. This has involved considerable analysis and statistical testing. The testing phase is nearing completion, and selection of the regional prediction equation has been made for several regions at this time. In conjunction with the equation development effort, a considerable number of conferences have been held between the principal investigators and their associates and consultants on the project.

Efforts have also been made to gather data and information on seeding costs on an acre and seasonal basis. Such information is needed in the eventual cost-benefit analysis.

Hypothetical Seeding Models

As indicated in earlier monthly reports, two types of hypothetical seeding models are being employed in our studies. These are designated constant-change and variable-change models. With the constant-change models, yield changes associated with constant seeding-induced increases (or decreases) in all rainstorms are calculated. For example, calculations are made of yield changes resulting from a 10-% increase in monthly rainfall during July and August, based upon the assumption that all rains will be increased 10%, on the average, by seeding.

However, it was considered more likely that seeding-induced rainfall yield varies with rainstorm intensity. Therefore, we have selected a series of variable-change models which are being applied in our analyses. These are believed to envelop the range of known and potential seeding effects on growing season rainfall. They were formulated on the basic assumption that the percentage increase (or decrease) in rainfall from seeding would be greater when atmospheric conditions produce light rainfall naturally. This assumption is supported by the latest findings from the Whitetop radar analyses (Braham and Flueck, 1970).



Regions with Different Corn Yield-Weather Relationships in Illinois.

The following hypothetical variable-change models are being used in calculating potential crop benefits under cloud seeding performed to increase surface water during the summer months. Model E was recently added and does not appear in analytical results presented elsewhere in this report.

Daily Rainfall (inches)	Variable Percentage Change for Given Model			
	E	A	B	C
0.10 or less	150	100	75	50
0.11-0.50	70	50	30	20
0.51-1.00	30	20	10	0
Over 1.00	10	0	-10	-20

The three variable-change models listed below are used for calculating potential benefits assuming over-seeding could decrease the natural rainfall during extremely wet periods.

Daily Rainfall (inches)	Variable Percentage Change for Given Model		
	X	Y	Z
0.10 or less	-50	-75	-100
0.11-0.50	-30	-50	-75
0.51-1.00	-10	-30	-50
Over 1.00	0	-15	-30

Determination of Daily Rainfall Models

For use with the variable-change seeding models, daily rainfall models are derived for each year in each of the regions. For a given region, models are derived for each month used in the hypothetical seeding analyses. Only July and August rainfall are modified hypothetically in the prediction equation for most regions, since rainfall in the other months had insignificant correlation with crop yields during the 38-year sampling period (1931-1968). The method used to derive the regional daily rainfall model for a given month in a given year is outlined below.

1. The monthly rainfalls for each station in the given region are ranked from high to low to determine the regional median.

2. For each station, the percentage of its monthly rainfall resulting from daily amounts in the following class intervals is determined:

    a. over 1.00 inch
    b. 0.51-1.00 inch

c. 0.11-0.50 inch
d. 0.10 inch or less

3. From the calculation in number 2 above for each regional station, the average percentage of the regional rainfall in each of the above four class intervals is determined. For example, if there were three stations with 60, 30, and 9%, respectively, of their monthly rainfall occurring in daily amounts over one inch, then the average regional percentage in this class interval would be 33%. The sum of the average regional percentages for all class intervals will then add up to 100%.

4. Next, the median monthly rainfall for the region (number 1 above) is multiplied by the average regional percentage for each class interval. This provides the portion of the regional median rainfall to be assigned to each class interval.

5. Next, the regional monthly distributions established in number 4 above are modified through application of the variable-change seeding models described previously. The modified monthly rainfall totals in each year, as obtained with each seeding model, are then inserted in the regional prediction equation to determine the change in yield expected from the additional surface water obtained from the hypothetical seeding.

Development of Regional Prediction Equations

The weather effect on crop yields varies considerably over the continental United States. In the arid regions the crop yield is almost entirely dependent upon weather, and in semi-arid areas it plays a less important, but significant role. In the more humid climates where rainfall is usually sufficient, the interplay is much more difficult to ascertain. Thompson (1966), Changnon and Neill (1967), and Shaw and Durost (1965) have shown that in many years an increase in rainfall will actually reduce the average yield of corn per acre in the corn belt region.

The actual assessment of the weather effect upon crop yield is a very difficult problem. Because it is a difficult problem, various assessment methods have often been met with criticism. Most of the criticism has been involved with how to allow properly for the technology factor/s. There, has been a continuing increase in the average yield of corn per acre during the past 30 years, and it has become quite large in the past 15 years. It is the general concensus that this is largely due to increased technology. The farmer has learned to use more efficient planting rates, appropriate fertilizers, hybrid corn, terracing, contour farming, improved varieties, greater use of chemical pesticides, and improved skills in farming operations. However, as Thompson (1969a) has noted the recent period of rapid increase in yield has also been a period of very favorable corn weather.

Two methods for determining corn yield-weather relationships have been considered. The first method will be referred to as the weather index-experimental plot method and the second as the Thompson method. The first step in the weather index-experimental plot method is to construct a weather index for the area of interest (Shaw and Durost, 1965). The weather index is a method of measuring the effects of weather by the use of variation in experimental crop yield data. In this method, the average yield series from certain experimental plots within a certain crop reporting district of the state are determined. Next, a trend is determined for the experimental crop yield series. This is usually done by one of three techniques. The first technique involves fitting a linear trend to the yield data through the use of regression. The second technique involves the determination of moving averages for the experimental plot data series. Certain adjustments are then made in an attempt to eliminate the effects of extending the period of the moving average beyond the data sample. The third technique involves the use of several linear trends to approximate the appropriate overall trend. In this approach it is necessary to eliminate certain parts of the data, estimate data for gaps in the record, and to use various averages to smooth the series thus obtained. The weather index is computed by dividing the actual crop yield by the trend yield. The weather indices thus obtained are usually weighted and averaged to obtain weather indices for entire states or for the entire area of the corn belt itself (Shaw and Durost, 1962).

An adjusted crop yield series is then obtained for the crop reporting district or for the state by dividing the actual yield by the weather index. The weather effect for any year is then determined by the subtraction of the adjusted yield estimates from the actual yield. The adjusted series is considered to be the trend due to technology. A second type of weather index, which allows for weather-technology interaction, is sometimes computed by using data from experimental plots in which the technology has been held constant and from experimental plots in which the technology has been allowed to vary over time. With the use of certain adjustments, the second type of weather index can be obtained. However, work by Shaw and Durost (1965) indicates that the ratio between the two types of indices is close to unity.

The Thompson method has varied over the years. Thompson used a multiple regression technique involving various weather variables, technology trends, and crop yield. In Thompson's early work (Thompson, 1963), the technology variable was strictly linear, and nothing more than the year factor. That is, the years are considered to be technology and are added to the multiple regression as another linear variable. The relationship can be expressed in the form of Equation 1:

$$\text{Crop yield} = A + \sum_{k=1}^{m} B_1 T_k + \sum_{k=1}^{m} \sum_{j=2}^{n} B_j W_k \qquad (1)$$

where:

A = the intercept of the multiple regression

B_1 = the partial regression coefficient for technology (years)

B_j = the partial regression coefficient for a given weather variable

T_k = technology (years)

W_k = a particular weather variable

n = the number of weather variables

m = the number of years

The expected yield is obtained by solving Equation 1 using the values of the weather variables and technology for the various years of record. The technology trend (the yield expected under normal weather conditions) is then obtained by substituting into the equation the average of each weather variable and the value of technology for each year.

For the influence of an individual variable on the crop yield, the corresponding partial regression coefficient and the multiple regression intercept are used. For those terms which do not involve interaction, the other variables are held at average weather conditions. For terms involving interaction, one can calculate yield curves based on various levels of the other variables. The first modification of the Thompson method (Thompson, 1964) involved the use of a trend line based on the rate of adoption of hybrid corn from 1935 up to 1945 and the increase rate of fertilizer (particularly nitrogen) from 1950 to 1963. This trend is determined empirically by splitting the linear trend into various components to allow for the hybrid corn and fertilizer application. In the next modification (Thompson, 1966), the technology trend is split into two variables. This is primarily an empirical adjustment to allow for the differing rates of fertilizer application and hybrid corn production over the years.

Next, in an attempt to eliminate criticism due to a small number of degrees of freedom, Thompson (1969a) first computes regression equations for each state by using two time trend variables for the technology influence. Next, from the regression equations, he computes the trends expected with normal weather for each state. He then pools the data from all five states, using yield expected with normal weather in place of the original technology trends.. Thus, there is a considerable increase in the number of degrees of freedom. In the most recent modification, Thompson (1969b) divides the trend into three variables, two linear and one curvilinear. These variables are related to different periods of the historical record and are based primarily upon the use of nitrogen fertilizer.

For the present study, the Thompson method was used instead of the weather index-experimental plot method for the following reasons:

1. Data on experimental plots are not readily available in many parts of Illinois and in other states. Further, the years of records available for existing plots are sparse and intermittent.

2. The desirability of using the moving average technique to isolate the trend is highly questionable.

3. It was considered questionable whether a few isolated plots are truly representative of the soil-weather conditions throughout large areas.

4. For the assessment of the possible benefits of weather modification, one needs a technique that is relatively simple to apply and in which data for the method are readily available. The Thompson method makes use of data which exist and can be obtained easily.

Thus, the Thompson method was chosen, but with some modification. It was believed that the technology factor would vary considerably throughout the state. Thus, a technology trend which was developed for the entire state might not be appropriate for the various subareas within the state. Thompson had used an empirical method of developing the technology trend from inspection of fertilizer and hybrid corn data. However, it was found that this type of data was not available for the various subareas within the state of Illinois. Areas of specific corn-weather-soil relationships had already been determined (Changnon and Neill, 1967). Thus, it was decided to use a technology trend in each area which would be based upon first-, second-, and third-order technology terms in the multiple regression equation for a given area. The choice of whether to use a first-, second-, or third-order term was then dictated by the data and results obtained in each area. The revised technique is described below.

Eight weather variables were used and these included preseason precipitation (September-May), May mean temperature, June mean temperature, July mean temperature, August mean temperature, June precipitation, July precipitation, and August precipitation. Four squared terms were used and these included preseason precipitation, June precipitation, July precipitation and August precipitation. Three weather interaction terms were used which included June temperature interacted with June precipitation, July temperature interacted with July precipitation, and August temperature interacted with August precipitation. Thus, in the regression equations, there were eight weather variables, but the equation involved 15 weather terms.

The first step in the technique for a given area was to determine the multiple regression using the 15 weather terms (as averaged over the area) and the linear technology trend as independent variables, and the yearly average corn yield as the dependent variable. The second step of the technique was to determine the multiple regression equation with the same weather terms and the linear technology term, but with a second-order technology term added. An F-test was used to determine if there was a significant addition to the sum of squares of the multiple regression when the second-order term was added. If there was an increase in the sum of squares contribution, the new regression equation was then determined using linear, second-order, and third-order terms of the technology variable. Again, the F-test was applied to see if there was an increase in the sum of squares. If there was an increase, a new regression equation was determined using linear, second-, third-, and fourth-order terms of the technology variable. Whenever there was no increase in the sum of squares when the next higher order term of the technology variable was added, the lower order equation was chosen as the appropriate equation. Equations for the various corn areas in Illinois were found to have either second-order or third-order technology terms.

Next, a weather-technology interaction was considered. It was decided to add terms involving cross products between the linear technology variable

and certain weather variables to the highest order equation obtained in each subarea. These terms will be referred to as weather-technology interaction terms. Two methods for determining the interaction terms were used. The first method involved an investigation of the unstandarized regression coefficients for the equations in the various subareas. If the regression coefficients were significant at the 0.05-probability level, the associated weather variable was then included in the regression equation as a cross product between it and the linear technology term. In this method, the number of interaction terms was found to vary over the various corn areas of the state of Illinois. The second method involved choosing arbitrarily the same weather-technology interaction terms for all corn areas. The terms chosen were the June temperature-precipitation interaction, the July temperature-precipitation interaction, and the August temperature-precipitation interaction. Multiple regression equations with both types of interaction were determined for all areas of the state.

Initial Results of Region 11S Analyses

Tables 1 and 2 show the effect of various seeding models on July and August rainfall during the 1931-1968 period in region 11S which is located in southern Illinois. Model A with a median rain increase of 26% and increases of 40-50% occasionally agrees quite well with seeding results claimed in the past by some commercial cloud seeders. Model C with its median near 0% and fluctuations between increases and decreases would satisfy the past attitude of certain cloud physicists better. Model C would also be more realistic for the Illinois region, based upon latest findings with the Missouri Whitetop data (Braham and Flueck, 1970); that is, seeding may increase or decrease the summer rainfall depending upon existing or predominant atmospheric conditions of moisture and stability.

Table 3 summarizes the results of the first computer analysis of the various seeding models on corn yields in region 11S during 1931-1968. Yield differences in bu/acre are shown for each model, based upon comparison of the "altered" yields with the predicted yield with no seeding. These were accomplished using the regional equation without interaction between variables. Also shown in Table 3 are the area average July-August rainfall for each year and the departure from the 1931-1968 average. The last column shows the most efficient model in each year, that is, the one which resulted in the largest yield increase or the least decrease when all models decreased the yield. Model A was the most efficient in 32 of the 38 years and produced increased yields in 27 of the 38 years.

Table 4 summarizes the data in Table 3. Here, the average yield change (increase or decrease) is shown for each model for all years combined and for years with above and below normal rainfall in the July-August period. Only models A and B would have increased the average annual yield over the 38-year period. All other models would have had a net disbenefit for the 38-year period.

Not much difference in results is obtained when the 38 years are divided into above and below average rainfall periods. Only model A would have achieved average annual increases in both dry and wet periods. All models except A and B

Table 1. Effect of various seeding models on July rainfall in region 11S during 1931-1968.

Seeding models	Percentage change in natural rainfall equalled or exceeded for given percentage of months						
	5	10	25	50	75	90	95
All months increase models							
A	+42	+38	+33	+26	+21	+17	+14
B	+26	+23	+18	+12	+7	+3	+1
C	+14	+11	+7	+1	-3	-6	-9
All months decrease models							
X	-25	-23	-20	-14	-11	-8	-6
Y	-42	-40	-37	-33	-29	-26	-24
Z	-66	-64	-57	-52	-47	-44	-42
Below normal months							
A	+46	+42	+37	+31	+27	+22	+20
B	+30	+28	+22	+18	+13	+10	+8
C	+17	+15	+11	+6	+1	-2	-4
Above normal months							
X	-17	-15	-12	-10	-8	-17	-61
Y	-37	-34	-31	-28	-25	-24	-23
Z	-56	-53	-49	-46	-44	-42	-41
C	-9	-8	-6	-4	-1	+1	+2

Table 2. Effect of various seeding models on August rainfall in region US during 1931-1968.

Seeding models	Percentage change in natural rainfall equalled or exceeded for given percentage of months						
	5	10	25	50	75	90	95
All months; increase models							
A	+52	+47	+37	+27	+19	+11	+8
B	+34	+29	+21	+13	+7	0	-3
C	+20	+16	+8	+2	-4	-9	-12
All months decrease models							
X	-30	-26	-20	-15	-12	-8	-6
Y	-49	-44	-37	-33	-29	-25	-23
Z	-73	-67	-61	-52	-47	-42	-40
Below normal months							
A	+61	+50	+39	+30	+24	+20	+18
B	+42	+33	+22	+17	+12	+10.	+8
C	+27	+19	+11	+6	+2	-2	-4
Above normal months							
X	-16	-14	-12	-10	-8	-5	-3
Y	-35	-33	-31	-28	-24	-21	-19
Z	-55	-53	-50	-46	-42	-38	-35
C	-12	-10	-8	-5	-1	+1	+3

Table 3. Yield difference (bu/acre) for given seeding model in region 11S.

Year	A	B	C	X	Y	Z	Rain (inches)	Departure from normal (inches)	Most efficient
1931	-0.7	-2.3	-4.4	-5.3	-7.7	-10.0	7.88	+1.41	A
1932	+2.4	+0.2	-1.4	-2.9	-5.5	-8.0	8.24	+1.77	A
1933	-0.1	-1.0	-1.6	-1.3	-2.5	-4.0	5.08	-1.39	A
1934	-2.0	-1.0	-0.4	-0.3	+0.1	-0.1	8.39	+1.92	Y
1935	+0.8	0.0	-0.8	-2.1	-3.6	-5.2	4.59	-1.88	A
1936	-0.1	0.0	0.0	+0.1	-0.1	-0.5	2.46	-4.01	X
1937	+4.2	+2.9	+1.8	-0.1	-2.7	-6.0	5.10	-1.37	A
1938	-1.3	-0.5	-0.2	-0.2	-0.8	-2.4	8.73	+2.26	X
1939	+2.9	+1.5	+0.5	-1.6	-3.8	-6.3	6.59	+0.22	A
1940	-0.5	-1.3	-1.6	-2.8	-3.4	-4.2	2.92	-3.55	**A'**
1941	+1.8	+1.4	+1.1	-0.4	-1.7	-3.5	4.73	-1.74	A
1942	+0.7	+0.2	-0.5	-0.8	-2.2	-4.2	6.88	+0.41	A
1943	+1.0	+0.4	-0.2	-0.7	-1.6	-3.1	2.31	-4.16	A
1944	+2.9	+1.1	-0.1	-2.2	-4.2	-6.3	6.56	+0.09	A
1945	+0.5	-1.1	-2.3	-4.5	-6.4	-9.1	5.76	-3.71	A
1946	-2.9	-6.0	-8.4	-9.8	-13.6	-17.7	9.03	+2.56	A
1947	+3.9	+2.1	+0.6	+0.1	-3.5	-6.7	6.61	+0.14	A
1948	-2.0	-0.1	+0.9	+1.0	+0.1	-0.2	9.16	+2.69	X
1949	+1.7	+0.5	-0.3	-3.4	-4.5	-6.5	4.29	-2.18	A
1950	+6.8	+3.4	+0.9	-2.7	-7.1	-11.5	8.81	+2.34	A
1951	+2.6	+1.4	+0.3	-1.9	-4.7	-8.4	6.67	+0.20	A
1952	+1.7	+0.9	+0.2	-1.0	-2.8	-5.1	4.52	-1.95	A
1953	+1.1	+0.3	-0.5	-1.0	-2.4	-4.1	2.81	-3.66	A
1954	+0.4	-0.1	-0.8	-2.7	-4.0	-5.2	6.00	-0.47	A
1955	-0.7	-0.1	+0.2	+0.2	-0.4	-1.9	6.22	-0.25	X
1956	-0.8	-3.4	-3.8	-6.3	-9.4	-13.1	6.48	+0.01	A
1957	+1.4	+0.9	+0.2	-0.6	-2.6	-5.5	7.94	+1.47	A
1958	-7.3	-1.4	+2.3	+2.6	+6.1	+6.4	13.88	+7.41	Z
1959	+5.8	+2.0	-1.0	-2.2	-7.6	-12.7	10.62	+4.15	A
1960	+3.7	+2.1	+0.8	-0.5	-3.0	-5.9	5.10	-1.37	A
1961	+0.5	+0.5	0.0	-0.3	-2.1	-5.5	9.49	+3.02	A
1962	+3.6	+2.1	+0.8	-0.3	-2.9	-5.9	7.06	+0.59	A
1963	+0.6	+0.2	-0.6	-1.3	-3.5	-7.1	7.16	+0.69	A
1964	+3.1	+1.9	+0.8	-1.0	-3.2	-5.8	5.55	-0.92	A
1965	+3.5	+1.6	0.0	-1.5	-4.1	-6.8	6.26	-0.21	A
1966	+2.1	+0.9	+0.2	-1.9	-3.2	-4.7	4.70	-1.77	A
1967	+2.3	+0.2	-1.5	-4.7	-8.5	-13.3	6.49	+0.02	A
1968	+1.2	+0.7	-1.0	-2.7	-4.6	-6.7	4.63	-1.84	A
Number +	27	23	15	5	3	1			
Number -	11	13	20	33	35	37			
Average	+1.2	+0.3	-0.5	-1.8	-3.6	-6.0	6.47		

would have substantially reduced the average yield in above normal rainfall periods. The decrease models (X, Y, and Z) would have resulted in a general disbenefit in wet years as well as in dry years, and, therefore, would not have been generally useful if achieved in practice.

Table 4. Effect of various seeding models on corn yields in region 11S based on 1931-1968 data.

July-August periods	Number of periods	Average yield change (bu/acre) for given seeding model					
		A	B	C	X	Y	Z
All periods	38	+1.2	+0.4	-0.5	-1.8	-3.7	-6.0
Below normal rainfall	18	+1.4	+0.5	-0.1	-1.5	-3.3	-4.8
Above normal rainfall	20	+0.9	-0.1	-0.8	-2..0	-4.1	-7.0

The major indication from this first test of our approach is that the rainfall yield from seeding must be well understood and well controlled under operational conditions to benefit materially corn yields over a substantial period of time in Illinois. There is danger of producing a long term disbenefit if the seeding output can not be well controlled. The danger potential is also related to forecasting capability, and the region 11S analysis stresses both the need for seeding control and precipitation forecasting for efficient utilization.

From the analyses performed to date on data for several of the 13 corn regions, it appears that differences in the median percentages obtained from a given seeding model are quite small between regions. Indirectly, this indicates that the distribution of daily rainfalls is similar between regions when averaged over a long period (1931-1968). For example, applying model A in eight regions completed at this time we find the median seeding-induced increase in the July-August rainfall for the 1931-1968 period ranging only from 24% to 26% among these regions which include samples from most parts of the state. When the regional data were divided into months with above and below normal rainfall, these smaller stratified samples showed somewhat larger differences between regions, but these still do not appear to be really significant and very likely reflect sampling vagaries.

The seeding increase models, such as A, B, and C, show larger percentage increases from the hypothetical seeding as the percentage of normal monthly rainfall becomes increasingly negative. The decrease models (X, Y, and Z) are not greatly affected as the percentage of normal rainfall increases in the above normal months.

Overall, model C corresponds to a small increase model; however, it acts as a decrease model, on the average, in wet months and an increase model in dry months. Models A and E are the only increase models that consistently produce

a rain increase in excess of 20%. Model B does so only with very dry conditions. In above-normal rainfall months, models Y and Z consistently show a decrease greater than 20%.

Construction of frequency curves for eight regions analyzed to date has indicated that models A, B, and E result in monthly rainfall (July and August) being increased to 100% or more of the normal in 99% of the below-normal months. Model C is somewhat less effective, producing above-normal rainfall in 70% to 90% of the below-normal months with considerable variation between regions.

WORK PLANS FOR NEXT PERIOD

It is anticipated that computation of the daily rainfall distributions for the 1931-1968 period and application of each of the hypothetical seeding models to these distributions will be completed for the remaining regions in the corn yield study in the early part of the next work period. It is expected also that development of the regional prediction equation will be completed for all 13 regions in the near future. Then, computation of rain modification effects on corn yields using both the constant-change and variable-change seeding models will be pursued through computer analyses involving the 1931-1968 rainfall distributions, the various seeding models, and the optimum regional prediction equations. It is expected that most and possibly all of these regional analyses will be completed for corn in the next 6 months. Computation of the daily rainfall distributions during the 1931-1968 sampling period and application of the variable-change seeding models to these daily distributions will be initiated for the soybean regions to obtain basic computer input for the soybean evaluation.

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APPENDIX

The professional and technical personnel associated with the project and their assignments during this report period are listed below.

Person	Title	Principal Duties
S. A. Changnon, Jr.	Acting Section Head and Co-Principal Investigator	Planning and supervision
F. A. Huff	Co-Principal Investigator	Planning, supervision, and development of climatic rainfall models and hypothetical seeding models
Dr. P. T. Schickedanz	Statistical Meteorologist	Development of crop-weather prediction equations
Prof. Earl Swanson	Agricultural Economist	Planning, with major emphasis on economic considerations in the benefits evaluation
Elmer Schlessman	Meteorological Analyst	Development of rainfall and hypothetical seeding models
Donald Satterfield	Student Assistant	Data analysis
Linda Schmidt	Student Assistant	Data analysis