Evaluation of Potential Effects of Weather Modification on Agriculture in Illinois

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(Manuscript received 26 July 1971, in revised form 15 October 1971)

ABSTRACT

An investigation was made of the potential effects of modifying growing-season rainfall on the yields and economic benefits of the two major Illinois crops, corn and soybeans. Crop yield and weather data for the 38-year period, 1931–68, were used to develop multiple regression equations relating crop yield to technology trends and various temperature and precipitation parameters. This was done for each of 13 regions with similar yield characteristics. Hypothetical seeding models were then used with the appropriate regional equation to evaluate the effects of seeding-induced changes in July-August rainfall on crop yields. Frequency distributions were developed to define expected gains or losses from seeding with each hypothetical model under assumed seeding operations lasting 1, 2, 3 and 5 years. Results indicated that in most regions of Illinois, corn and soybean crops would be benefited in the majority of the growing seasons through a cloud seeding program. Reaction to the potential seeding was found to vary substantially between regions with the same seeding model. Furthermore, seeding effectiveness may vary considerably from year to year with the same model in the same region due to the temporal variability in daily rainfall distribution characteristics.

1. Introduction

During the past two years, research has been carried on to provide quantitative estimates of the potential effects of cloud seeding on the two major Illinois crops, corn and soybeans. Previously, pilot studies (Changnon and Neill, 1967) had demonstrated the feasibility of providing these estimates for a representative midwestern state (Illinois) and for deriving the necessary analytical techniques for extension of the evaluation to other areas.

Major attention has been given to three basic tasks in the above research. These include 1) determination of weather-yield relationships for corn and soybeans in Illinois with division of the state into regions of equivalent-yield characteristics, 2) development of methods to evaluate quantitatively the effect of any future seeding-induced rainfall changes on yields of these crops, and 3) general assessment of the economic value of yield increases resulting from cloud seeding.

A primary consideration in the development of the methodology for assessing increased crop yields (benefits) from rainfall augmentation in Illinois has been to establish methods widely applicable in the United States. This basic requirement led to the decision that crop yields should be related to standard climatological variables, such as temperature and precipitation, for which long-term records are readily available throughout the country. Soil moisture measurements, for example, would be very useful in defining crop-weather relationships, but such measurements are only available for a relatively few sites, often provide data for a short period of time, and results are applicable only over a small area. However, in view of the lack of precise measurements of other parameters entering into the derivation of potential effects of cloud seeding, the above restriction is considered acceptable in this initial effort to provide a first approximation of the potential effects of weather modification on agriculture.

2. Data used and analytical procedures

A necessary initial step in the study was to determine the regions within the state having similar crop-yield relations. Regional differences should result from the interaction of different soil types, varying climatic conditions, and, possibly, degree of technological advancement. Therefore, an objective delineation of crop-weather regions was undertaken through use of county data on past weather conditions and crop yields. In the Illinois study, the state was divided into 13 regions, based on evaluation of crop yield and weather statistics derived for each of the 102 counties in the state. The method used in this procedure is described in detail elsewhere (Changnon, 1969).

Next, a multiple regression equation was derived for each of the two crops in each region. In these regional equations, crop yield was related to technology indices and various parameters of temperature and precipitation. The equations were derived from crop yield and climatological data during the 38-year period, 1931–68, for which satisfactory historical records of yields and weather were available in Illinois. Using the appropriate equation, hypothetical seeding models were then applied to actual weather data in each year of the sampling period to obtain estimates of yield increases or decreases resulting from potential augmentation of summer rainfall.

3. Development of regional regression equations

The basic assumptions in the development of the regional regression equations were that they would be used for 1) assessing the effect of weather variables on crop yields for which reliable data are available in the historical records, and 2) estimating how the yields would have been changed if the important precipitation variables, July and August rainfall [defined by Changnon and Neill (1967)], had been altered through application of rain modification. The equations were not intended to be used as future prediction models, but only to achieve a first approximation of cloud seeding effects on corn and soybean yields over a substantial period of time in which a wide range of weather conditions were experienced and during which modern agricultural technology was available. Results would then provide guidance in evaluating the potential benefits or disbenefits of weather modification in the long-term when applied to the two major Illinois crops.

A set of weather variables was used that would be expected to affect crop yields. For example, sub-moisture is known to be an important factor and this is directly related to pre-season precipitation. Certainly, the temperature and precipitation during the crop growing season (May–August) are important as well as the interaction between temperature and precipitation. In addition to the basic weather variables listed in the previous section, the following were used: second-order variables of rainfall for June, July and August; pre-season precipitation; and temperature-precipitation interactions for June, July and August.

Thus, there were 15 weather variables used in each regional equation, all of which were shown to be important in determining the crop yield in different areas of Illinois in the previous study of Changnon and Neill (1967). In addition, there were five to six technology and technology-weather interaction variables (discussed later) which were found to vary according to the region of interest. Thus, when a multiple regression equation was used to express the relation of the independent variables (technology and weather) with the dependent variables (crop yield), the number of regression coefficients was either 20 or 21. With 38 years in each sample, the resulting degrees of freedom were either 15 or 16.

The small number of degrees of freedom would be particularly serious if the regression coefficients were themselves being studied, or one contemplated extrapolating the regression surface beyond the range of the values of the independent data in the sample. This means one should not attempt to apply the equations to a period of time other than that from which the data were derived. However, the equations used here are not intended, as indicated earlier, as crop yield prediction models, but as weather modification assessment tools. It is believed that use of the regression equations for this purpose is not seriously hindered by the restriction in degrees of freedom.

The first step in developing the weather-crop yield equation for each area was to determine the multiple regression equation using the 15 weather variables and the technology terms as independent variables and the crop yield as the dependent variable. Since experimental plot data and/or fertilizer data for the various areas were not available, they could not be used to assess the technology factor. Accordingly, time was made one of the factors in the multiple regression and any part of the long-time change in yields which was not associated with differences in the weather variables was ascribed to time. Each year was numbered 0, 1, 2, . . . , 38 and included as a factor in the multiple regression as the time trend variable T (technology). This method was used by Fisher (1954) and by Thompson (1963, 1964, 1969a, b). In addition, weather-technology interaction terms were included. The three terms selected for this purpose were those involving interactions of temperature and precipitation with technology for the months of June, July and August.

After the general form of the regression equation had been established, the remaining problem concerned the order of the technology term. This was determined in the following manner. First, the multiple regression equation was devised to include the crop yield variable, the linear technology variable, the weather variables, and the technology-weather interaction variables (19 terms in all). Second, a multiple regression was determined with the same variables as above, 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 the F-test indicated an increase in the sum-of-squares contribution, a new regression was evaluated as before, but with a third-order term added. The F-test was then applied again, to determine if there was an increase in the sum of squares. The procedure was continued until there was no increase in the sum of squares when the next higher order of the technology variable was added. When there was no increase, the equation which had the last increase was chosen as the appropriate equation. The equations for the various corn regions in Illinois had either second- or third-order technology terms, while the various soybean regions had either first- or second-order terms. Among the 13 regions, the multiple correlation coefficients for the regressions ranged from 0.96 to 0.99.

Summarizing, the regression equation approach was

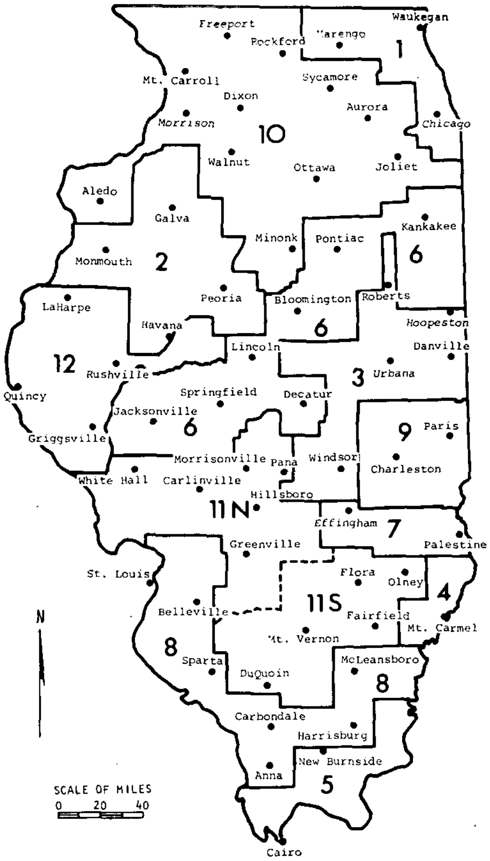


FIG. 1. Location of regions and rainfall sampling stations.

adopted because of certain major advantages such as: 1) the capability of using historical data on crop yields accumulated for counties, along with rainfall and temperature data from numerous long-term cooperative weather stations of the National Weather Service; 2) the opportunity to test crop response under actual farm conditions; 3) the simplicity of the technique which provides an approximate profile of crop response; and 4) the suitability of the technique for application in other areas of the United States. However, certain disadvantages must also be recognized. These include 1) the possibility that the data (yields and weather) may not be from geographic units having uniform production conditions and which conform to optimum sizes of seeding units, 2) the historical weather data may not include all types of weather conditions relevant for weather modification, and 3) specific technology-weather interactions cannot be identified. Overall, however, the method is believed to be the most suitable at this time for the task undertaken in the Illinois study.

4. Hypothetical seeding models

Two types of hypothetical seeding models were used. One type (constant-change model) investigates the effects of various constant-percentage increases applied to the naturally occurring monthly rainfall. The second type (variable-change model) is considered more realistic; it assumes that seeding effectiveness is altered with the intensity of the naturally occurring daily rainfall. For use with the variable-change models, daily rainfall distributions had to be calculated in each region for each of the 38 years. Sufficient constant-change and variable-change models were selected and tested to cover the expected range of seeding capability in the foreseeable future. No provision was made for inducing rainfall on rainless days. Cloud seeding knowledge and technology have not progressed adequately at this time to make such estimates feasible, and the capability of producing significant rainfall under this condition remains very controversial.

In calculating seeding-induced effects on crop yields, it was assumed that no long-range weather forecasting capability of sufficient accuracy to be used in planning seeding operations was available. Consequently, no provision was made in this study for initiating or terminating seeding operations during July and August on the basis of precipitation forecasts. Also, temperature was not varied in the regional prediction equations in calculating seeding effects. The observed mean temperature for each month was used, and it was assumed that the hypothetical increases in rainfall from short-duration seeding operations would not alter temperatures sufficiently to change crop yields significantly.

From hypothetical seeding, frequency distributions of yield changes were developed for each specific model, each crop, and each region. The yield-change distributions for the two crops were then pooled on an annual basis, and economic frequency distributions of seeding benefits developed for each region. All frequency analyses were based upon normalization of crop yields to 1968 technology levels (last year of sample). Average crop prices for the 1965–69 period were used in assessing economic benefits, along with the regional acreage distribution of two crops in 1968. Prices used were $1.13 per bushel for corn and $2.56 per bushel for beans. Frequency distributions were developed for potential operational seeding periods lasting 1, 2, 3 and 5 consecutive years.

Fig. 1 shows the location of the 13 regions of equivalent yield characteristics used in the Illinois study, and the stations used to derive climatological information. Areas ranged in size from over 11,000 mi^2 in Region 10 in northern Illinois to less than 1000 mi^2 in Region 4 in the southeastern part of the state. These regions were developed from county weather-yield studies (Changnon and Neill, 1967) which indicated those counties with similar yield-weather relationships based on soil types, climate, and inherent farming practices (technology). Highest crop yields are normally obtained in the northern and central parts of the state.

Table 1 shows the hypothetical seeding models used in the study. The upper part of the table shows the percentages assigned to each of the variable-change models. For example, Model A, which will be used herein frequently for illustrative purposes, assumes a 100% rainfall increase can be achieved on a day in which the naturally occurring rainfall is 0.10 inch or less. The percentage of seeding-induced rainfall then is decreased gradually to zero on days with natural rainfall $\geqslant 1$ inch. With this model, it was assumed that natural atmospheric processes would have reached a level of efficiency on such days that seeding would not increase rainfall further. Also, storm rainfall in excess of 1 inch is considered of little agricultural value in Illinois because it will usually be carried away as surface runoff and may produce significant soil erosion. Essentially three increase models (E, A ,B) were used, along with a crossover model (C), and three decrease models (X, Y, Z). Decrease models, if attainable, could be used to reduce rainfall in overly wet periods, an occasional problem in Illinois (Changnon, 1969).

In the lower part of Table I the constant-change models are shown. In these, it is assumed that all rainfall amounts will be changed at the same rate regardless of intensity. The constant-change values have been placed below the variable-change model with which they correspond closely with respect to average change in total monthly rainfall. Thus, for example, the long-term average effect of Model A on July–August total rainfall is an increase of about 25%.

5. Seeding-induced changes in corn and soybean yields

Fig. 2 illustrates the differential effect of seeding operations on corn over periods of 1–5 years in duration. Probability curves are shown for corn yield changes in bushels per acre (bu acre^{-1}) for Model A in Region 11S, an area in which clay soil conditions and climatic stress are such that seeding could conceivably increase yields in many years. The 2-, 3-, and 5-year curves were constructed from moving averages of yield changes in the 38-year sampling period. As expected, the possibility of a major benefit is greater in a single-year operation (selected at random), but the possibility of a disbenefit (yield loss) is also greater with short-period operations. In this particular case, the probability of a yield gain is 73% with a single-year operation and 96% with a 5-year operation. If properly controlled, seeding would appear to be a definite asset in Region 11S.

Table 1. Variable-change and constant-change seeding models used to modify naturally occurring rainfall.

Daily rainfall (inches)	Variable percentage change for given model						
	E	A	B	C	X	Y	Z
0.10 or less	150	100	75	50	−50	−75	−100
0.11–0.50	75	50	30	20	−30	−50	−75
0.51–1.00	30	20	10	0	−10	−30	−50
Over 1.00	10	0	−10	−20	0	−15	−30
Constant-change model percentages	40	25	12		−15	−30	

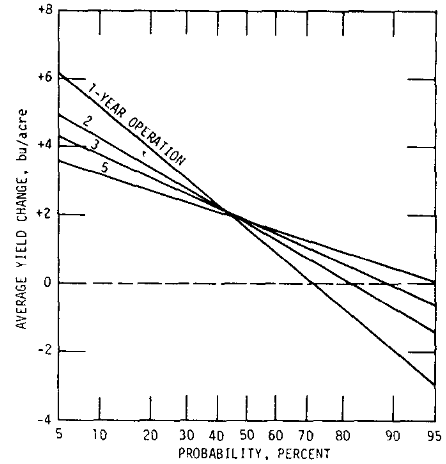
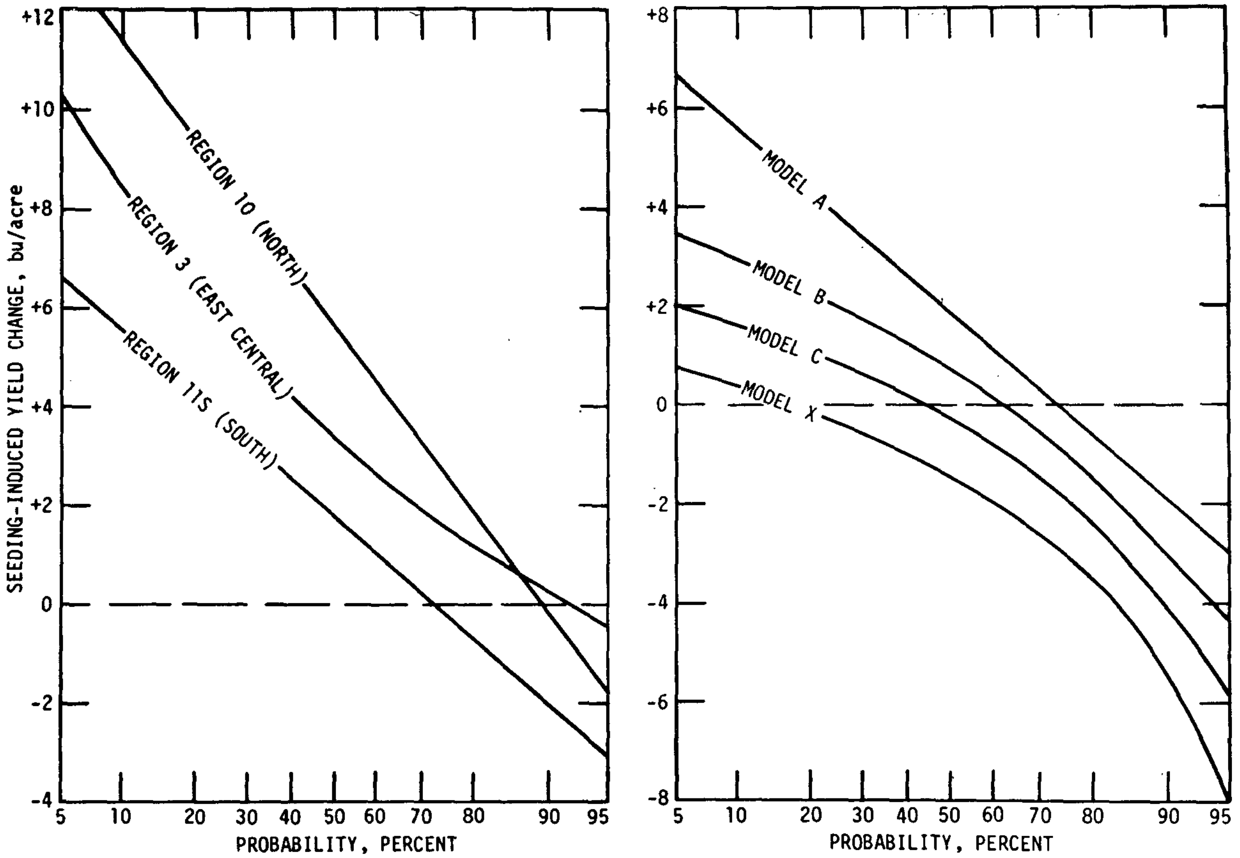


Fig. 2. Effect of seeding operation length on average yield changes in Region 11S with Model A.

In Fig. 3, the variance in seeding benefits that may occur between regions and between different models in the same region is illustrated. Fig. 3a shows comparative frequency distributions of corn in three regions, based on Model A and a single-year type of operation. As indicated by the intersection of the regional curves with the zero yield-change line, the probability of a yield benefit is 73% for Region 11S, 90% for Region 10 in the northern part of the state, and 92% for Region 3 in east central Illinois. This differential reaction to seeding is related to soil and climatic differences between regions and possibly to differences in utilization of available technological gains. Regions 3 and 10 are normally high yield areas with generally more advanced technological practices than found in Region 11S.

Fig. 3b illustrates the comparative yield changes with corn obtained from use of several variable-change models based on a single-year operation in Region 11S. It is apparent 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 southern Illinois. Otherwise, there is danger of producing a long-term disbenefit. The danger potential is also related to forecasting capability, and there is need for both seeding control and long-range (1-month) precipitation forecasting for efficient utilization of weather modification.

Fig. 4 shows a comparison of seeding effects from application of Model A to corn and soybeans in Region 11S. These curves illustrate a property typical of all models and most Illinois regions; that is, the year-to-year cloud seeding effect varies more with corn than with soybean yields. Thus, the probability of a large seeding-induced yield increase is more likely with corn, but, on the other hand, a larger decrease may occur also. In Region 11S, the average yield increase for corn with Model A is 1.8 bu acre^{-1} compared with about 1.2 bu acre^{-1} for soybeans. Among the 13 regions, the average



a. Regional comparisons of Model A b. Model comparisons in Region 11S

FIG. 3. Comparative frequency distributions of seeding-induced corn yield changes.

yield gain for corn with Model A ranged from less than 1 to over 6 bu acre^{-1} with a state average of 2.6 bu acre^{-1}. Similarly, the soybean regional averages ranged from -1 to $+2$ bu acre^{-1} with a state average of 0.8 bu acre^{-1}. As brought out in Fig. 4, a continuous year-to-year seeding program in Region 11S with a Model A capability would increase yields in 70–80% of the years, but would have an adverse effect in the remaining years.

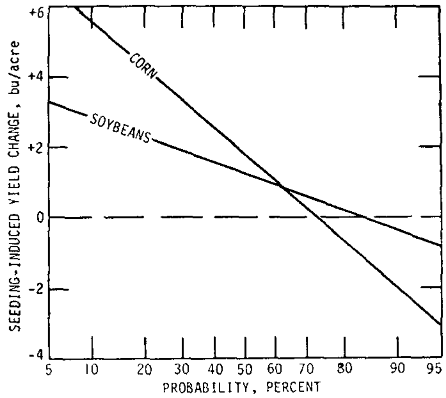


FIG. 4. Comparison of corn-soybean frequency distributions with Model A in Region 11S.

At this point, it is interesting to consider one of the major problems involved with cloud seeding—what is the differential effect of seeding on various crops in a given region. In Region 11S, it was found that Model A would have helped both the corn and soybean crops in 26 out of the 38 years in the sampling period, and would have harmed both crops in one year. In the remaining 11 years, about 30% of the total years, one crop would have benefited while the other was having its yield suppressed by the Model A seeding. The 13-region average for Model A showed both crops helped in 27 years, both harmed in 3 years, and differential effects in 8 years (21% of total years). However, the number of years with differential effects varied widely among regions, ranging from 0 in Region 9 to 22 years in Region 2.

Table 2 summarizes the average effect of seeding-induced rainfall on corn and soybean yields through use of the variable-change models. State average yield changes (in both bushels per acre and percent) are shown for the two crops with each model, based upon weather conditions experienced in the 1931–68 period and 1968 technology. From this table, it is apparent that the percentage yield change is very similar for the two crops with the various models. This table also shows that the increase models are most useful, on the average, and that relatively large percentage increases in July-August rainfall, as typified by Model E, would be most desirable.

6. Economic analyses of seeding effects

Fig. 5 shows the frequency distribution of economic benefits in Region 11S resulting from application of several of the variable-change seeding models. Income difference in dollars per seeded acre has been plotted against probability in percent based upon single-year seeding operations. That is, the probabilities represent values for a crop growing season selected at random. Seeding costs, which our survey indicates are of the order of 5–15 cents acre^{-1}, are not included in the graph. Frequency distributions similar to those in Fig. 5 were computed for each region and for seeding operations having a duration of 1, 2, 3 and 5 years.

The optimum curve in Fig. 5 represents the income gain assuming the seeder has the capability to select the best variable-change model for use in any given year. As indicated earlier, Models E and A are definite increase models. Model C is a crossover model with nearly equal probability of producing gains or losses in a given year selected at random, and Model X is a decrease model which would be used only to suppress rainfall in overly wet years.

Fig. 5 not only illustrates the relatively wide variance in economic benefits that can result from various seeding capabilities (seeding models), but stresses the variability that may occur from year to year with use of the same seeding model. For example, with Model A, a reasonably efficient increase model, the median increase is approximately $2.50 per acre with a 5% probability of a gain of $6.80 per acre or a loss of $1.80 per acre. Of course, if a seeder had the seeding-induced capabilities represented by Model A and the forecasting knowledge to eliminate those years in which seeding would be harmful, the lower portion of the probability curve in Fig. 5 could be largely eliminated. However, note in Fig. 5 that substantial gains could not be made every year even with the use of the optimum increase or decrease model.

Table 2. State averages of yield changes associated with a continuous seeding program using variable-change models.

Average yield change	Yield change for given model						
	E	A	B	C	X	Y	Z
				Corn			
Bushels per acre	+5.2	+2.6	+0.9	−0.9	−3.7	−7.8	−13.1
Percent	+5.8	+2.9	+1.0	−1.0	−4.1	−8.7	−14.6
				Beans			
Bushels per acre	+1.2	+0.8	+0.3	−0.2	−1.2	−2.5	−4.2
Percent	+4.2	+2.8	+1.0	−0.7	−4.2	−8.7	−14.7

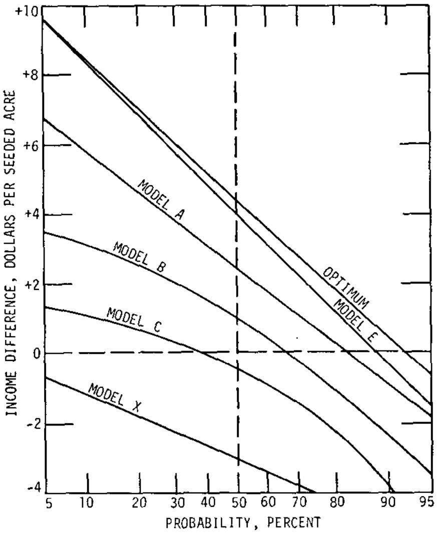


Fig. 5. Economic benefits in Region 11S with variable-change models.

The average economic gain with Model A ranged from less than $1 acre^{-1} to approximately $6 acre^{-1} among the 13 regions, with an overall state average of nearly $3 acre^{-1}. For comparison purposes, the optimum model showed a range from $1–$10 acre^{-1} with a state average of approximately $5 acre^{-1}.

One reason for the year-to-year variability in the efficiency of a given seeding model is illustrated in Fig. 6. This graph shows the frequency distribution of seeding-induced changes in the monthly rainfall for July in Region 11S for the variable-change models of Fig. 5. Using Model A as an example, we see that the median effect of this model is an increase of 26% over the naturally occurring regional rainfall. However, in a year selected at random, there is a 5% probability of a 42% or more increase in July rainfall and a similar

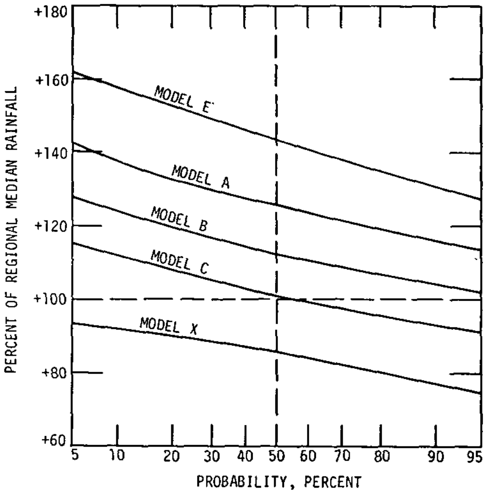


Fig. 6. Effect of variable-change models on July rainfall in Region 11S.

TABLE 3. Comparison of added income per seeded acre with various seeding models, based on 13-region medians.

Model	Added income per acre (dollars) equalled or exceeded for given probability (%) 5	10	20	30	50	70	90	95	Break-even point (%)
Optimum	12.5	11.0	9.0	7.4	5.4	2.8	0.0	−1.6	85
E	12.4	10.5	8.8	7.1	4.2	2.5	−0.9	−3.2	85
A	8.6	7.4	6.1	4.9	2.5	0.8	−0.9	−1.9	77
B	5.8	4.4	3.8	2.6	1.1	−0.2	−2.6	−3.6	66
C	3.4	2.4	1.6	0.8	−0.4	−1.4	−3.8	−5.1	42
X	1.2	−0.1	−0.9	−1.5	−2.6	−3.8	−5.6	−8.8	10

probability of less than a 14% increase. This variation is due to the natural temporal variability in the distribution characteristics of daily rainfall upon which the variable-change models operate.

The time variability in the effectiveness of rain augmentation with a given model, as illustrated in Fig. 6, indicates that seeding success may vary substantially between years with application of the same seeding method. In turn, this provides a partial explanation for the controversial results obtained in past cloud seeding experiments and commercial operations, and, at the same time, vividly portrays one of the problems encountered in the statistical verification of cloud seeding effectiveness.

It is interesting to note that Model A with its median increase of 26% and increases of 40–50% occasionally agrees quite well with seeding results claimed in the past by some commercial cloud seeders. Models C and X results would agree more closely with findings in the Arizona experiments (Battan, 1966) and the Whitetop experiment in Missouri (Decker and Schickedanz, 1966; Braham and Flueck, 1970).

Table 3 provides an additional measure of the economic benefits that could be derived from application of variable-change seeding models. In this table, a comparison has been shown of the added income per seeded acre with various models, based upon median values for the 13 regions. Therefore, this provides an indication of the statewide benefit that could be attained. For each model, Table 3 shows the added income for selected probability levels. Also, the break-even point, or the probability of an economic gain in a year selected at random, is shown in the table. For example, assuming the entire state was being subjected to a seeding program, Model A indicates a probability of an income increase of \$8.6 acre^{-1} in 5% of the years on a typical farm, a \$2.5 or greater increase in 50% of the years, and a loss of \$1.9 or more in 5% of the years (95% level). On the average Illinois farm, application of Model A would achieve an economic gain in 77% of the years.

Table 4 shows a comparison of the economic benefits with selected variable-change and constant-change models in Region 11S. The average effect of Model E on monthly rainfall increase over the 1931–68 sampling period was similar to the 40% constant-change model; that is, the 38-year average with Model E was approximately a 40% increase in total July-August rainfall. The average effect of Model A was nearly equal to the 25% constant-change model, and Model B was similar to the 12% constant-change model. Overall, the constant-change models were somewhat more effective than were the "equivalent" variable-change models. Other analyses indicated that the variable models were somewhat more effective in near-normal years, and that the constant models were considerably better in well-below-normal years. This may be due primarily to the basic assumption of little or no seeding effect on heavy rainfall days in the variable models. In below-normal years, augmentation of rainfall on relatively heavy rainfall days would be desirable as long as saturation did not occur. However, seeding effectiveness on such days is questionable (as assumed in the variable models) and undesirable if erosion is substantial.

Fig. 7 is based upon use of the variable-change optimum model and illustrates how the economic benefits may vary between individual regions. Thus, Fig. 7 shows that Region 8 has the highest median income benefit among the four regions shown, but its year-to-year gain has a substantially greater range. The differences shown in Fig. 7 are related strongly to the soil properties of the regions, and, to a lesser extent,

TABLE 4. Comparison of added income per seeded acre with various constant- and variable-change seeding models in Region 11S. See text for explanation.

Model	Added income per acre (dollars) equalled or exceeded for given probability (%) 5	10	20	30	50	70	90	95	Break-even point (%)
E	9.7	8.5	7.0	6.0	4.2	2.5	0.0	−2.2	90
A	6.8	5.8	4.7	3.9	2.5	1.1	−0.9	−1.8	83
B	3.6	3.2	2.6	2.0	1.0	−0.2	−2.3	−3.6	68
40%	11.2	10.2	8.9	8.0	6.4	4.8	1.5	−2.4	93
25%	7.3	6.6	5.7	5.1	4.1	3.1	0.8	−1.4	92
12%	3.6	3.2	2.8	2.5	2.1	1.6	0.5	−0.5	93

to climatological differences in daily rainfall distributions within the state. Region 8 is located in southern Illinois (Fig. 1) where thin clay soils predominate, so that seeding-induced rainfall would be more helpful, on the average, than in the central portion of the state where Region 3 with deep soils is located. However, frequent rains are needed in southern Illinois, so that the year-to-year effectiveness of the seeding model can vary substantially, based upon the time and intensity distribution characteristics of the naturally occurring rainfall. Region 5 in extreme southern Illinois is in a poor crop-yield area in which seeding could only produce very modest gains and in which the presence of "wet" soils would make rainfall modification of questionable value in many years.

7. Conclusions

In general, analytical results indicate that in most regions of Illinois corn and soybean crops would be benefited economically in the majority of the growing seasons through a cloud seeding program, provided that the seeding operator had the capability to produce rainfall increases $\geqslant 10\%$. However, the results of this study also show that the operator must be able to define accurately the rainfall output from his seeding treatment or more damage than benefit could result from his activities. This problem was illustrated clearly in the frequency curves of yield gains and losses with the variable-change models.

Reaction to potential seeding was found to vary substantially between regions in Illinois when the same seeding model was employed. This variation results primarily from differences in soil properties between regions, and, to a lesser extent, to differences in growing-season climate.

As shown by the frequency distributions of rainfall changes associated with the several variable-change models, seeding effectiveness may vary considerably from year-to-year with the same seeding model. This results from the temporal variability in the natural distribution characteristics of storm and daily rainfall (intensity and volume) which, in turn, affect the seeding-induced rainfall output. This temporal variability complicates the problem of statistical verification of seeding results and helps explain some of the controversial results obtained in past cloud seeding experiments and commercial operations.

From a percentage standpoint, the statewide average yield change resulting from seeding was found to be very similar for both crops with the various hypothetical seeding models employed in the study. However, average yield change (bu acre^{-1}) was greater with corn which has a much higher acreage yield than soybeans. Also, comparisons indicated that the year-to-year variability in seeding effect was greater with corn than with beans.

Analyses of corn and soybean reaction to seeding in each of the 38 years of the sampling period indicated that differential effects may occur in a significant percentage of the years; that is, one crop may be helped and the other harmed. For example, the statewide average with Model A, a moderate rainfall increase model, indicated that opposite yield change effects (gain or loss) would occur in approximately 21% of the years with a wide variance from 0% to 58% of the years among the 13 regions.

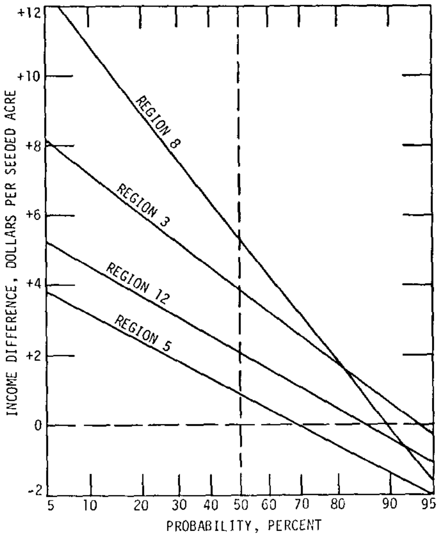


Fig. 7. Variation of economic benefits between regions with variable-change optimum model.

Acknowledgments. This research was supported by the Division of Atmospheric Water Resources Management, Bureau of Reclamation, under Contract 14-06-D-6843. Dr. Earl Swanson, Professor of Agricultural Economics, University of Illinois, provided assistance in the economic evaluations. Dr. Paul Schickedanz was responsible for development of the regional regression equations, and Elmer Schlessman supervised much of the data analyses.

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