POTENTIAL ECONOMIC BENEFITS OF HAIL SUPPRESSION TO CROP PRODUCERS IN DIFFERENT REGIONS OF THE UNITED STATES

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INTRODUCTION

Changnon and Morgan, in a recent issue of this journal, review a number of past hail suppression efforts as to the effectiveness of these efforts in reducing hail and/or altering rainfall. In addition, they specify future scenarios and an associated level of hail suppression effectiveness for each scenario. The research reported in that paper was part of a 15 month technology assessment of hail suppression in the United States (TASH). Another component of that multidisciplinary effort was an evaluation of the economic incentive for farmers in different regions of the nation to support the adoption of hail suppression. The results of that evaluation are reported in this paper.

It is important to note that the research reported here is not designed to estimate the entire benefits of widespread hail suppression activities. Rather, this effort analyzes this technology from the vantage point of crop producers considering the adoption of a hail suppression effort in their local area.

DESCRIPTION OF THE ESTIMATION PROCESS

Even though hail suppression programs, if initiated, will most likely be undertaken as a group process, it is important to evaluate the economic incentive of hail suppression for individual farmers. The individual farmer perspective is appropriate because agriculture is a likely beneficiary from successful hail suppression efforts and because it is reasonable to expect that individual farmers must perceive direct benefits from hail suppression activities before they would support initiation of such programs (Farhar).

At first glance it might seem that an accurate perception of the individual farmer's concern for hail loss could be gained by estimating the average annual hail loss to crops in a region (Boone). But calculations of the average effect would not completely depict an individual farmer's concern for hail as a production risk. This potential inaccuracy arises because the farm operator must be concerned about the distribution of hail losses among years as well as the average loss. For example, a 3 or 4 percent average crop loss due to hail may be of less concern if those losses occur every year rather than as a 40 percent loss one year with no loss in other years. The large crop loss in one year is particularly damaging for the undercapitalized farming operation which could be forced into partial or total liquidation if cash receipts are insufficient to cover cash expenses in a particular year.

To more accurately depict the farmer's economic incentive to favor adoption of hail suppression, a detailed analysis of the potential gains of hail suppression was conducted for several areas of the nation. Six areas, represented by specific locations, were selected for this analysis. They are:

Area	Type of Farming	Annual Historic Hail Loss	Specific Location
Northwestern Kansas	Wheat	12%	Township 13S south, 29 west; Gove county
Southwestern North Dakota	Wheat	11%	Township 131 north, 85 west; Grant county
West Central Texas	Cotton	20%	Statistical township 9; Castro county
East Central Illinois	Corn/ Soybeans	1.5% (corn) 3.7% (soybeans)	Township 15 north, 2 east; Macon county
North Central Iowa	Corn/ Soybeans	7.6% (corn) 13.6% (soybeans)	Township 98 north, 27 west; Kossuth county
Central North Carolina	Tobacco	1.7%	Pitt county[1]

The crops chosen in these six areas are crops for which national hail losses are significantly large -- either because the crop is particularly susceptible to hail or because very large quantities of the crop are grown. The specific locations chosen are representative of larger regions which produce major portions of the national production of these crops. In addition, these areas have histories of significant hail loss levels relative to the region they represent. (This last stipulation implies that the estimates resulting from this study will overstate the case for hail suppression -- if such a case can be made at all for the larger region.) Only six areas were studied because of time and resource limitations.

To account for the year-to-year variability of the hail hazard, this analysis evaluated both average income and variability of income from crop production given a specified level of hail suppression effectiveness. The hail suppression effectiveness levels presented here bracket the possible effectiveness levels detailed by Changnon and Morgan. Three levels of reduction in crop damage due to hail are considered: 20, 50 and 80 percent. In addition, three levels of rainfall variation are associated with each

[1]Because of the lack of adequate hail loss data at the sub-county level (in North Carolina), county loss data were used. This limitation should lead to an understatement of yield variability for this area.

level of crop damage reduction. These rainfall alternatives are a 10 percent decrease, no change, and a 10 percent increase in rainfall during the hail season.

For all the strategies considered, disaster provisions of the 1973 Agricultural and Consumer Protection Act are assumed to be in effect (Agricultural Stabilization and Conservation Service). Basically this program involves payments to farmers if their actual yield falls below established target yeilds for wheat, corn and cotton. There are no direct costs to the farmer for participating in this program.

Using historic yield variability coefficients and present-day technology, the study creates a series of yearly net income estimates for a range of hail suppression effectiveness levels. Each potential effectiveness level has an annual net income equation associated with it (1):

$$NI_i^t = (AP * Y_i^t * TS) + (P_{dp}^t * TS) - PC - C_{hs} \tag{1}$$

where t = year of the simulation series,[2]

- NI_i^t = net income to a crop-share tenant in the t-th year for the i-th level of hail suppression effectiveness,
- AP = 1972-74 average price for the crop at a major market appropriate for each area, i.e., Kansas City for the northwestern Kansas area (U.S. Department of Agriculture),
- Y_i^t = estimated yield for the t-th year given 1973 technology and the i-th strategy (Y_i^t varies by non-hail related yield fluctuations and the hail suppression effectiveness level assumed),[3]
- TS = crop-share tenant's portion of the crop (Commodity Economics Division, USDA),
- P_{dp}^t = amount of the federal disaster payment given the t-th year yield (Agricultural Stabilization and Conservation Service),
- PC = tenant's share of production costs, not including hail suppression costs (Commodity Economics Division, USDA), and
- C_{hs} = cost of hail suppression, assumed equal to $1 per harvested acre (Henderson).

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[2]Because of data limitations, the time series used in this study varied by area, ranging from 20 to 49 years. The data base used in each area was: 1925 to 1972 in North Carolina; 1954 to 1973 in Iowa; 1953 to 1974 in Texas; 1926 to 1974 in North Dakota and Kansas; and 1948 to 1974 in Illinois. The State Crop Reporting Service in each of these states was very cooperative in providing all available county yield data for use in this study.

[3]Y_i^t is created by first regressing yields for the simulation time period on simple trend variables representing technology. The percentage error between the predicted and actual yields are then combined with the yield estimate fixed at the 1973 technology level to give a base series of yields. This base series is further adjusted to account for reduced crop damage due to a specific hail suppression effectiveness level. Hail loss data were made available by Fosse. Essentially this procedure recreates the period of time for which there is data in each area and estimates the net income outcome if present-day technology and assumed levels of hail suppression effectiveness had been available in each year of that period. A detailed presentation of this process is given by Potter.

ESTIMATION RESULTS FOR EACH AREA

For each of the hail suppression effectiveness levels, the previously described process generates a net income estimate for each year of the simulation series. These estimates are averaged and, in addition, an estimate of yearly income variability determined for each strategy. Tables 1 through 6 present these coefficients for each of the six areas considered. The specific variables presented are average net income for the simulation period, the standard deviation of the net income series, and the coefficient of variation.[4] Although the standard deviation is a measure of the pure variability of an income series; the coefficient of variation allows comparison between two situations in which both the average income and standard deviation of income vary.

The $25.58 per acre net income estimate for Strategy A of Table 1 indicates that a crop share tenant in this northwestern Kansas area could expect to earn this average income assuming the tenant elected not to purchase either hail or all-risk crop insurance and no hail suppression programs were in effect in this region. The variability of this income stream is relatively high with a standard deviation of $29.92 leading to a coefficient of variation of 117.

The data of Table 1 clearly show that in the Kansas area the benefit of hail suppression program to the individual crop producer is directly related to the effectiveness of that program. Ignoring rainfall effects, a 20% reduction in crop damage due to hail only slightly increases average income and does not improve certainty of income relative to options presently available. Two factors reduce the positive effects of hail suppression. One, of course, is the $1 per harvested acre suppression cost. The second factor is the federal disaster payment program. The tenant is estimated to receive an average of $1.80 per harvested acre for each year of the simulation period for Strategy A. But 20 percent hail suppression effectiveness with no change in hail season rainfall reduces this payment to $1.70 per harvested acre and a 10 percent increase in precipitation at this effectiveness level further reduces the disaster payment to $1.27 per acre.

The 50 and 80 percent effectiveness levels (Strategies F and I) result in higher average incomes and more certain incomes than does Strategy A, even with the $1 cost and lowered disaster payments. But any change in rainfall in this area can very much alter the benefits from hail reduction. A 10 percent increase in rainfall makes the 20 percent damage reduction level superior to Strategy A. Decreasing hail season rainfall by 10 percent, however, can overcome the income benefit of a 20 or 50 percent damage reduction to make Strategies B and E inferior to Strategy A. For

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[4]The coefficient of variation is defined as the standard deviation of income divided by the average income (this quantity multiplied times 100). Therefore, a lower value for the coefficient of variation implies greater income certainty than does a higher value.

Table 1: Estimated Results for Wheat Production in Northwestern Kansas

Strategy			Average Net Income ($/ac)	Standard Deviation of Net Income ($/ac)	Coefficient of Variation
A)	No hail insurance, no hail suppression		25.58	29.92	117
	Reduction in Crop Damage	Change in Rainfall			
B)		10% decrease	22.60	29.34	130
C)	20%	no change	25.74	29.54	115
D)		10% increase	28.47	30.21	106
E)		10% decrease	24.34	28.94	119
F)	50%	no change	27.35	29.29	107
G)		10% increase	30.11	29.95	99
H)		10% decrease	25.98	28.86	111
I)	80%	no change	29.12	29.09	100
J)		10% increase	31.88	29.77	93

Table 2: Estimated Results for Wheat Production in Southwestern North Dakota

Strategy			Average Net Income ($/ac)	Standard Deviation of Net Income ($/ac)	Coefficient of Variation
A)	No hail insurance, no hail suppression		7.52	20.60	273
	Reduction in Crop Damage	Change in Rainfall			
B)		10% decrease	7.42	19.66	265
C)	20%	no change	7.62	19.70	258
D)		10% increase	7.83	19.74	252
E)		10% decrease	9.18	18.85	205
F)	50%	no change	9.40	18.90	201
G)		10% increase	9.62	18.97	197
H)		10% decrease	11.34	19.08	168
I)	80%	no change	11.56	19.19	166
J)		10% increase	11.67	19.41	166

Table 3: Estimated Results for Corn & Soybeans Production In North-Central Iowa

	Strategy		Average Net Income ($/ac)	Standard Deviation of Net Income ($/ac)	Coefficient of Variation
A)	No hail insurance, no hail suppression		53.93	18.36	34
	Reduction in Crop Damage	Change in Rainfall			
B)		10% decrease	52.40	16.18	31
C)	20%	no change	55.50	16.11	29
D)		10% increase	58.62	16.09	27
E)		10% decrease	56.35	11.10	20
F)	50%	no change	59.45	11.05	19
G)		10% increase	62.58	11.03	18
H)		10% decrease	60.30	8.27	14
I)	80%	no change	63.40	8.24	13
J)		10% increase	66.53	8.25	12

Table 4: Estimated Results for Corn & Soybeans Production In East-Central Illinois

	Strategy		Average Net Income ($/ac)	Standard Deviation of Net Income ($/ac)	Coefficient of Variation
A)	No hail insurance, no hail suppression		49.55	11.83	24
	Reduction in Crop Damage	Change in Rainfall			
B)		10% decrease	47.46	11.25	24
C)	20%	no change	49.63	11.33	23
D)		10% increase	51.80	11.42	22
E)		10% decrease	48.33	10.70	22
F)	50%	no change	50.50	10.77	21
G)		10% increase	52.67	10.85	21
H)		10% decrease	49.20	10.44	21
I)	80%	no change	51.37	10.50	20
J)		10% increase	53.54	10.56	20

Table 5: Estimated Results for Cotton Production in the High-Plains Area of Texas

Strategy			Average Net Income ($/ac)	Standard Deviation of Net Income ($/ac)	Coefficient of Variation
A)	No hail insurance, no hail suppression		1.89	51.23	2715
	Reduction in Crop Damage	Change in Rainfall			
B)		10% decrease	1.70	51.90	3047
C)	20%	no change	3.57	52.12	1461
D)		10% increase	5.43	52.29	963
E)		10% decrease	9.01	53.92	598
F)	50%	no change	9.86	54.37	551
G)		10% increase	11.75	54.54	464
H)		10% decrease	14.72	57.45	390
I)	80%	no change	15.64	57.93	370
J)		10% increase	17.60	58.07	330

Table 6: Estimated Results for Tobacco Production in Central No. Carolina

Strategy			Average Net Income ($/ac)	Standard Deviation of Net Income ($/ac)	Coefficient of Variation
A)	No hail insurance, no hail suppression		361.06	362.53	100
	Reduction in Crop Damage	Change in Rainfall			
B)		10% decrease	343.83	358.93	104
C)	20%	no change	364.21	359.35	99
D)		10% increase	385.54	359.47	93
E)		10% decrease	350.32	357.56	102
F)	50%	no change	370.71	357.96	97
G)		10% increase	392.03	358.07	91
H)		10% decrease	356.82	356.30	100
I)	80%	no change	377.20	356.69	95
J)		10% increase	398.53	359.79	90

this analysis, weather modification activities were assumed to be undertaken primarily to suppress hail -- with rainfall fluctuations as side effects. Therefore, rainfall effects in each area are accounted for only in months when hail suppression activities are likely to be undertaken in each area -- April through August in northwestern Kansas.

The southwestern North Dakota region studied is also a primarily wheat producing region. But Table 2 shows that the average net income is much lower and the coefficient of variation is much higher in the North Dakota area. As in the Kansas area, 20 percent reductions in crop damage are only marginally better than the no hail suppression activities. And federal disaster payments are again a factor. Federal disaster payments to the tenant, which would average $1.69 per harvested acre for Strategy A, are reduced to $1.33 per harvested acre if a 20 percent reduction in crop damage due to hail and a 10 percent increase in May to August rainfall were to occur.

But unlike the Kansas situation, 50 percent effectiveness in this area is considerably superior to the strategy without hail suppression. This superiority occurs both in terms of average income and variability of income. For example, Strategy E which combines 50 percent reductions in hail-caused crop damage and 10 percent less rainfall is estimated to increase average income by $1.66 per acre over Strategy A. On a percentage basis this is a 22 percent increase in income over Stategy A and contributes to a 23 percent decrease in the coefficient of variation. The 80 percent effectiveness strategies are even more attractive than the 50 percent level. These estimates substantiate the efforts of farmers to organize an operational hail suppression program in this region (Butchbaker).

Hail suppression, especially at more than the 20 percent effectiveness level, holds promise for reducing income variability in the western Corn Belt area represented by the north-central Iowa estimates of Table 3. Although hail suppression at the 80 percent effectiveness level, Strategy I, increases net income by only 23 percent, income variability is reduced by over 60 percent. This result indicates that the hail hazard is a major factor in year-to-year yield fluctuations in this region. However, it should be noted that variability of crop production is not nearly as severe a problem in this Iowa area as it is in the two Great Plains areas just discussed. This factor is substantiated by the coefficient of variation estimates of Tables 1 and 2 vs. those of Table 3.

For this area, ten percent rainfall fluctuations in the months of June to August were also considered. These fluctuations do not greatly offset the effects of reduced hail damage. Net income estimates tend to be positively related to rainfall changes in these hail season months with a 10 percent fluctuation in rainfall causing a 6 percent change in per acre net income.

With no hail suppression, average net income in the eastern Corn Belt region represented by the east-central Illinois data of Table 4 is estimated to be $49.55 per acre. The standard deviation of that net income series is only $11.83, resulting in a coefficient of variation of 24.

Hail losses in this area have historically been much less severe than in the western Corn Belt region represented by the Iowa region. In the Illinois township, hail losses averaged only 1.5 percent for corn and 3.7 percent for soybeans for the simulation period. Because of the relatively slight hail losses experienced in this region, hail suppression results in relatively minor benefits either in terms of average income or variability of income. The 80 percent effectiveness level with no rainfall effects, Strategy I, contributes only a 4 percent increase in average net income. Ten percent rainfall fluctuations in the months from June through August are positively related to a 4 to 5 percent change in net income at each hail damage reduction level.

Using terminology of the Crop Hail Insurance Actuarial Assocation, an area described as statistical township 9 in Castro County[5], Texas, was selected as a High Plains cotton producing area (Fosse). This area suffers extreme yield fluctuations. For the 1953 to 1974 period, average cotton yields were 281 pounds of cotton lint per acre with a standard deviation of 145 pounds per acre. Hail was a major contributor to this variability with 20 percent annual losses due to hail. An additional indication of the income variability experienced in this region is given by the results of Stategy A in Table 5. The average annual net income for the no hail suppression situation is $1.89 per acre but the standard deviation of that income is $51.23 per acre.

The estimates of Table 5 indicate that hail suppression at the 50 or 80 percent level could be tremendously attractive to this region's farmers. Average net income estimates for Strategies F and I are $9.86 and $15.64 per acre, respectively. These estimates are substantially higher than for Strategy A and contribute to greater certainty of income. At these levels of hail suppression effectiveness, the possibility of 10 percent reductions of April to November rainfall do not nearly offset the benefits estimated by reduced crop damage due to hail.

Federal disaster payments are a very significant factor for this area. For the no hail suppression situation, annual average disaster payments were estimated at $27.28 per acre. Although these payments can be reduced by successful hail suppression, these payments would still

[5]Several of the procedures adopted for the other study areas were altered for this area. The actual county yield data for this county exhibited extreme variability and trend variables could not be found which explained any systematic change in yield overtime. Therefore the percentage change from average yield during this period was used to depict yearly yield variability. Further when 1972-1974 average cotton prices were used net income estimates were negative, indicating that farmers in this area could not expect to cover variable costs with these prices. Because a decision to plant given this price expectation would not agree with common sense, the output price was adjusted upward to 50¢ per pound which resulted in positive average incomes above variable costs.

be a major positive income factor. Even for Strategy J where 80 percent hail suppression and 10 percent increased growing season rainfall are assumed, payments under the 1973 Agricultural and Consumer Protection Act are estimated at $17.25 per acre annually.

The data of Table 6 presents estimates for tobacco production in Pitt County in central North Carolina. Hail loss for tobacco for this county averaged 1.7 percent per year for the period 1925 to 1972. With no hail suppression, average annual income is estimated at $361.06 per acre in this area with a standard deviation of $362.53 per acre.

From the data of Table 6 it would appear that reducing hail damage to tobacco would not be economically exciting in this area. Even the 80 percent effectiveness level only translates into a 4 percent increase in net income. But the estimates of Table 6 do indicate sensitivity to rainfall in the months from May to September. These data suggest a $20 - $22 per acre variation in net income being directly related to 10 percent change in rainfall.

An additional consideration regarding the hail hazard is the presence of various types of insurance protection which the farmer can purchase. Although both commercial hail insurance and all-risk crop insurance were evaluated in the TASH project, specific results for these possibilities are not presented here for purposes of brevity. Generally, both hail insurance and all-risk insurance, where available, were found to reduce income variability but at a cost of reduced average income. The all-risk programs had lower average income estimates than the hail insurance provisions, but the former provided coverage for a broader range of risks.

COMPARISON BETWEEN REGIONS

The discussion of this section has so far concentrated on results between different strategies within one farming area. Another goal of this analysis, however, is to identify those regions where hail suppression holds greater potential benefits.[6] Therefore, Table 7 which compares Stategy A (the no hail suppression situation) with the nine hail suppression situations, Stategies B through H, has been prepared. In Table 7 the average income and coefficient of variation estimates have been normalized so that the outcomes for Strategy A are equal to 100 for both variables and outcomes for the other strategies are expressed as percentages of the Strategy A results.

[6] It should be re-emphasized that each of the six specific locations selected represent relatively high hail loss areas for the larger farming region they represent. Further, within these areas a township with historically high hail loss in a county with historically high hail loss was selected. Therefore the strongest economic pressure for adoption of hail suppression technology in the larger farming regions should be present in the areas discussed here.

Table 7: Comparison of Average Income and Coefficient of Variation of Income for Each Hail Suppression Strategy with that of the No Hail Suppression Situation, Strategy A.

Strategy			Percents Average Net Income is of Strategy A Net Income						Percent Coefficient of Variation is of Strategy A Coefficient of Variation					
			Ill.	IA.	Kans.	N.C.	N.D.	Tex.	Ill.	IA.	Kans.	N.C.	N.D.	Tex.
A)	No hail suppression		100	100	100	100	100	100	100	100	100	100	100	100
	Reduction in Crop Damage	Change in Rainfall												
B)		10% decrease	96	97	88	95	99	90	100	91	111	104	97	112
C)	20%	no change	100	103	101	101	101	189	96	85	98	99	95	54
D)		10% increase	105	109	111	107	104	287	92	79	91	93	92	35
E)		10% decrease	98	104	87	97	122	477	92	59	102	102	75	22
F)	50%	no change	102	110	107	103	125	521	88	56	91	97	74	20
G)		10% increase	106	116	118	109	128	622	88	53	85	91	72	17
H)		10% decrease	99	112	102	99	151	779	88	41	95	100	62	14
I)	80%	no change	104	118	114	104	154	828	83	38	85	95	61	14
J)		10% increase	108	123	125	110	155	931	83	35	79	90	61	12

To further highlight the differential hail suppression potentials between regions, the data of Table 7 have been graphed in Figures 1 through 6. For each of the six areas, the net income percentage is graphed on the horizontal axis and the coefficient of variation percentage is graphed on the vertical axis of Figures 1 through 6. Therefore, movements to the right indicate increasing average income and movements downward indicate decreasing income variability (relative to Strategy A). The most advantageous strategies are therefore in the lower righthand corner of each of Figures 1 through 6.

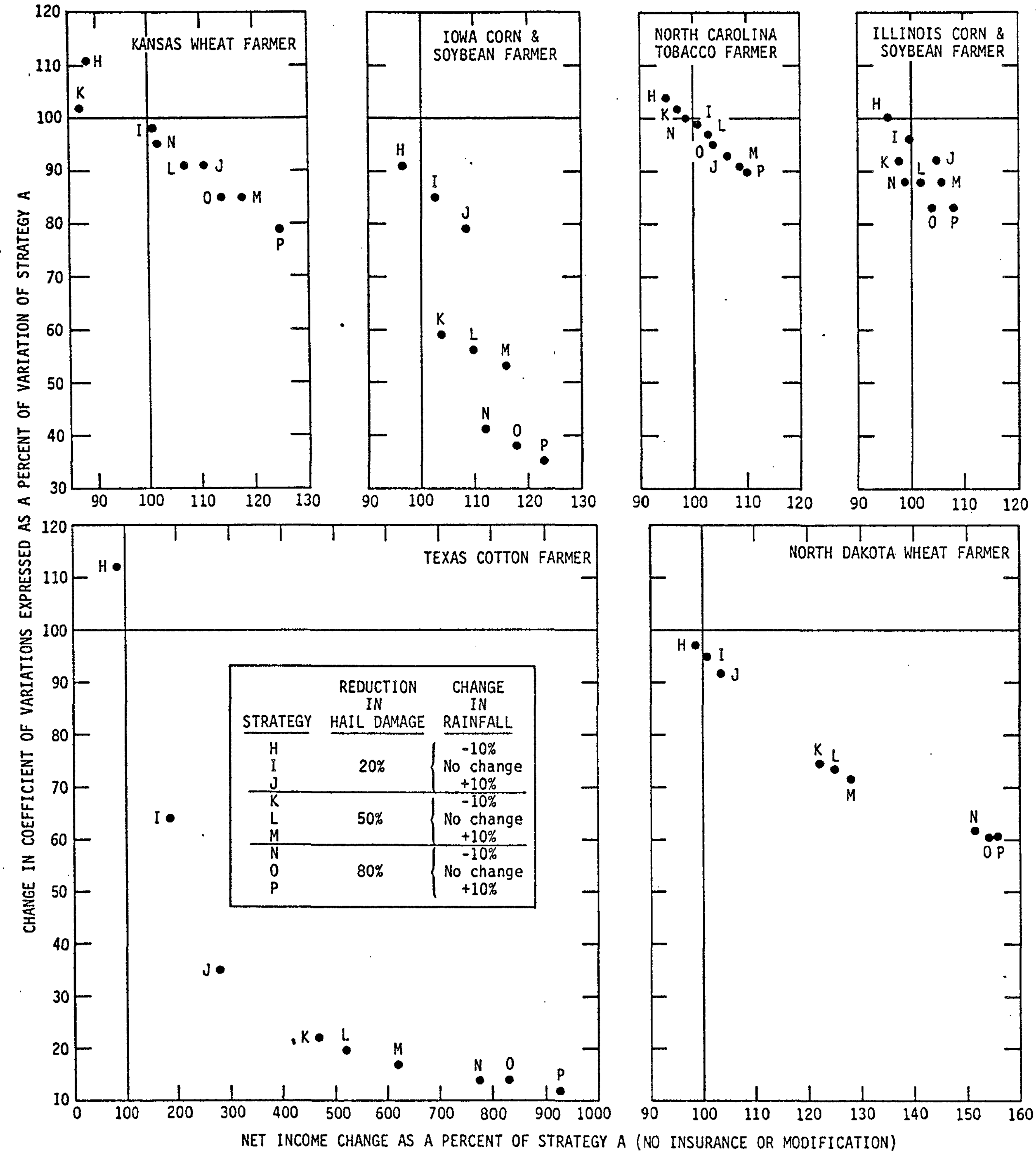
If we view the six figures as a group, the regional differences in hail suppression potential are readily apparent. The data for the two eastern-most regions, North Carolina - tobacco and Illinois - corn/soybeans, show little potential for hail suppression benefits. The results for both of these regions are bunched very closely to the intersection of the two axes. And, of course, that intersection point represents the outcome with no hail suppression.

In contrast, the graphs for the other areas: Texas - cotton; Iowa - corn/soybeans; Kansas - wheat; and North Dakota - wheat, indicate that economic potential for hail suppression may be present. In these more westerly areas, hail suppression with no rainfall effect is indicated to have potential gains. Although only the Texas region shows a sharp advantage at the 20 percent level, all four areas show significant potential benefits at the 50 and 80 percent levels.

The results displayed among hail suppression effectiveness levels in each of these areas is also informative. For Kansas, relatively large benefits are indicated for only five of the nine strategies. These five; strategies F, I, D, G, and J, represent (respectively) 50 and 80 percent effectiveness with no change in rainfall and all three hail suppression levels with 10 percent increases in rainfall. For North Dakota, the larger benefits occur for the 50 and 80 percent levels -- for all three rainfall assumptions. In this region potential gains are indicated for both average income and certainty of income. For Iowa, the most pronounced benefits relate to the certainty of income variable. And the data for the Texas region, although of the poorest quality of the six regions studied, show economic differentials of sufficient magnitude to indicate a potential interest for hail suppression at even relatively low levels of effectiveness.[7]

Another interesting feature depicted by the six graphs is the varying sensitivity to rainfall fluctuations exhibited in the six areas. Of course, changes in rainfall are shown to affect average income and variability of income in all six locations. But in North Carolina and Kansas, the 10 percent fluctuations in hail season rainfall are shown to have quite pronounced effects relative to reduction of hail damage. In North Carolina all three negative rainfall fluctuations result in poorer outcomes than Strategy A. And for the Kansas example, Strategies H and K (which combine 10 percent reductions in hail season rainfall with 20 and 50 percent hail suppression

[7]Because of the much wider range of outcomes for the Texas area, the axes of Figure 6 are scaled differently than the axes of the other five figures.


KANSAS WHEAT FARMER
IOWA CORN & SOYBEAN FARMER
NORTH CAROLINA TOBACCO FARMER
ILLINOIS CORN & SOYBEAN FARMER
TEXAS COTTON FARMER
NORTH DAKOTA WHEAT FARMER
CHANGE IN COEFFICIENT OF VARIATIONS EXPRESSED AS A PERCENT OF VARIATION OF STRATEGY A
NET INCOME CHANGE AS A PERCENT OF STRATEGY A (NO INSURANCE OR MODIFICATION)
STRATEGY
REDUCTION IN HAIL DAMAGE
CHANGE IN RAINFALL
H I J 20% -10% No change +10%
K L M 50% -10% No change +10%
N O P 80% -10% No change +10%

effectiveness, respectively) result in reduced certainty of income and greater than 10 percent reductions in net income. Conversely 10 percent increases in hail season rainfall are related to relatively large benefits in these two areas.

SUMMARY AND IMPLICATIONS

The study discussed in this paper evaluated the potential benefits of hail suppression to the individual crop producer assuming differing levels of effectiveness with regard to reducing crop damage due to hail and/or altering rainfall during the hail season. For purposes of this paper, adoption of the suppression program is assumed to be a localized decision for each of the six areas considered. Therefore the area affected by the suppression program can be assumed to be small enough so that output increases occasioned by the program will not be of sufficient magnitude to depress the national price for the commodity in question. This view relates to the economics of the adoption decision when, for example, the decision is being considered by a group of farmers in a region.

A readily apparent conclusion from the estimates detailed in the report concerns the considerable east-west differential in potential benefits. The results for the regions in the Plains states; Texas, North Dakota, and Kansas indicate the presence of considerable potential economic interest for hail suppression in these areas. The estimates for the Texas region show economic differentials of sufficient magnitude so as to indicate a potential interest for hail suppression at even relatively low levels of effectiveness. The Kansas and North Dakota results display relatively strong possible benefits for hail suppression if moderate to high effectiveness levels can be obtained.

For the north-central Iowa region, the potential attractiveness of hail suppression would primarily be from the standpoint of reducing uncertainty of income for the grain farmer. A 50 percent reduction in the crop damage caused by hail is estimated to reduce the variability of income (as measured by the standard deviation of the income stream) by 40 percent.[8] It must be noted, however, that variability of income is not nearly as severe a problem in the Iowa situation as it is for the areas in the Plains states. For the no hail suppression situation for example, the coefficient of variation (standard deviation/mean income) is 34 for the Iowa area but is 117 for the Kansas example.

Results for the Illinois and North Carolina regions indicate a very low economic interest for hail suppression in these regions. Although high levels of hail suppression effectiveness do increase average income and reduce variability of income somewhat in these areas, the benefits are small relative to their presently attainable income streams.

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[8] Variability of income as defined in this analysis refers only to income fluctuations caused by variations in crop yields. Price variability is not incorporated in these estimates.

But the estimates of the study also stress the importance in some areas of the effect of rainfall fluctuations possibly associated with hail suppression activities. An interesting example is the Kansas area where wide swings in benefits are associated with rainfall fluctuations. In this area, the gains attained by an 80 percent reduction in crop damage due to hail are estimated to be almost entirely offset by a 10 percent reduction in hail season rainfall. This relationship can be contrasted to the North Dakota situation where fluctuations in hail season rainfall are associated with minor deviations in benefits. In that example, large gains are estimated for 80 percent reductions in crop damage even with 10 percent less hail season rainfall.

An additional finding of this report was the surprising magnitude of federal disaster payments, as specified in provisions of the 1973 Consumer and Agricultural Protection Act, in the higher risk producing areas. In the southwestern North Dakota region, for example, disaster payments averaged 22 percent of average net income (assuming no hail suppresion). And an extreme case is presented in the Texas High Plains example, where average net income would have been negative with
A further importance of these payments is that higher levels of hail suppression effectiveness can reduce the magnitude of the payments. Therefore, the presence of these provisions may work to lessen the attractiveness of the hail suppression technology.

Although numerous implications could be discussed based on the estimates detailed in this paper (and, of course, different people may derive alternative conclusions from evaluating the same set of numbers), the authors would like to stress three factors they consider most interesting. The first of these comments is that the benefits derived from the same level of hail suppression effectiveness may be considerably different in different agricultural regions. For example, whereas a 50 percent reduction in crop damage with no change in hail season rainfall is shown to be potentially attractive in the Iowa situation, the same level of effectiveness has only marginal economic benefit for the same crops in Illinois. Consideration of the potential economic benefits, therefore, is important in determining where efforts to improve the hail suppression technology should be undertaken. This factor is especially important if we couple this idea of an east/west disparity of benefits with the differing likely abilities to achieve significant hail suppression effectiveness, which also tends to follow an east/west bias (Changnon and Morgan).

Also, likely potential effectiveness must be considered even in regions where hail suppression could be considered economically attractive. Only in the Texas situation, for example, does a considerable economic benefit result for hail suppression at the 20 percent level. And in the Kansas area, benefits from relatively large reductions in crop damage can be offset by reductions in hail-season rainfall. This need for evaluation of likely effectiveness is further emphasized if we heed the warning of Sax, et. al., "The idea that 'seeding is cheap' and hence that a little success, measurable or not, pays for it, and in any case 'keeps the farmer happy,' is poor politics, and even worse medicine."

The final implication to be presented has to do with efforts to improve the technology of hail suppression. The estimates developed in this paper suggest to the authors, at least, that in those areas where suppression seems attractive the large pay-off would accrue to improving the likely effectiveness (decreasing crop damage and/or increasing rainfall) rather than to providing more efficient and therefore cheaper operational systems. Of course, if the 80 percent effectiveness level has been attained, reducing operational costs is probably the only route to improving the net benefits of hail suppression. However, if that level has not been reached, it would seem most prudent to concentrate on methods whereby the 50 to 80 percent effectiveness levels can be achieved -- with a high degree of certainty.

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REFERENCES

Agricultural Stabilization and Conservation Service. Emergency and Disaster Assistance Available through ASCS. BI No. 13, U. S. Department of Agriculture, Washington, D. C., August, 1974 and personal communications with county ASCS staff in each area.

Boone, Larry M. Estimating Crop Losses Due to Hail. Agricultural Economic Report No. 267. Economic Research Service, United States Department of Agriculture, Washington D. C., December, 1974.

Butchbaker, A. F., "Results of the Bowman-Slope Hail Suppression Program" Journal of Weather Modification. Vol. 5, No. 1, June, 1973.

Changnon, Stanley A. Jr. and Morgan, Griffith M. Jr., "The Present Status and Future Potential of Hail Suppression." Journal of Weather Modification, Vol. 8, 1976.

Commodity Economics Division. Firm Enterprise Data System. Economic Research Service, U. S. Department of Agriculture, Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma. 1975.

Farhar, Barbara. "Weather Modification and Public Opinion in South Dakota, 1972 and 1973" Journal of Applied Meteorology. Vol. 14, No. 5, August, 1975.

Fosse, Ray E. Assistant Secretary of the Crop-Hail Insurance Actuarial Association. Chicago, Illinois. Personal Communication.

Henderson, Thomas. President, Atmospherics Incorporated. Fresno, California. Personal Communication.

Potter, Craig W. "Economic Aspects of Hail Suppression to the Individual Farmer." Unpublished M.S. thesis, University of Illinois, (Forthcoming).

Sax, R. I., Changnon, S. A. Jr., Grant, L. O., Hitschfeld, W. F., Hobbs, P. V., Kahan, A. M., and Simpson, J. "Weather Modification: Where Are We Now and Where Should We Be Going." Journal of Applied Meteorology. Vol. 14, No. 5, August, 1975.

Sharp, Everett S. Director of the Actuarial Division, Federal Crop Insurance Corporation, U. S. Department of Agriculture. Personal Communication.

U. S. Department of Agriculture, Agricultural Statistics, 1974. Washington D. C., 1974.