EVALUATION OF AN OPERATIONAL HAIL SUPPRESSION PROJECT IN TEXAS

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INTRODUCTION

An investigation was performed to evaluate statistically the results of the first 4 years of an ongoing hail suppression project in Texas so as to gain information relative to a decision on a future hail suppression effort in Illinois (Changnon et al., 1974). Continuous hail suppression operations over a 4-year period and in a fixed area offer a good opportunity to assess the effects of cloud base seeding as reflected in surface hail data. Two sets of hail data with long-term historical records in and around the 2-county area in Texas with hail suppression projects in the 1970-73 period were investigated.

HAIL DAY RESULTS

There were only three National Weather Service Stations with quality hail-day records in and around the seeded area, which comprises Hale and Lamb counties in the Texas Panhandle area. These stations, including Lubbock and Levelland in the non-seeded area and Plainview in the seeded area, all had records that show only the occurrence of hail by day. However, hail-day data have been and can be used to evaluate hail suppression experiments (Thom, 1957), and were investigated, to a limited extent, to ascertain possible effects of the suppression activities in 1970-73.

Table 1 presents various hail-day data relating to 1) the recent period (1947-73) average, 2) the number of hail days in each of the individual seeded years (1970-73), and 3) the averages for this recent 4-year seeded period. Also shown for each station and period are the percentage departures from the 1947-73 average. These stations have hail-day records extending before 1947, but prior studies (Henderson and Changnon, 1972) have shown (Fig. 1) that a sizeable climatic shift occurred during the 1946-47 period. This shift, which was possibly due to the impact of large-scale regional irrigation developments in the 1940's on the regional weather, resulted in 100%, on the average, increases in hail days during the 1946-55 period. Thus, it appears most reasonable to compare and evaluate the 1970-73 hail frequencies against those after 1946.

As shown in Table 1, the Plainview (seeded area) values in each of the seeded years were below normal, and the 4-year value was 59% of the long-term average. One of the two stations in the non-seeded area (Lubbock) also had a below normal 4-year value, but it was not as low as that at

Plainview. Levelland (non-seeded area) had a much above normal 4-year value.

Table 1. May-October Hail Days from National Weather Stations

		Average[1]	1970	1971	1972	1973	1970-73 Average
Plainview	Number of Days	3.9	2	3	2	2	2.3
	% of Average[1]	100	51	77	51	51	59
Lubbock	Number of Days	3.5	1	2	5	2	2.5
	% of Average[1]	100	29	57	143	57	71
Levelland	Number of Days	1.5	1	1	6	1	2.3
	% of Average[1]	100	67	67	400	67	153

(1) Averages based on 26 years of data, 1947-73.

Table 2 expresses the Plainview and Lubbock hail-day values or the 1970-73 period in relation to all other 4-year values of two past periods, 1947-73 and 1919-73 (when records began). Since 1946 there have been 24 possible 4-year combinations (1947-50, 1948-51, 1949-52, etc.), and only 2 of the 24 (8%) at Plainview had values lower than the 9 hail days in 1970-73. These values were 7 hail days for 1947-50, and 8 days in 1948-51, and these are not mutually exclusive. This evaluation shows the general infrequency of the low hail-day value of 1970-73. The recent low values are also depicted in Figure 1. The low 1970-73 values at Plainview (8%) is a relatively less frequent event than the low Lubbock value (17% of the time). This further suggests that 1970-73 value in the seeded area was quite low and lower than those in nearby non-seeded areas.

Table 2. Comparison of May-October Hail Days in 1970-73 with 4-Year Frequencies in Past Record Periods.

		Number of 4-Year Periods with Hail Days Totals < 1970-73 Values			
		1947-73 Period		1919-73 Period	
	1970-73 Hail Days	Number	% of Time	Number	% of Time
Lubbock (no seed area)	10	4	17	22	42
Plainview (seed area)	9	2	8	17	33

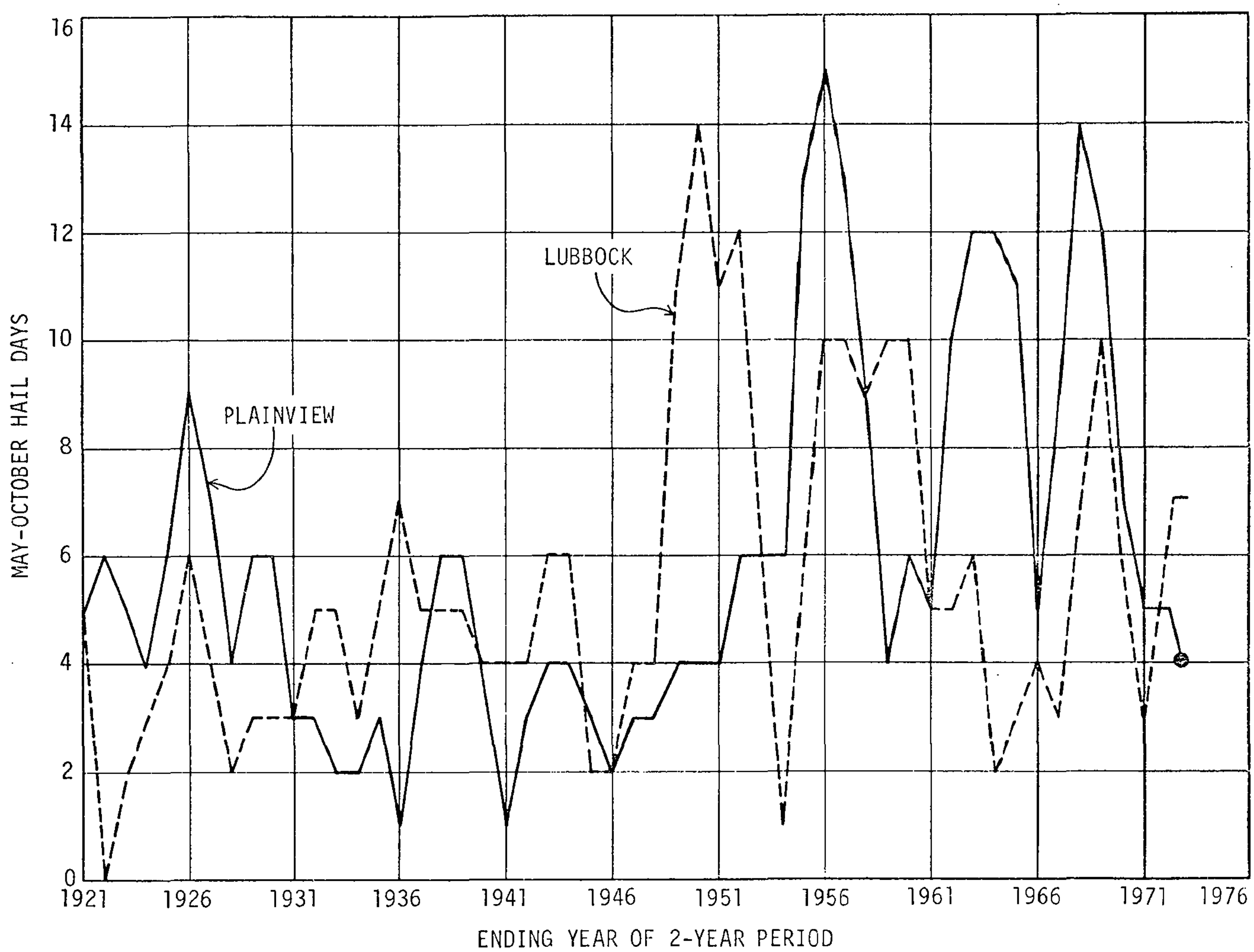


Figure 1. 2-Year Moving Totals of May-October Hail Days.

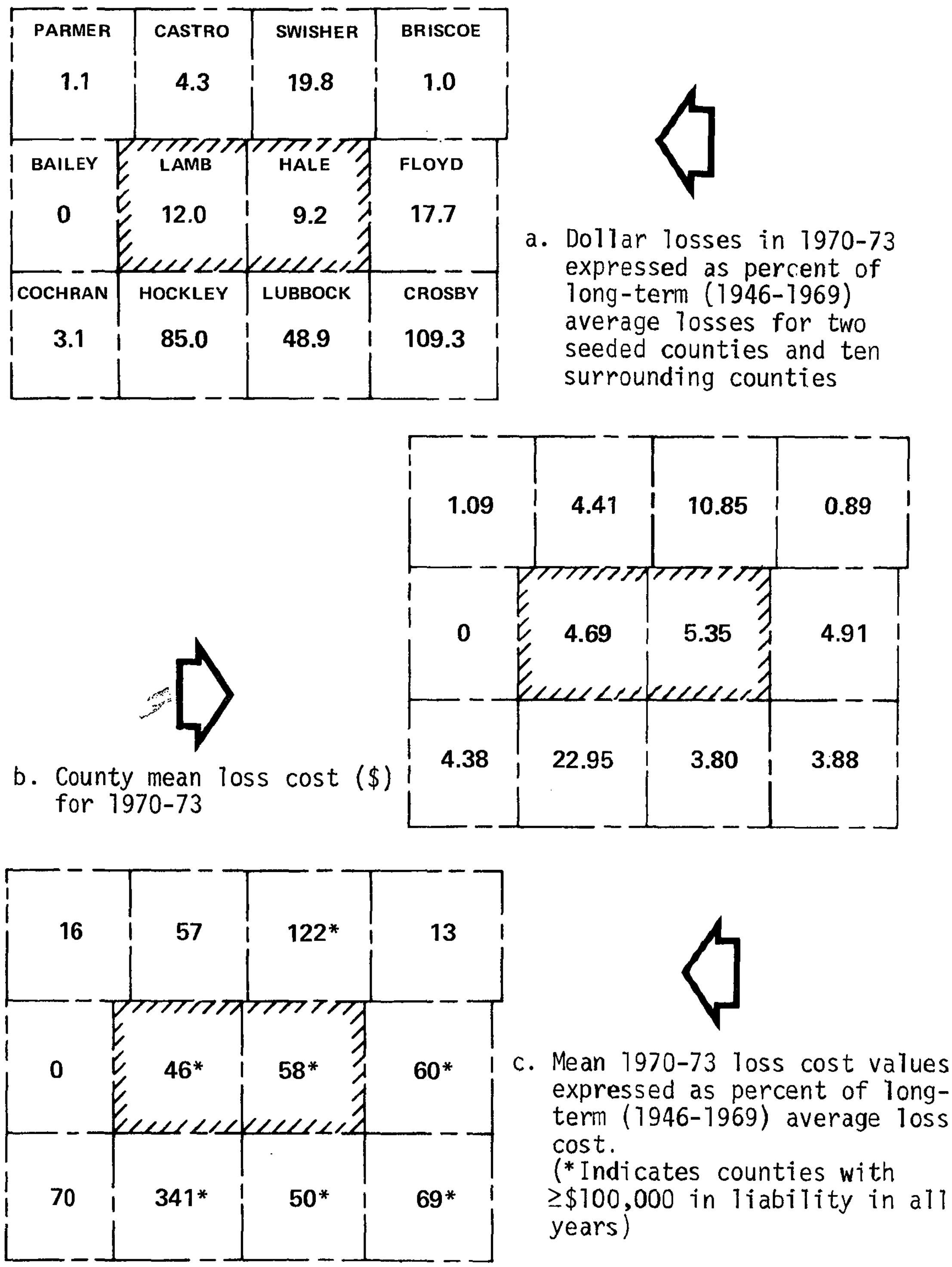
Extensive studies utilizing Illinois hail-day data have been performed to determine the length of time to detect various levels of reduction in hail day frequencies (Changnon and Schickedanz, 1969). Although these are based on Illinois data, and were done for a real and not point frequencies, the results offer some opportunity to assess the Texas results. The historical data for a 1000-square-mile area in western Illinois (based on data from 5 stations) shows an average summer frequency of 2.5 hail days, which is somewhat comparable to the point average at Plainview. If one accepts the assumptions necessary in the use of sequential test (no major trends in the historical data, which is not a bad assumption for the 1947-69 period in the Texas station data), the Illinois results suggest detection of a 40% (Plainview had 41%) reduction in 3.2 years at a significance level of 0.05 (5% chance that reduction is due to natural causes). If this test is tightened to the 1% level of significance, then the detection time increases to 4 years. Hence, if one accepts translation of Illinois area results to Texas and the sequential test assumptions, one would conclude that the Plainview hail-day data indicate that hail-day frequency has been suppressed by about 40%.

CROP-HAIL INSURANCE RESULTS

Crop-hail insurance data from the Crop-Hail Insurance Actuarial Association for the 1946-73 period were also investigated in a manner used previously (Henderson and Changnon, 1972). Data available for each county included 1) the annual amount of liability ($), 2) the annual amount of losses($), and 3) the annual loss cost value (loss, $/liability, $ x 100). Loss cost is the best means of comparing losses, either on a spatial or temporal basis, because it normalizes the losses to the fluctuations in the liability which can be large (see Fig. 3). Data analyzed included that of the two counties (Lamb and Hale) in the seeded area in 1970-73, and that from the 10 surrounding counties.

The annual county losses in 1970-73, their average annual losses for 1970-73, and the long-term (1946-69) average losses appear in Table 3. The two seeded (labeled as target) area counties have low losses in all 4 years. Their mean losses were 9.2% of the long-term average (Hale) and only 12.0% (Lamb). However, nearby counties to the west had lower losses and percentages in 1970-73 (Table 3 and see Fig. 2a), but those to the south and east (except Briscoe) had higher losses and loss percentages than the target counties.

The total crop liability of these same two pairs of counties were also compared (Fig. 3). The liability has fluctuated considerably, and it decreased greatly in both areas between 1962 and 1966. In the seeded area and period, 1970-73, the values reached their lowest on record, whereas in this same period the non-seeded liability was increasing. The seeded area liability values in 1971, 1972, and 1973 were the three lowest ones in the 1946-73 period. The 1970-73 liability in the non-seeded area was 82% of the $3.8 million area average, whereas that in the seeded area was 19% of that area average ($3.8 million). Comparison of their percentages of average (82 vs 19) shows a 63% reduction in liability in the seeded area. Thus, liability values and losses (Fig. 2a) both reached extremely low



a. Dollar losses in 1970-73 expressed as percent of long-term (1946-1969) average losses for two seeded counties and ten surrounding counties

b. County mean loss cost ($) for 1970-73

c. Mean 1970-73 loss cost values expressed as percent of long-term (1946-1969) average loss cost.
(*Indicates counties with ≥$100,000 in liability in all years)

Figure 2. Mean 1970-73 Loss Cost Expressed as Percent of Long-Term (1946-49) Average Loss Cost.

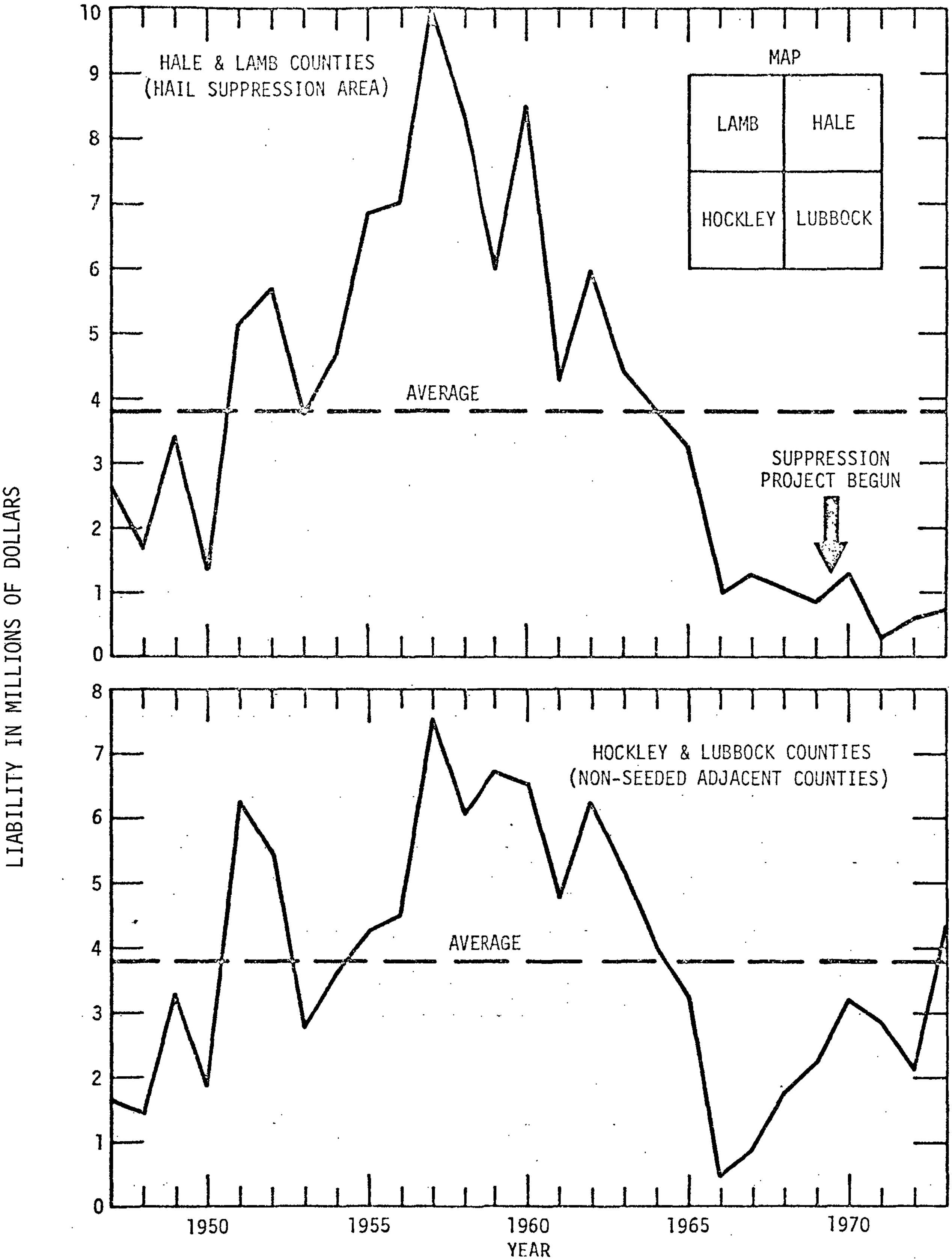


FIG. 3. COMPARISON OF CROP (WHEAT-COTTON) HAIL LIABILITY IN 2-COUNTY AREAS OF TEXAS

levels, as defined on a temporal and on a spatial basis, in the seeded years of 1971-73. Values of both in 1970, the first year of seeding, did not exhibit an exceptional difference from those of prior years.

Table 3. Comparison of 1970-73 County Insurance Loss Values.

Counties	Losses, $1,000 Average 1946-69	1970	1971	1972	1973	Average 1970-73	Average of 1970-73 as % of 1946-69 Average
Target							
Hale	260	66	9	4	16	23.8	9.2
Lamb	125	3	6	45	6	15.0	12.0
Surrounding Control							
Bailey	57	0	0	0	0	0	0
Floyd	97	13	39	4	13	17.2	17.7
Lubbock	134	40	74	78	70	65.5	48.9
Swisher	118	6	13	16	58	23.3	19.8
Hockley	135	20	41	320	61	110.5	85.0
Parmer	77	0	0.6	2.4	0	0.8	1.1
Briscoe	29	0	0.5	0	0.5	0.3	1.0
Castro	93	0	3	9	4	4.0	4.3
Cochran	52	6	0.4	0	0	1.6	3.1
Crosby	70	59	96	55	96	76.5	109.3

Losses and liability are not the best means to evaluate the temporal or spatial changes in crop-damaging hail during 1970-73. The loss costs for the individual seeded years, their average (1970-73), and their long-term (1946-69) averages appear in Table 4. The yearly values in Hale County all remained below the long-term average, resulting in a 4-year average of $5.35 which was 58% of the long-term average. Interestingly, this is 42% below "normal", a departure nearly identical to the 41% value in hail days at Plainview (Table 1) which is in Hale County.

The yearly loss costs for the other seeded county, Lamb, show two values slightly above the long-term average (1971 and 1972), and two values much below (1970 and 1973) the 1946-69 average. The 4-year results show an average of $4.69 which is 46% of the long-term average.

The pattern of the 1970-73 mean county loss costs appears in Fig. 2b. This shows that the target (seeded) counties were higher than those in all but two surrounding counties (Hockley with $22.95 and Swisher with $10.85.

Table 4. Comparison of 1970-73 Loss Cost Values.

$$(\text{Loss cost} = \frac{\text{Losses, \$}}{\text{Liability, \$}} \times 100)$$

Counties	Loss Cost, $ Average 1946-69	1970	1971	1972	1973	Average 1970-73	1970-73 Average as % of 1946-69 Average
Target							
Hale	9.15	7.14	3.56	1.67	4.31	5.35	58
Lamb	10.13	0.96	11.40	12.57	1.10	4.69	46
Surrounding Control							
Bailey	8.90	0	0	0	0	0	0
Floyd	8.18	2.90	17.18	1.05	3.53	4.91	60
Lubbock	7.60	1.77	8.68	5.76	2.84	3.80	50
Swisher	8.88	5.35	21.83	8.94	11.69	10.85	122
Hockley	6.72	2.63	17.38	41.75	3.18	22.95	341
Parmer	6.74	0	0.61	3.34	0	1.09	16
Briscoe	6.68	0	13.92	0	0.61	0.89	13
Castro	7.73	0	2.22	18.30	3.12	4.41	57
Cochran	6.25	4.53	4.97	0	0	4.38	70
Crosby	5.67	2.54	8.68	3.34	3.93	3.88	69

However, a more meaningful regional comparison involves use of the 1970-73 mean loss costs adjusted for the departure from the long-term (1946-69) averages. The resulting percentage values appear in Table 4 and are also plotted in Fig. 2c. This pattern shows that the seeded counties have values (46% and 58%) that are lower than 5 of the surrounding values (341%, 122%, 70%, 69% and 60%); equivalent to 2 of the nearby values (57% and 50%); and higher than 3 of the county values (16%, 13%, and 0%). The tendency for low values in the northwest portion of the area and high values in the southern portion appears in Figs. 2a and 2c, suggesting a climatic trend surface across the area for this 4-year period.

However, in evaluating the loss cost percentages (Fig. 2c) it is important to consider that the liability (area coverage) in 5 surrounding counties was at very low levels in the 1970-73 period. Their liabilities are so low as to suggest their results (losses and loss costs) in 1970-73 are not too representative. Those seven counties with adequate liability, considered to be those with more than $100,000 liability (>5% of the area insured), are indicated in Fig. 2c. Comparison of these seven percentage values indicates that the losses in the seeded counties were quite low with the Lamb value being the lowest and the Hale value lower than all but one (Lubbock County) of the five surrounding counties.

The county loss cost data were also inspected on a temporal basis. Hale County had a 1970-73 average loss cost of $5.35 (Table 4). Comparison of this value with all other possible 4-year loss costs in 1946-73 (25 possible values) showed only one other lower value, $3.00 in 1949-52. Lamb County had a 1970-73 average loss cost of $4.69 (Table 4), and it was lower than any other in that county during the 25, 4-year periods beginning in 1946. The next lowest loss cost was $4.85 in 1946-49. Hence, each of the 1970-73 values of the seeded counties was extremely low, one the second lowest on record and the other the lowest. These represent occurrences in the lowest 4 to 8% of the time.

The data for the two seeded counties also were combined, and the joint mean loss cost value calculated for 1970-73 was $5.05. This was the lowest 4-year value among the 25 possible 4-year loss cost values of the 1946-73 period. The next lowest was $5.43 for 1951-54, and the 2-county average was $9.75. Hence, the 1970-73 value was 48% below average.

Two sets of counties with extensive liability, one bracketing the seeded area (Lubbock and Swisher counties) and one parallel and adjacent to it (Lubbock and Hockley counties), were used to form two "control areas". The 2-county average loss costs of these two areas were used to compare with those of the target area. The Lubbock and Swisher (north-south) control area average annual loss cost for 1970-73 was $4.59, or 57% of the long-term average. There were three other 4-year periods (1951-54, 1952-55, and 1953-56) with lower loss costs than that for 1970-73 in this bracketing north-south control area. The parallel control area (Hockley-Lubbock) had an average annual loss cost for 1970-73 of $6.63 which was 92% of the long-term (1946-69) average of $7.16. The 2-county target decrease of 48% is not terribly greater than the 43% decrease of one control area (Lubbock-Swisher), but it is much greater than the 8% decrease in the parallel control area. Such differences point to the difficulty of using the target-control approach for hail evaluation, particularly because losses in adjacent counties have low correlation coefficients, generally less than +0.6 (Henderson and Changnon, 1972). The temporal evaluation of the loss cost values may be the more meaningful.

The seeded area had a loss cost in 1970-73 that was 48% below average and the lowest on record. The 1970-73 loss cost in Lamb County was 54% below the long-term average (and a record low), and that for Hale County was 42% below average and the second lowest on record.

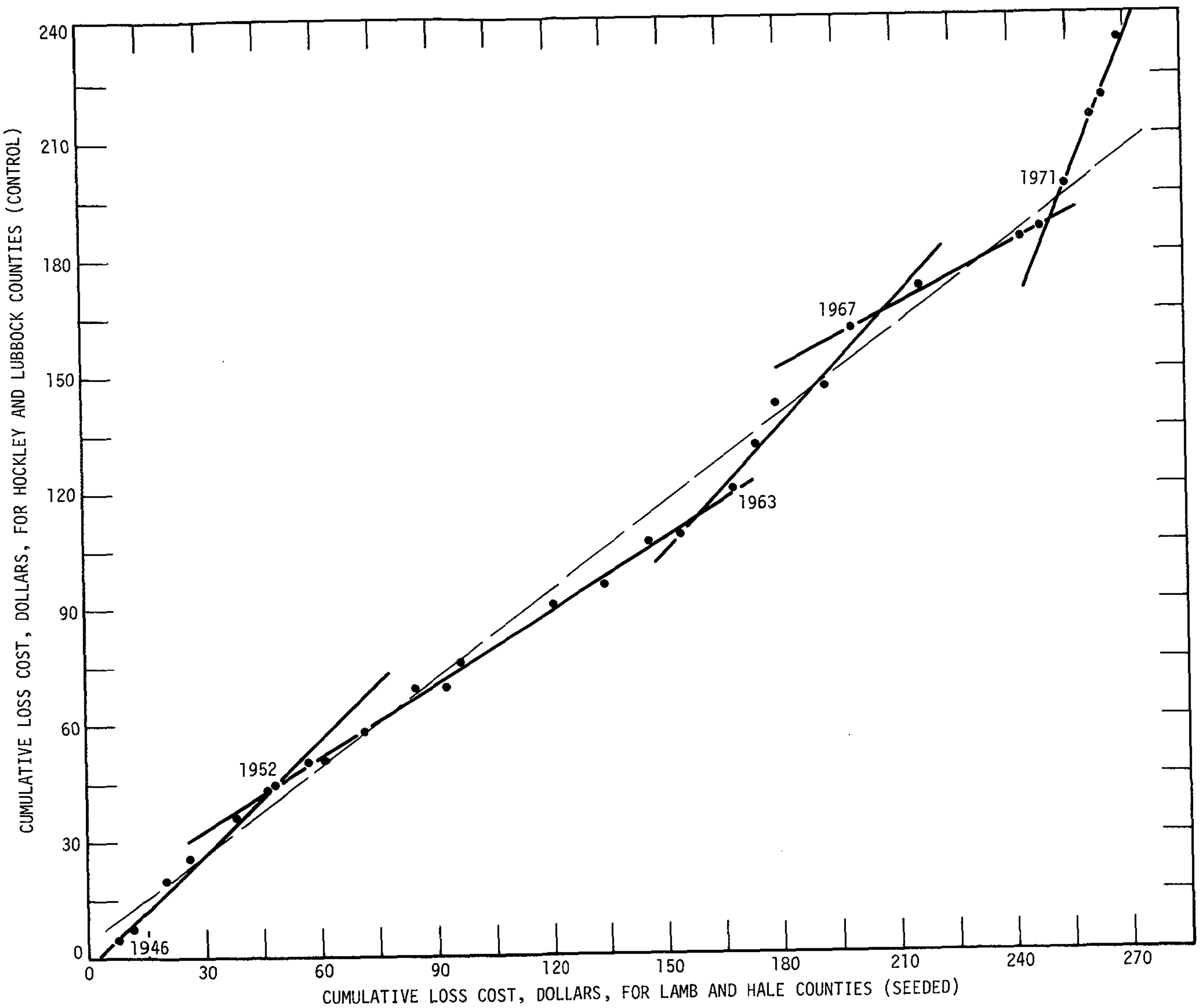


Figure 4. Relationship between cumulative Loss Cost Values in 2-county seeded area and in the adjacent 2-county control area.

The loss costs of the two seeded (target) counties and those of two adjacent counties (parallel according to the direction of prevailing west-east storm motion) to the south (Hockley and Lubbock - see Fig. 2a) were compared. A cumulative plotting of the two sets of annual losses appears in Fig. 4. If the relationship between their annual losses was perfect, the dots would follow the 1:1 dashed line. They do closely approximate it up through 1970, but there are periods of 5 to 10 years in length when specific and slightly different relationships appear, as noted by fitted straight lines and the individual years when each started (1952,1963, 1967, and 1971). The shift which began in 1971 is the greatest difference in relationship. It shows that the losses in the seeded county area were not increasing as rapidly (or were relatively low) as they had been in any previous sequence of years.

Extensive studies of hail insurance data for areas in Illinois and in Colorado comparable in size to the 2-county seeded area provide estimates of the times to detect reductions in hail from potential suppression efforts in those areas. Results presented here for both Colorado and Illinois involve continuous seeding designs (seeding of all hail days) and assumptions of the sequential test (no up or down trends). A 48% reduction in dollars of loss (total loss) in an Illinois area of 1500 mi^2 would be detectable in 3.5 years at a very high significance level (type 1 error of 0.05, type 2 error of 0.1). The results for dollar losses in a study area of a 1800 mi^2 area in northeast Colorado reveal a detection of a 48% reduction in 4 years at high level of significance (type 1 error = 0.01, type 2 error = 0.5).

CONCLUSIONS

The percentage reductions in hail found in the seeded (2-county) area for a variety of parameters (hail days, liability, losses, and loss cost) are summarized in Table 5. First all ten values show a reduction below that expected from time or space expectations, and 8 of the 10 values are reductions of 41% or more. All of the temporal departures are quite great (41%, 81%, 89%, and 48%) and are record lows or near record values. From a temporal standpoint, it thus appears that the 1970-73 hail reductions in Hale and Lamb counties reflect suppression activities, and probably at a significant level (if the Illinois and Colorado test results are translatable and the necessary statistical assumptions are met).

From a regional standpoint, the low hail values in the seeded counties show a greater variation (5% to 80%), which is probably due to relatively poor regional relations found in hail data. A few other counties in the area experienced near record low hail values, although all of these were from counties with such low liability to be considered questionable values. There is some slight suggestion of a natural regional scale hail incidence pattern that would help lead to low values in the seeded counties, but this also probably exists because of the low liabilities in counties west and northwest of the target area. A question that could be asked, and is difficult to answer, is whether the low loss cost values in the three counties east and southeast of the seeded counties (Fig. 2c) were due 1) to a natural period of low hail incidence in the area, or 2) to seeding effects leading to the suppression of hail in the downwind areas as well as in the target area.

Table 5. Evaluation of Various 1970-73 Hail Values in 2-County Seeded Area.

Evaluation Basis	Plainview Hail-Day Data	2-County Liability Values	2-County Losses	2-County Loss Costs
Temporal	41%, 3rd lowest on record*	81% below average, lowest on record*	89% below average, lowest on record*	48% below average, lowest on record*
Spatial	12% reduction based on Lubbock; 94% based on Levelland	63% reduction by comparison to 2 adjacent counties	80% below mean of 5 counties with adequate liability	43% reduction by comparison with Lubbock-Hockley; 5% with Lubbock-Swisher

*Record period is 1946-73

Most of the data examined strongly suggest that the suppression was successful. The best single measure is considered to be the 48% temporal reduction in loss costs (Table 5). Another estimate is afforded by the simple average of the 10 values in Table 5 which is 56% (the median is 55.5%).

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REFERENCES

Changnon, S. A., and P. T. Schickedanz, 1969: Utilization of hail-day data in designing and evaluation hail suppression projects. Monthly Weather Review, 87, 95-102.

Changnon, S. A., G. M. Morgan, Jr., N. G. Towery, G. Achtemeier, and R. C. Grosh, 1974: The Design of Hail Suppression Experiment for Illinois. Preprints 4th Conf. on Wea. Mod., AMS, Boston, 293-300.

Henderson, T. J., and S. A. Changnon, 1972: Results from an applications program of hail suppression in Texas. Preprints Third Conference on Weather Modification, American Meteorological Society, Boston, 260-267.

Schickendanz, P. T., S. A. Changnon, and C. G. Lonnquist, 1969: A Statistical Methodology for the Planning and Evaluation of Hail Suppression Experiments in Illinois. Part 2 of Final Report NSF Grant GA-482, Illinois State Water Survey, Urbana, 140 pp.

Schickendanz, P. T., and S. A. Changnon, 1970: A Study of crop-hail insurance records for northeastern Colorado with respect to the design of the National Hail Experiment. Final Report NCAR Contract 155-70, Illinois State Water Survey, Urbana, 86 pp.

Thom, H. C. S., 1957: A method for the evaluation of hail suppression. Technical Report 4, U.S. Advisory Committee on Weather Control, Washington, D.C. 42 pp.