# A STATISTICAL ANALYSIS OF HISTORICAL HAIL SUPPRESSION EFFORTS IN SOUTH DAKOTA USING CROP-HAIL INSURANCE DATA

Roger K. Sandness
Department of Geography
South Dakota State University
Brookings, South Dakota 57007

Abstract. An assessment of spatial and temporal patterns in crop damage as a function of hail suppression is presented. An examination of the effects of cloud seeding on the amount of crop-hail damage sustained, was carried out for the state of South Dakota for the period 1948-1982. This was done to establish if the counties of South Dakota which engaged in weather modification efforts, experienced a reduction in crop-hail damage when compared to those counties which did not employ cloud seeding. Within the limitations of the data employed and the analyses performed, no significant decrease in the amounts of crop-hail damage as the result of weather modification efforts was found.

## 1. INTRODUCTION

The purpose of hail suppression programs in South Dakota was to decrease crop damage from hail. One measure of the effectiveness of the program is the change in loss cost values (insurance losses paid per $100 of insured crop value) between seeded and nonseeded areas over space and time. This paper assesses the spatial and temporal patterns of loss cost values based on the following stratification of data:

1. Over all years, all counties of the state: on a statewide, seeded counties, and nonseeded counties basis.

2. Spatial basis: over all years, for three areas of the state; on an area-wide, seeded counties, and nonseeded counties basis.

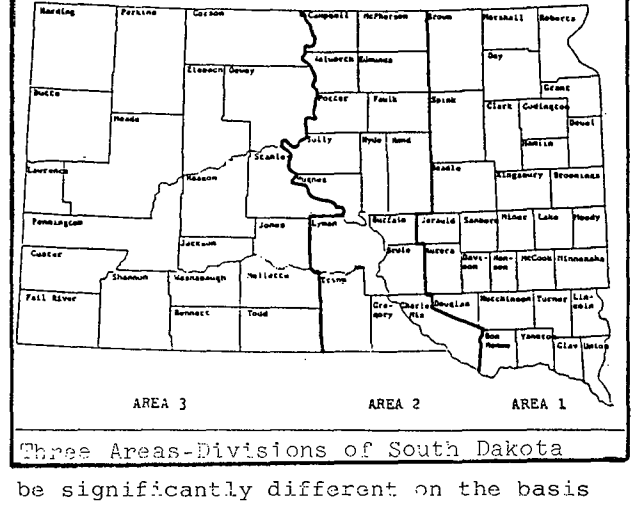
3. On a temporal basis, the state: all counties, seeded counties, and nonseeded counties; and the three areas: all counties, seeded counties, and nonseeded counties.

4. On combined temporal and spatial basis: Groups of Years and the three areas of the state for seeded and nonseeded status.

The Crop-Hail Insurance data maintained by the National Crop Insurance Service (NCIS) in Chicago gives a statewide coverage of insurance losses paid along with the total insured liability. The employment of these data in the statistical analysis of hail suppression programs are not without limitations. The insurance data generally represent coverage for only about five per cent of most counties (Henderson & Changnon, 1972). The cloud seeding project might sample a period unrepresentative of the conditions in the historical insurance data period (Hsu & Changnon, 1983). The nonseeded counties are used as a control group, however there may be a down wind effect that is modifying the hail within these counties (Schickendanz, 1977). Using hail insurance data in the evaluation of hail suppression projects does remain controversial (Changnon, 1985). However, since these NCIS data are the only data available over the period of time to be evaluated, little choice is left but to employ the insurance data. The loss cost values can be used as a measure of the effectiveness of hail suppression programs to decrease crop hail damage (Changnon, 1969; Henderson & Changnon, 1972; Changnon, 1975; Changnon, 1985). This paper assesses the spatial and temporal patterns of loss cost values for the state of South Dakota for the years 1948-1982.

The state was divided into three areas (FIGURE 1) which were determined to

FIGURE 1




Three Areas-Divisions of South Dakota

be significantly different on the basis of insurance liability (Sandness, 1990). These areas were used in the analyses as presented in this paper.

When several counties as a group for a single year or a single county over several years were compared, a weighted loss cost value was employed. This weighted loss cost value as suggested by Rose and Jameson (1986) avoids an extreme local event of low liability linked with high loss cost values from having a greater weight than is appropriate in expressing losses (Sandness, 1990). Seeded counties are those counties which participated in hail suppression efforts and the nonseeded counties are those counties which did not participate. A

single county may have been seeded for one or more years during the 35-year period (1948-1982). No counties were participants in the hail suppression program for all 35 years. The following equation (EQUATION ONE) was used in calculating the WLC:

EQUATION ONE

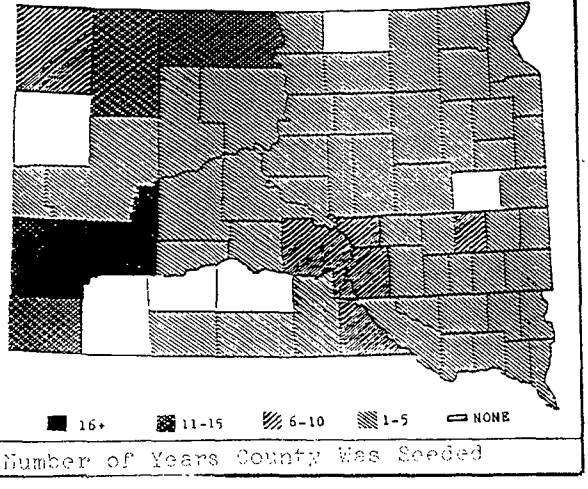
$$WLCk = \frac{\sum_{j \in J_n} LC_{ij} \times LI_{ij}}{\sum_{j \in J_n} LI_{ij}}$$

Where:
$LC_{ij}$ = Lost Cost for county i for year j.
$LI_{ij}$ = Liability for county i for year j.
i = County i.
j = year contained in one of the following three year-categories.
$J_0$ = All 35 years.
$J_1$ = Seed Years.
$J_2$ = Nonseed Years.
k = ' '; All Counties.
k = '1'; Seed Counties.
k = '2'; Nonseed Counties.

2. COUNTY AND AREA-WIDE ANALYSIS
Pair-wide Analysis of Seeded and Non-seeded Years

A comparison of the Weighted Loss Cost Values for the seeded counties (WLC1) and the Weighted Loss Cost Values for the non-seeded counties (WLC2) was made over the entire 35-year period. In order to increase the reliability of county data and reduce the risk of including anomalous or extreme observations, only counties which participated in three or more years of seeding during the 35-year (1948-1982) period were included in the analysis. FIGURE 2 shows the number of years each county was

FIGURE 2




seeded using five-year incriment categories. A paired t-test for the difference in means of WLC1 and WLC2 was performed for the whole of the state as well as for the three individual areas.

The results at the 0.05 level show a significant difference between the weighted loss costs for seeded and non-seeded years for the entire state and for Area 1 (TABLE 1). For Areas 2 and 3, no significant differences between the seeded years' and nonseeded years' weighted loss cost values were observed. The difference of means (WLC1-WLC2) are all negative indicating that the seeded weighted loss cost values were less than the nonseeded weighted loss cost values. This indicates a positive effect, but not significant in all cases, of the seeding carried out in South Dakota.

TABLE 1

Results of Paired T-Test (Paired by Counties) for the Difference of Means Between WLC Values in Seed and Nonseed Counties by State and the Three Areas: Only Counties with Three or More Seeded Years are included in this Analysis

| Prob >\|T\| | Counties | Difference of Means (WLC1-WLC2) | T |
|---|---|---|---|
| 0.0093 | All | -1.19 | -2.71* |
| 0.0001 | Area 1 | -1.87 | -5.08* |
| 0.9990 | Area 2 | -0.01 | -0.00 |
| 0.4815 | Area 3 | -0.70 | -0.74 |

* Significant at the 0.05 level.

A two-way analysis of variance was conducted on the Weight Loss Cost (WLC) based on area and seed status. The results at the 0.05 level indicate a significant difference between the seeded and nonseeded loss cost value by areas. (TABLE 2). The seeding status was not found to be significant at the 0.05 level

TABLE 2

Results of a Two-Way Analysis of Variance on WLC for Area and Seed Status

| SOURCE Prob>\|F\| | DEGREES FREEDOM | SUM OF SQUARES | F |
|---|---|---|---|
| Area 0.0001 | 2 | 445.94 | 50.02** |
| Seed 0.2138 | 1 | 6.97 | 1.56 |
| Seed*Area 0.0821 | 2 | 22.81 | 2.56 |
| Error | 108 | 481.38 | |

** Significant at the 0.05 Level.
Only counties with three or more years of seeding are included in this analysis.

of significance (TABLE 2). Combining the information from TABLE 1 and 2, it is apparent that when the area is the entire state, area is significant. By dividing, the state into three areas, only Area 1 is significant in determining the amount of crop-hail damage sustained under seeded and nonseeded conditions. In considering seed status and area, the interaction among them was not found to be significant.

In March, 1971, the state passed legislation (House Bill 550) which gave the Weather Control Commission the directive to carry out a statewide program of precipitation management with the goal of providing net economic benefit to the state of South Dakota. Appropriations of state funds were made for the purpose of developing a statewide program (Donnan. et al., 1976).

The Weather Control Commission established a county/state cost share ratio of 1 to 3: for every one dollar invested by the county, three dollars were contributed by the state. Under the authorization of South Dakota Compiled Laws 10-18 as amended, the county commissioners had the power to levy a tax of one mill upon assessed valuation to finance the counties' share of the costs. For the 1972 seeding year, 26 counties participated; in 1973, 42 counties; in 1974, 46 counties; and in 1975, 45 counties.

South Dakota's Weather Modification Program started in 1971 and was terminated June 30, 1976 (Donnan, et al., 1976). The termination was the result of the decision of the 1976 legislature to cut off state funding for the fiscal year July 1, 1976 through June 30, 1977. According to Donnan, et al., (1976) this was a political decision; it was not based on findings about the effects or lack of effects of cloud seeding operations.

To obtain an in-depth understanding of the efficiency of seeding and the three areas of the state on WLC values during the four years (1972-1975), a two-way analysis of variance was performed for each of the four years. For each year in the 1972-1975 period, all seeded counties in each of the three areas (1, 2, and 3) were combined to obtain a single WLC value. Similarly, WLC values were obtained for nonseeded counties. This led to the formulation of a two-way analysis of variance with one observation in each of the six cells (3 Areas x 2 Seed Status).

Results of the two-way analysis of variance for each of the four years in the period 1972-1975 are presented in Table 3.

TABLE 3

Results of a Two-Way Analysis of Variance for WLC Based on Area and Seed Status by Year 1972-1975

| SOURCE | DEGREES FREEDOM | SUM OF SQUARES | F | Prob>\|F\| |
|---|---|---|---|---|
| 1972 | | | | |
| Area | 2 | 20.80 | 0.98 | 0.5048 |
| Seed | 1 | 7.00 | 0.66 | 0.5016 |
| Error | 2 | 21.20 | | |
| 1973 | | | | |
| Area | 2 | 111.62 | 3.61 | 0.2168 |
| Seed | 1 | 6.63 | 0.43 | 0.5798 |
| Error | 2 | 30.90 | | |
| 1974 | | | | |
| Area | 2 | 19.90 | 1.13 | 0.4700 |
| Seed | 1 | 0.14 | 0.02 | 0.9106 |
| Error | 2 | 17.68 | | |
| 1975 | | | | |
| Area | 2 | 3.09 | 0.52 | 0.6558 |
| Seed | 1 | 0.07 | 0.02 | 0.8939 |
| Error | 2 | 5.89 | | |

No significant difference in WLC values can be observed between seeded and nonseeded counties during the four years. In short, no concrete evidence emerged suggesting that during those four years a significant reduction occurred in hail damage to crops. TABLE 4 contains the WLC1 and WLC2 values for each of the four years of the program, along with the number of counties contained in each of the cells of the two-way analysis of variance.

TABLE 4

Weighted Loss Cost and Number of Counties by Area by Seeding Status by Year 1972-1975

| Year | WLC1 | # Ctys. | WLC2 | # Ctys. |
|---|---|---|---|---|
| 1972 | | | | |
| Area 1 | 2.58 | 15 | 3.00 | 16 |
| Area 2 | 2.35 | 6 | 9.74 | 10 |
| Area 3 | 7.84 | 5 | 6.53 | 15 |
| 1973 | | | | |
| Area 1 | 1.80 | 25 | 1.35 | 6 |
| Area 2 | 6.88 | 11 | 15.35 | 5 |
| Area 3 | 3.30 | 6 | 1.57 | 14 |
| 1974 | | | | |
| Area 1 | 2.50 | 28 | 0.36 | 3 |
| Area 2 | 7.54 | 11 | 4.25 | 5 |
| Area 3 | 3.30 | 7 | 6.05 | 13 |
| 1975 | | | | |
| Area 1 | 1.87 | 28 | 4.33 | 3 |
| Area 2 | 2.07 | 9 | 1.26 | 7 |
| Area 3 | 4.41 | 8 | 2.12 | 12 |

WLC1 are seeded counties.
WLC2 are nonseeded counties.

## 3. TEMPORAL ANALYSIS

In order to determine whether time or variation over time played any significant role in affecting loss cost values, temporal analyses were undertaken. The WLC were calculated over all counties by year, over all seeded counties by year, and over all nonseeded counties by year (TABLE 5) using equation one.

TABLE 5

WLC by Year Over All Counties, Seeded Counties, and Nonseeded Counties

| | All | | Seeded | | Nonseeded | |
|---|---|---|---|---|---|---|
| Year | # | WLC | # | WLC1 | # | WLC2 |
| 1948 | 66 | 2.82 | 0 | - | 66 | 2.82 |
| 1949 | 67 | 4.82 | 0 | - | 67 | 4.23 |
| 1950 | 64 | 2.70 | 0 | - | 64 | 2.70 |
| 1951 | 66 | 2.35 | 21 | 3.91 | 45 | 1.87 |
| 1952 | 66 | 2.72 | 11 | 2.97 | 55 | 2.70 |
| 1953 | 66 | 3.16 | 7 | 2.52 | 59 | 3.32 |
| 1954 | 67 | 2.54 | 5 | 2.59 | 62 | 2.54 |
| 1955 | 67 | 5.97 | 0 | - | 67 | 5.97 |
| 1956 | 66 | 8.98 | 0 | - | 66 | 8.98 |
| 1957 | 67 | 4.08 | 0 | - | 67 | 4.08 |
| 1958 | 67 | 3.09 | 0 | - | 67 | 3.09 |
| 1959 | 67 | 3.69 | 0 | - | 67 | 3.69 |
| 1960 | 67 | 5.10 | 0 | - | 67 | 5.10 |
| 1961 | 66 | 5.93 | 2 | 2.95 | 64 | 5.95 |
| 1962 | 67 | 4.20 | 5 | 9.85 | 62 | 3.93 |
| 1963 | 67 | 5.12 | 3 | 7.92 | 64 | 5.08 |
| 1964 | 67 | 4.49 | 3 | 15.53 | 64 | 4.33 |
| 1965 | 67 | 3.47 | 3 | 8.36 | 64 | 3.40 |
| 1966 | 67 | 3.45 | 5 | 11.97 | 62 | 3.16 |
| 1967 | 67 | 3.92 | 5 | 6.93 | 62 | 3.78 |
| 1968 | 67 | 4.73 | 9 | 11.45 | 58 | 4.21 |
| 1969 | 67 | 8.35 | 6 | 11.51 | 61 | 8.20 |
| 1970 | 67 | 6.92 | 10 | 8.90 | 57 | 6.75 |
| 1971 | 67 | 2.74 | 6 | 12.52 | 61 | 2.27 |
| 1972 | 67 | 4.15 | 26 | 2.91 | 41 | 4.84 |
| 1973 | 67 | 2.90 | 42 | 2.51 | 25 | 3.98 |
| 1974 | 67 | 3.30 | 46 | 3.17 | 21 | 3.89 |
| 1975 | 67 | 2.15 | 45 | 2.06 | 22 | 2.44 |
| 1976 | 67 | 3.20 | 12 | 2.51 | 55 | 3.43 |
| 1977 | 67 | 4.20 | 0 | - | 67 | 4.20 |
| 1978 | 67 | 6.11 | 1 | 8.45 | 66 | 6.10 |
| 1979 | 67 | 4.04 | 1 | 11.85 | 66 | 4.03 |
| 1980 | 67 | 6.88 | 1 | 21.56 | 66 | 6.88 |
| 1981 | 67 | 5.80 | 1 | 31.56 | 66 | 5.79 |
| 1982 | 67 | 4.20 | 1 | 19.32 | 66 | 4.18 |

A '-' = no seeded counties for that year.

The adjusted liability for the entire state expressed in 1982 dollars for each year j was calculated using the following equation (EQUATION TWO):

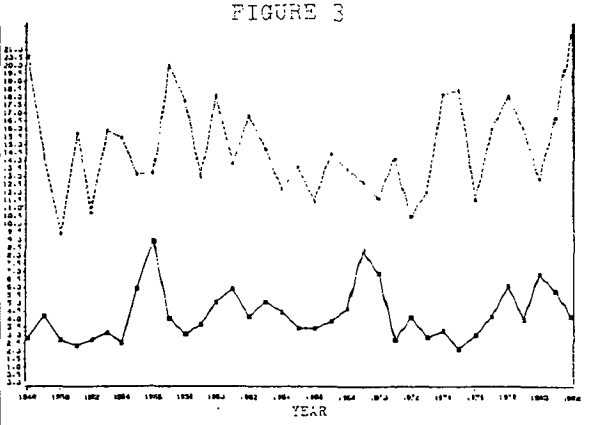
EQUATION TWO

$$ALI_j = \sum_{i \in I_0} LI_{ij} \times m_j$$

Where:
$LI_{ij}$ is the liability for county i.
$I_0$ is all the counties, for year j=1,2,...,35.
$m_j$ is the dollar conversion factor for year j.

The Adjusted Liability (ALI) and Weighted Loss Cost (WLC) were plotted against time for the 35 year period (FIGURE 3). The ALI was plotted in an attempt to visualize any trends or patterns in the value of the insured liability on crops over time. The 1948 total ALI value is very close to the 1982 ALI value. When each of the five peak values of WLC is compared with the following year ALI, it is found that for three of the peak WLC years (1956, 1961, and 1980), the years following (1957, 1962, and 1981) witnessed a dramatic increase in ALI. For the other two WLC peak years, 1969 was followed by a drop in the ALI for 1970, and 1978 was followed by a decrease in ALI for 1979. The year 1981 did not have a particularly high WLC value, but was followed in 1982 by a record total ALI. The patterns observed for 1956, 1961 and 1980 with the following years' increase in ALI may be attributed to the need for protection after experiencing considerable hail damage in the area the previous year. However, this does not explain the reversal in the pattern for 1969 and 1978. Government farm programs may have affected the amount of protection needed by the farmers for those periods. The rapid rise in total protection in 1982 may have been tied to factors related to the general farm economy. Lenders required that the farmers have crop insurance as protection for the loan collateral (personal communication from Richard Shane, 1986).

FIGURE 3




WLC and Adjusted Liability (1948-1982)

The adjusted weighted loss cost (AWLC) takes into account the time-value of money. The AWLC is computed by summing the products of the loss cost values and liability and a dollar conversion factor divided by the sum of the products of the liability and dollar conversion factor.

A linear correlation analysis was conducted among the (AWLC) which takes

into account the time-value of money and the ALI for the year t and the year t+1 (TABLE 6).

TABLE 6

Results of Correlation Among AWLC and ALI for Period of 35-Years 1948-1982

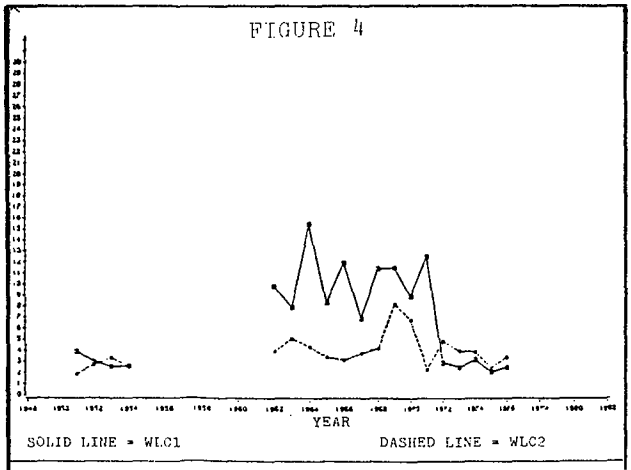
| | $ALI_t$ | $ALI_{t+1}$ | |
|---|---|---|---|
| $WLC_t$ | -0.13598 | 0.24917 | R |
| Prob>\|R\| | 0.4360 | 0.1553 | |

$AWLC_t$: Adjusted Weighted Loss Cost for year t.
ALIt : Adjusted Liability for year t.
$ALI_{t+1}$ : Adjusted Liability for year t+1.

For the year t a negative correlation existed between the AWLC and ALI, indicating a nonsignificant inverse relationship between AWLC and ALI. When the ALI for the year t+1 was compared with the AWLC for year t, a positive correlation existed, reflecting a lagged positive relationship between ALI and AWLC. This correlation coefficient, also, was not significant at the 0.05 level.

The WLC1 and WLC2 were plotted against years to gain insight into any trends over time (FIGURE 4). For all years except 1953 and the four years of the state program (1972-1975), the WLC1 is higher than the WLC2. On a statewide basis, it appears as though the seeded counties fared better than the nonseeded

FIGURE 4




WLC1 & WLC2: Three or More Seed Counties

counties with respect to loss cost during the seeded period 1972-1975, when a statewide program was in operation.

A similar approach was taken to analyze weighted loss cost trends over time on an area basis. The WLC1 was less than the WLC2 for Area 1 in 1972 and 1975, for Area 2 in 1972 and 1973, and for Area 3 in 1974. These tables and plots did not suggest a clear-cut conclusion, so t-tests for the difference of means in weighted loss cost for the state and for the three areas over all the years considered were performed (TABLE 7).

TABLE 7

Results of Paired T-Test (Paired by Years) for the Difference of Means between WLC1 and WLC2 on the Basis of State-Wide, and the Three Area Divisions: Only Years With Three or More Seeded Counties are Included in Analysis

| Basis | Difference of Means (WLC1-WLC2) | Std. Error of Mean | T | Prob>\|T\| |
|---|---|---|---|---|
| State | 2.95 | 0.94 | 3.14* | 0.0057 |
| Area 1 | 0.38 | 0.80 | -0.48 | 0.6592 |
| Area 2 | -0.20 | 1.76 | -0.11 | 0.9129 |
| Area 3 | 2.16 | 0.90 | 2.40* | 0.0281 |

* Significant at the 0.05 Level.

On a state-wide analysis, a significant difference was recorded between the seeded and nonseeded counties over all years. This rejection of the null hypothesis of no difference of the means, along with a positive difference, affirms the research hypothesis that a difference does exist but that seeding did not reduce crop hail damage. On an areal basis, there is no significant difference (at the 0.05 level) between the WLC1 and WLC2 for Areas 1 and 2. For Area 2, the difference is significant at the 0.05 level (TABLE 7). An apparent contradiction exists between TABLES 1 and 7 until the basis of the two tables is recalled. TABLE 1 reports the results for the t-test difference of means between WLC1 and WLC2, with the weighted loss cost values by county over appropriate years, with three or more seeded years of record, that is, providing a comparison over time. The results in TABLE 7 were obtained employing loss cost values over all appropriate counties with three or more counties seeded per year, that is, providing a comparision over space. In both contexts, mixed results are obtained regarding the difference in the amount of crop damage due to hail in the seeded and nonseeded counties of the state.

## 4. COMBINED SPATIAL AND TEMPORAL ANALYSES

A three-way analysis of variance was conducted on weighted loss cost for area, seed status, and time. The independent variable time was stratified into two groups of seventeen years each, starting with the 1949-1965 and concluding with 1966-1982. The seven pairs of hypotheses tested in the three-way analysis of variance are listed in TABLE 8; TABLE 9 presents the results of the three-way analysis of variance on the weighted loss cost values. Employing TABLES 8 and 9,

the following conclusions were reached:

1. That the WLC values are not the same for the three areas.

2. That the WLC values are the same for seed and nonseed status.

3. That the WLC values for the five periods are the same.

4. That the WLC values differences among areas are dependent on differences between seed status.

5. That the WLC values of an area are dependent on time periods (i.e., testing for absence of area X time interaction).

6. That the WLC differences among seed status are independent of differences between time periods.

7. There is significant interaction between the effect of area, seed status, and time on the WLC.

TABLE 8

The Hypotheses Accompanying the Three-Factor Analysis of Variance Where the Dependent Variable is the WLC Rate and Area, Seed Status, and Time are the Treatments

| | Hypothesis |
|---|---|
| 1 | $H_0$: WLC is the same in all three Areas.<br>$H_A$: WLC is not the same in all three Areas. |
| 2 | $H_0$: WLC is the same for seeded and nonseed treatments.<br>$H_A$: WLC is not the same for seeded and nonseed treatments. |
| 3 | $H_0$: WLC is the same for all time periods.<br>$H_A$: WLC is not the same for all time periods. |
| 4 | $H_0$: WLC differences among areas are independent of differences between seed status.<br>$H_A$: WLC differences among areas are not independent of differences between seed status. |
| 5 | $H_0$: WLC differences among areas are independent of time (i.e., testing for absence of Area x Time interaction).<br>$H_A$: WLC differences among areas are not independent of differences between time periods. |
| 6 | $H_0$: WLC differences among seed status are independent of differences between time periods (i.e., testing for absence of seed status x time interaction).<br>$H_A$: WLC differences among seed status are not independent of differences between time periods. |
| 7 | $H_0$: There is no interaction between the effect of Area, Seed Status, and Time on the WLC.<br>$H_A$: There is interaction between the effect of Area, Seed Status, and Time on the WLC. |

TABLE 9

Results of the Three-Way Analysis of Variance on Weighted Loss Cost for Areas, Seed Status and Time: Time is Two Blocks of Seventeen years, Nonoverlapping, for 1949-1982. (With Replication)

| Sourc | DEGREES FREEDOM | SUM OF SQUARES | F | Prob>\|F\| |
|---|---|---|---|---|
| Area | 2 | 519.07 | 67.90** | 0.0001 |
| Seed | 1 | 14.12 | 3.70*** | 0.0562 |
| Time | 1 | 0.91 | 0.24 | 0.6258 |
| Seed* Area | 2 | 25.05 | 3.28** | 0.0401 |
| Area* Time | 2 | 30.15 | 3.94** | 0.0212 |
| Seed* Time | 1 | 0.45 | 0.12 | 0.7311 |
| Seed* Area* Time | 1 | 17.95 | 4.70** | 0.0316 |
| Error | 171 | 653.62 | | |

** Significant at the 0.05 level.
*** Significant at the 0.06 level.

Material presented earlier in the study (TABLES 1, 2, 7, and 9) suggest that the WLC values are different with respect to the three areas, and that is again proven to be so in this analysis. The second conclusion listed above, states that there is no significant difference (at the 0.05 level) in the amount of crop-hail damage on the basis of seeded and nonseeded status (however, it is significant at the 0.06 level). The third conclusion above, indicates that time is not a significant factor; that is, the WLC is not a function of the time period being considered. The fourth conclusion listed above, states that the difference of WLC between areas are dependent on seed status. The fifth conclusion indicates an interaction between areas and time. The sixth conclusion above

indicates the lack of existence of interaction between seeding status and time periods. Finally, the seventh conclusion above, indicates an interaction between area, seeding status, and time. The effects of cloud seeding to reduce the crop-hail damage do not appear to be significant based on the data employed and analyses performed.

5. SUMMARY.

A comparison of WLC1 and WLC2 was made on a state-wide basis, with significant differences resulting (TABLE 1). On an area basis, for Area 1 a significant difference in WLC1 and WLC2 existed, but no significant difference is evident between WLC1 and WLC2 for Areas 2 and 3. Since the difference of means (WLC1-WLC2) was negative, this suggests seeding was effective in the reduction of crop-hail damage in Area 1 and on an entire state basis.

A two-way analysis of variance was conducted on WLC based on area and seeding status over all years of the 1948-1982 period (TABLE 2). The results indicate a significant difference between the WLC1 and WLC2 based on areas. Seeding status and the interaction of seeding status with area proved not to be significant at the 0.05 level (TABLE 2).

Two-way analysis of variance was performed for the three areas of the state for each of the years of the state-wide hail suppression program (1972-1975). In this analysis, neither area nor seeding status proved to be significant (at the 0.05 level) in determining the WLC (TABLE 3).

Special spatial arrangements of WLC for seeded and nonseeded counties were examined. In the first arrangement, groups of seeded counties surrounded by nonseeded counties were investigated. No conclusive evidence of a positive influence of cloud seeding on the amount of crop damage caused by hail could be fould. In a second arrangement, groups of nonseeded counties surrounded by seeded counties were investigated. Again, no conclusive evidence of a positive influence of cloud seeding on the amount of crop-hail damage could be found.

The ALI and AWLC were plotted against time in an attempt to visualize any trends or patterns in the value of insured adjusted liability on crops over time (FIGURE 3). No consistent pattern or trend was obvious. A linear correlation analysis was conducted between the ALI and AWLC for the year t and the year t+1. No significant relationships were determined (TABLE 6).

A paired t-test (paired by years) for the difference of means between the WLC1 and WLC2 on the basis of state-wide, and the three area divisions was performed (TABLE 7). On the state-wide basis, as well as for Area 3 on an area basis, a significant difference in the means of WLC1 and WLC2 existed at the 0.05 level. The difference was positive for Area 3 and for the state, suggesting that more damage occurred in the seeded counties than in the nonseeded counties.

A three-way analysis of variance on WLC for area, seeding status, and time yielded only area as significant (TABLE 9). No significant effect of cloud seeding on the WLC could be recognized.

A conclusion of the significance of cloud seeding in reducing hail is present in some, but generally lacking in most of the data employed and the analyses performed, no positive effect of cloud seeding on crop-hail damage can be recognized. This statistical analysis of hail suppression efforts in South Dakota was based on National Crop Insurance Services data. It is recognized that the employment of these data do remain controversial. Moreover, not all potential hail producing storms may have been seeded. Mechanical problems with aircraft and the seeding apparatus do occur preventing seeding operations at times. Decisions to seed or not seed are made by human beings, and not being infallible, some storms that should have been seeded may not have been seeded. The down wind effects on control counties is unknown and hence could be contaminating these data. This paper is not meant to be a definitive study of the effectiveness of cloud seeding in general, but only an attempt to look at South Dakota with the reservations suggested.

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