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An Exploratory Study of Crop-Hail Insurance Data for Evidence of Seeding Effects in North Dakota

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AN EXPLORATORY STUDY OF CROP-HAIL INSURANCE DATA FOR EVIDENCE OF SEEDING EFFECTS IN NORTH DAKOTA

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1. INTRODUCTION

Cloud seeding for hail suppression has been carried out in many parts of the world using a variety of techniques. Dennis (1980) discusses hypotheses as to how seeding could reduce damaging hailfall. Some randomized experiments based on such hypotheses have yielded significant evidence of seeding effects (e.g., Miller et al., 1975; Flueck et al., 1986) while others have not (e.g., Crow et al., 1979; Federer et al., 1986). In spite of these conflicting experimental results, operational hail suppression seeding programs continue and there are indications that at least some of them produce reductions in hail damage (e.g., Hsu, 1985; Dessens, 1986).

Studies of the climatology of hail damage to crops (Changnon, 1977) show that North Dakota experiences the highest dollar loss of any state in the United States, while southwestern North Dakota has the highest ratio of damage claims paid to insured crop liability. Operational seeding has been going on in western North Dakota since the 1950's, with regular hail suppression operations in some areas since 1961 (Rose and Jameson, 1986). The North Dakota program claims to be the longest continuing program in the world employing seeding from aircraft. Since 1976, the operations have been organized as the North Dakota Cloud Modification Project (NDCMP) and supervised by the North Dakota Weather Modification Board, an agency of the State of North Dakota. This sustained support is based on a perception that the seeding has been effective in reducing hail damage to crops. It seems reasonable to examine the available data for any indications that may support this perception.

Rose and Jameson (1986) and Miller and Fuhs (1986, 1987) conducted preliminary analyses of crop-hail insurance data from western North Dakota and neighboring regions. They found some indications of reduced hail damage in the seeded areas. The purpose of the present paper is to present the results of a further exploratory analysis of essentially the same data, using presumably more powerful statistical methods. We follow the philosophy advocated in Mielke et al. (1982) in this analysis.

2. CROP-HAIL INSURANCE DATA

Crop-hail insurance data are available for western North Dakota and adjacent regions from 1924 onward (CHIAA, 1978). These data indicate the yearly insured liability and damage claims paid, on a township by township or county by county basis. The use of such data for evaluating seeding effects has limitations, as discussed by Changnon (1969, 1985). Among them are the facts that only part of the crops in any given area are insured; crop sensitivity to hail damage varies over the season; and farming techniques, cropping patterns, crop yields, and crop values vary with time. However, the insurance data also have important advantages: they cover much larger areas than would be practical with any known hail measurement instruments; they cover a long historical period; and they are based on a relevant economic measure of the losses due to hail. We choose to base this exploratory analysis on these data because of these advantages, while at the same time recognizing their limitations.

Crop-hail insurance data are commonly expressed in terms of the ratio of damage claims paid (in dollars) to insured liabilities; this ratio is known as the loss ratio (LR). The use of these ratios, and of annual values, helps to mitigate some of the limitations of the hail insurance data.

Figure 1 shows a county map of the region of interest in western North Dakota, eastern Montana, and northwestern South Dakota. Seeding has been conducted from time to time in many of the counties of western North Dakota, but the six counties shown shaded have been regularly seeded using essentially the same techniques over the whole period of the NDCMP. The southwestern counties (Bowman, Hettinger, and Slope) are in NDCMP District I, while the northern counties (McKenzie, Mountrail, and Ward) are in District II. These six counties comprise the target area for these exploratory analyses; Appendices A and B summarize the history of seeding activity in those counties. The 12 easternmost counties of Montana provide an upwind control area. The control area is larger than the target area, but the insured liabilities for the two areas are similar over the years (Miller and Fuhs, 1987). The dollar liabilities, however, vary by a factor of about 10^3 over the period of record.

A change in the general quality of crop-hail insurance data beginning in the late 1940's has been suggested. However, data from the control area employed here were tested (using tests similar to those discussed below) and significant differences related to a division around that time were not found. Consequently, these exploratory analyses make use of the whole historical record (although other periods could readily be tested).

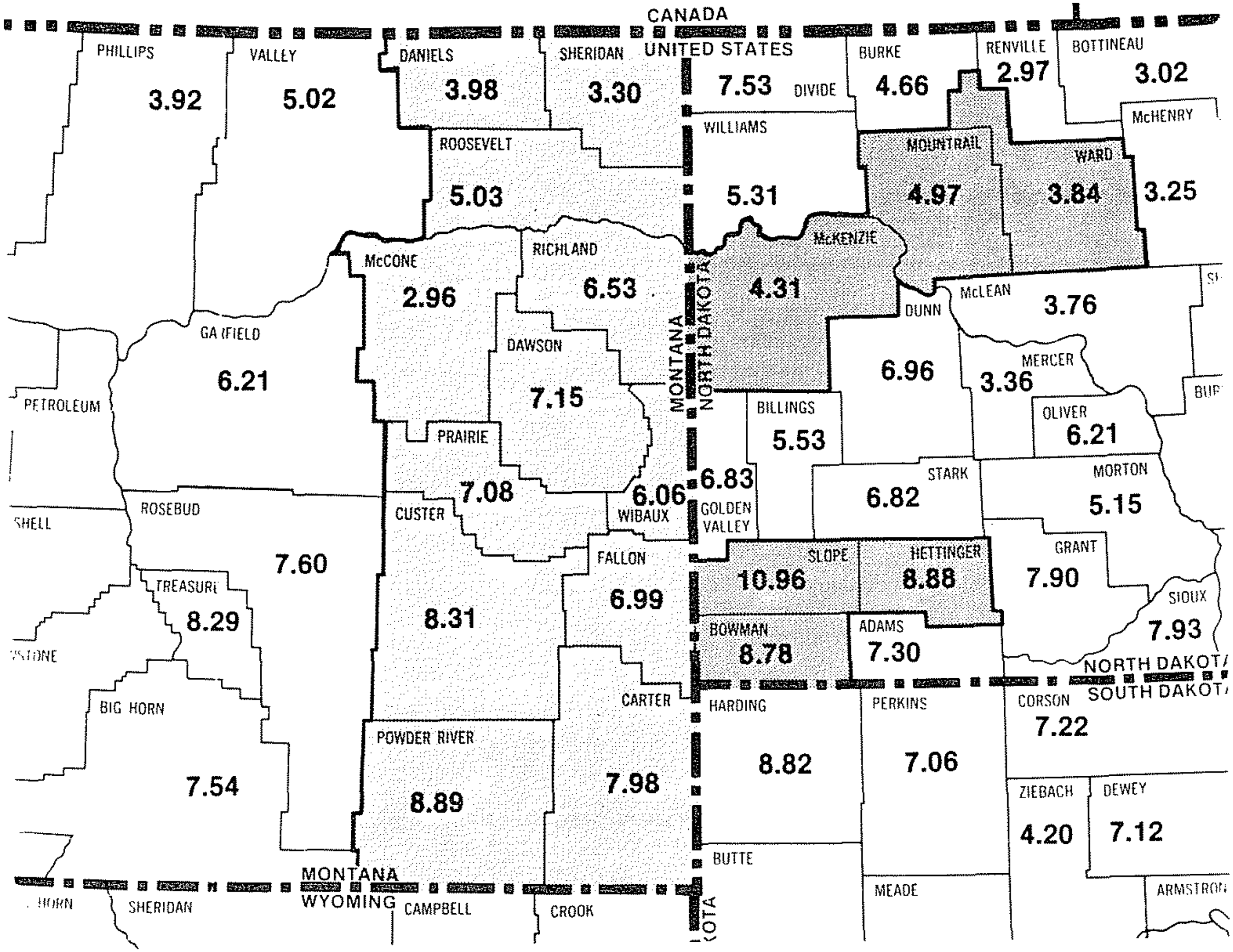

Fig. 1: Map showing the 1924-84 average county loss ratio values (percentages) for the region of interest. The NDCMP "combined target area" comprises the six shaded counties in western North Dakota. The twelve easternmost counties in Montana make up the "west control area."

3. HISTORICAL ANALYSIS FOR TARGET AREA

Figure 2 shows the historical record of the annual loss ratios for the six-county NDCMP target area. The data are tabulated in Appendix C. The values range from a low of 0.99% in 1973 and 1980 to a high of 19.63% in 1963. The median for the 61-year period (1934 omitted because the liability was extremely small) is 5.12%. Some visual indication appears of a downward trend after extensive hail suppression seeding began in the 1960's. Indeed, Rose and Jameson (1986) found indications of reduced hail damage in District I over this period. However, auxiliary tests summarized in Appendix D, based on data from the combined target area, have not provided much indication of this effect (perhaps because District I involves only 35% of the combined target area). Therefore, we concentrate here on the last 10 years, when the NDCMP was in operation. Nine of the 10 loss ratio values for those years are below the overall median value, and the tenth value is only slightly higher.

To explore whether the hail loss experience over this 10-year period differed significantly from that for the earlier period, a permutation analysis was run using the multi-response permutation procedures (MRPP; Mielke et al., 1981a,b; Mielke, 1985) in a univariate mode. The analysis proceeds by drawing samples of 10 years (without replacement) at random from the data population of 61 years. Then a measure of the separation between the two groups (the 10 years and the remaining years) in relation to the scatter in each group is calculated for each sample. These test statistics are then ranked and compared to the corresponding test statistic for the actual division into NDCMP and remaining years to determine a P-value. Details of the MRPP test procedure are discussed in Mielke et al. (1981a,b); MRPP tests have been used to evaluate randomized weather modification experiments (Mielke et al., 1984).

The results of the MRPP test indicate that the probability of finding loss ratio values as small as, or smaller than, those observed during the NDCMP years in a random sample of 10 from the population of 61 values is 0.0041. Hence it is unlikely that the ten NDCMP values are just a random sample from the population. However, this P-value cannot be interpreted in quite the same way as one from a randomized experiment, because the actual NDCMP years were not chosen at random (Gabriel and Petrondas, 1983). They were, however, chosen a priori and, with a P-value this small, the indication of a reduction in hail loss experience in the target area during the NDCMP years has some substance.

Whether the difference was due to the NDCMP seeding cannot be determined from the target area data alone. A climatological shift toward lower hail losses might have occurred during the NDCMP operational period. Changnon's (1984) hail climatology study gives little indication of such a shift, but a more specific examination of the possibility can be made using the control area data.

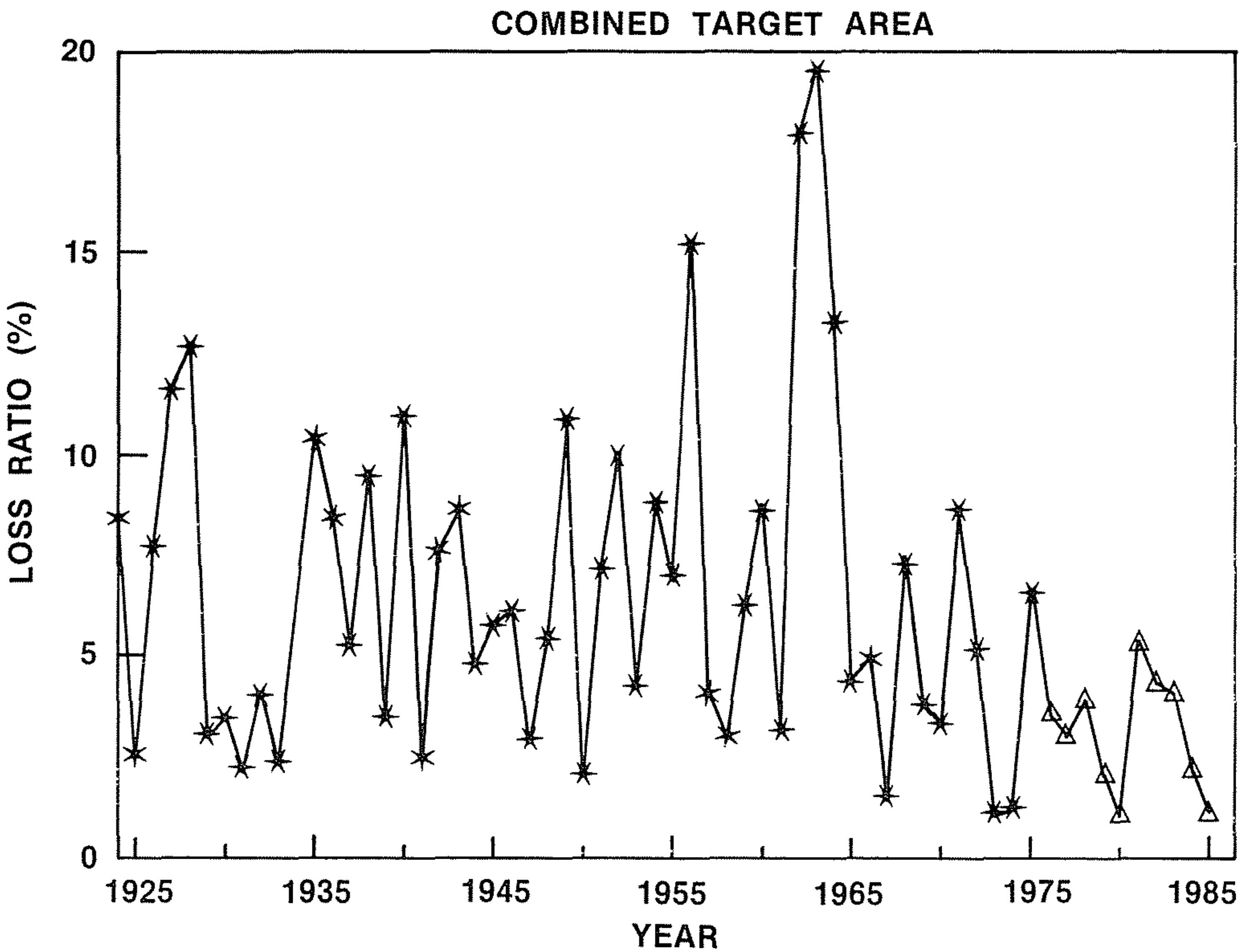

Fig. 2: Historical plot of annual loss ratio values for the combined target area. Asterisks indicate years prior to the NDCMP operations, while triangles indicate the NDCMP operational years.

4. HISTORICAL ANALYSIS FOR CONTROL AREA

Figure 3 shows the historical record of loss ratio values for the 12-county control area in eastern Montana. The values range from a low of 0.49% in 1985 to a high of 14.17% in 1940; the median for the 62-year period is 5.38%. There is not much visual indication of a historical trend; losses recorded during the period 1945-1961 were consistently low, but 7 of those 17 values were above the median. During the NDCMP years, 6 of the 10 values were below the median.

The same univariate MRPP test was applied to the control area data using 10-year random samples from the population. The results indicate the probability of obtaining values as extreme as, or more extreme than, those found during the 10 NDCMP years to be 0.973. In other words, the 10-year NDCMP operational period cannot be distinguished from a random sample from the population. This suggests no general climatological shift in hail damage occurrences associated with the NDCMP operational period.

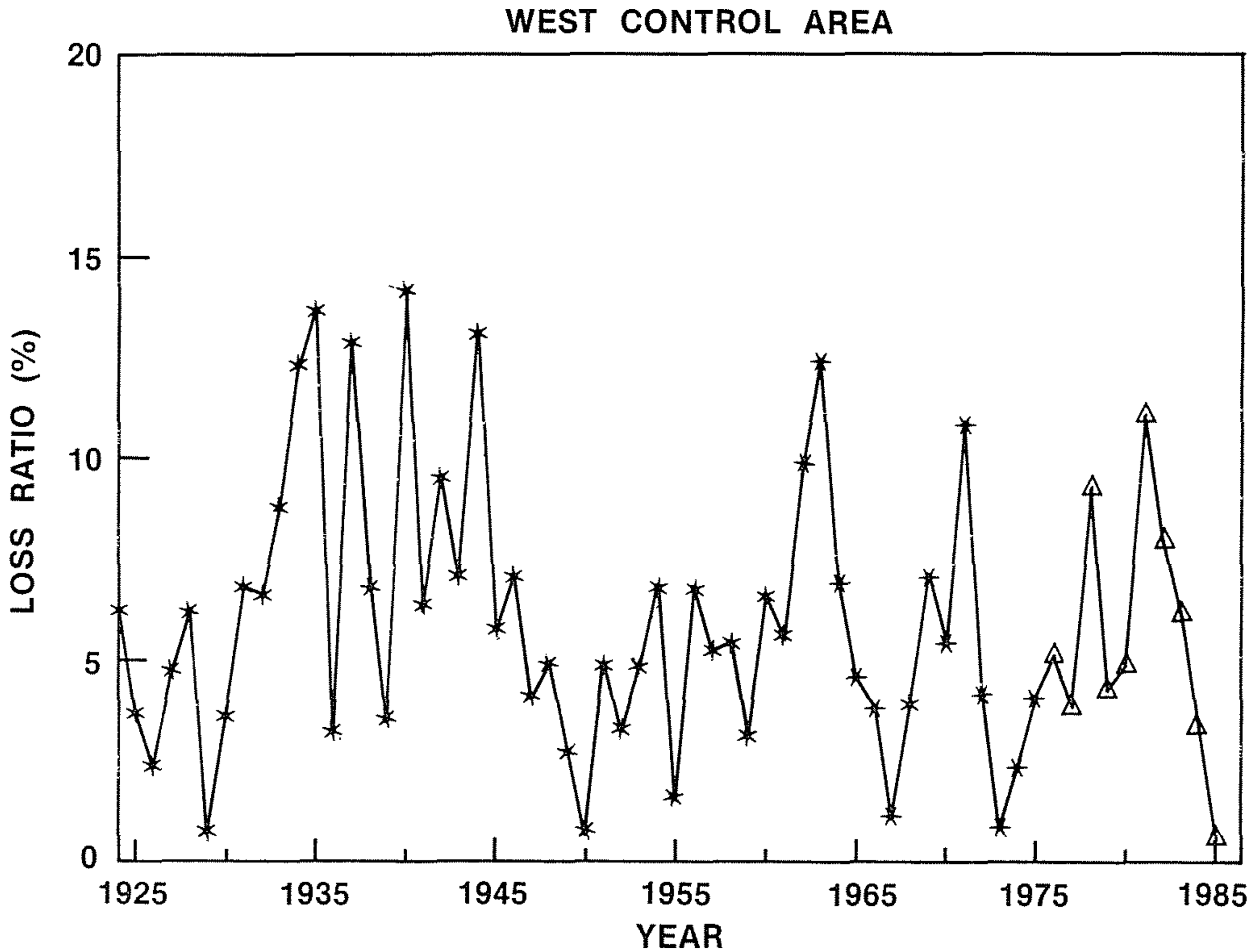

Fig. 3: Historical plot of annual loss ratio values for the west control area. Asterisks indicate years prior to the NDCMP operations, while triangles indicate the years when NDCMP operations were in progress.

5. TARGET-CONTROL REGRESSION ANALYSIS

Figure 4 shows a target-control scatter plot, comparing the yearly target and control area loss ratio values. A regression line was forced through the origin, with its slope determined by a least absolute deviation calculation (Bloomfield and Steiger, 1980). The least absolute deviation (LAD) regression has the advantage of not giving undue weight to individual outlying points. The target control LAD regression equation was found to be

loss ratio (target) = 0.789 x loss ratio (control).

The linear correlation between control and target values is not strong, but this relationship provides a rough prediction of the target area loss ratio from the control area value.

All but one of the points for the 10 NDCMP operational years lie on or below the LAD regression line. The (signed) residual displacement from this line was calculated for every point; the residuals ranged from +10.26% to -5.66%, with a median value of 0.66%. Then an MRPP test similar to that used for the historical record was carried out on these residuals. The resulting P-value of 0.002 indicates that the residuals for the NDCMP years were significantly more negative than would be expected in a random sample from the population. In other words, the target area loss ratio values during those years were significantly lower than would be predicted from the LAD regression line.

This small P-value justifies computation of separate LAD regression lines for the 10 NDCMP years and the 51 remaining years. The results, also indicated in Fig. 4, are:

NDCMP years: loss ratio (target) = 0.487 x loss ratio (control)

Earlier period: loss ratio (target) = 0.861 x loss ratio (control)

The separate regression equations provide a means for obtaining a point estimate of the difference in tha hail loss ratio in the target area during the NDCMP years. The ratio of the slopes is (0.487/0.861) = 0.565. This indicates that the crop hail damage in the target area during the NDCMP years was about 43.5% lower than would be predicted from the historical-period LAD regression equation.

This estimate may even be conservative, because some hail suppression seeding was carried out in parts of the target area for 10-15 years prior to the beginning of the NDCMP. The "historical-period" hail losses in the target area may have been reduced somewhat by that seeding (although auxiliary MRPP tests have not indicated significant differences). If so, the unseeded historical-period regression slope should be greater and the estimated reduction during the NDCMP years would be correspondingly larger.

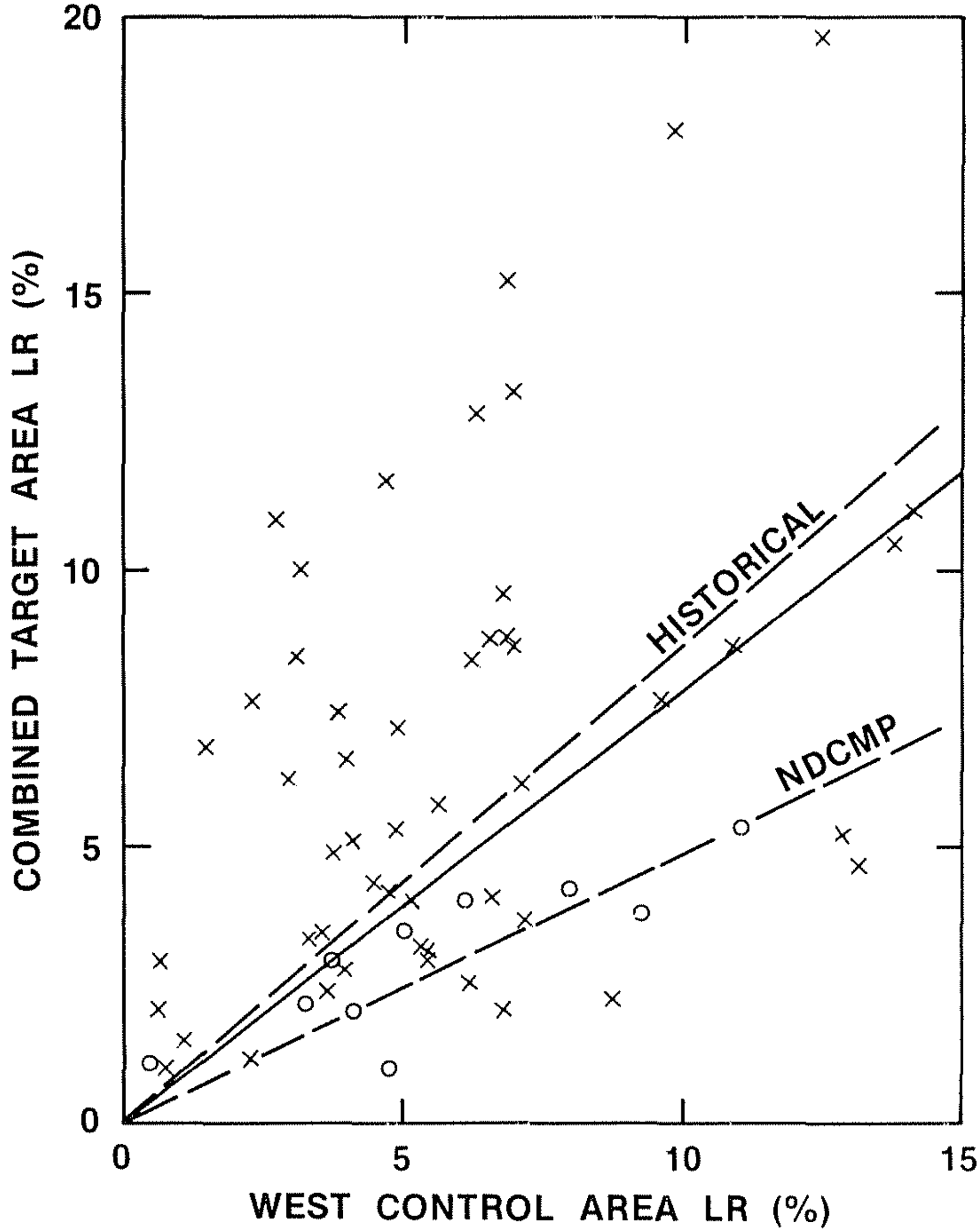

Fig. 4: Scatter plot comparing annual loss ratio (LR) values in the control and target areas. The solid line represents the least-absolute-deviation (LAD) regression equation for the entire 61-year data set. Dashed lines represent separate LAD regressions for the historical (up through 1975, indicated by crosses) and NDCMP operational (1976-85, indicated by circles) periods.

6. CONCLUSIONS

This exploratory analysis suggests that the crop-hail damage in the NDCMP target area averaged about 43.5% lower during the operational period. This estimate of the reduction in hail damage is very close to that reported by Dessens (1986) for an operational seeding program employing ground generators in France. The control-area historical analysis in Section 3 indicates that climatological variations were not a major factor in this difference. It therefore seems plausible to infer that the reduction was due to the NDCMP seeding operations. Of course, the possibility of a "second order" climatological shift, in which the relationship between hail damage experience in the control and target areas changed with time, cannot be excluded by this (or any similar) analysis of the insurance data.

Miller and Fuhs (1986) developed a rough estimate of the benefit-to-cost ratio for the NDCMP seeding operations. Their values suggest a benefit of about eight times the cost of the operations, if the 43.5% damage reduction is attributable to the seeding. This estimate is admittedly crude, but it also takes no account of possible benefits associated with effects of the seeding upon rainfall. Therefore, the sponsors of the NDCMP would seem to be fully justified in continuing their support of the seeding operations.

This exploratory analysis should be substantiated by either more extensive analysis over a longer operational period or a randomized experiment designed to guard against all possible types of climatological variations. A more detailed physical explanation of the means by which the seeding reduces hail damage is also needed.

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APPENDIX A: NORTH DAKOTA SUMMARY DATA

1) Area of state: 70,665 square miles (183,022 km^2)
   1980 population: 652,717; 53 counties.

2) County data for combined target area

County	1980 Population	County Area (Square Miles)
Bowman	4,229	1,162
Hettinger	4,275	1,133
McKenzie	7,132	2,754
Mountrail	7,697	1,837
Slope	1,152	1,219
Ward	58,392	2,041
	TOTAL:	10,146 (26,278 km^2)

Six counties in combined target area = 14.4% of state area.

3) Summary of seeded areas

Year	Square Miles (Estimate)	Percent of 6 Counties	Rounded Estimate
1952	796	7.8%	8%
1953	796	7.8%	8%
1954	3,878	38.2%	38%
1955	0	0.0%	0%
1956	0	0.0%	0%
1957	0	0.0%	0%
1958	592	5.8%	6%
1959	1,602	15.8%	16%
1960	0	0.0%	0%
1961	872	8.6%	9%
1962	5,639	55.6%	56%
1963	4,263	42.0%	42%
1964	7,247	71.4%	71%
1965	3,121	30.8%	31%
1966	2,785	27.4%	27%
1967	3,326	32.8%	33%
1968	8,260	81.4%	81%
1969*	7,901	77.9%	78%
1970*	10,146	100.0%	100%
1971*	10,146	100.0%	100%
1972*	10,146	100.0%	100%
1973	10,146	100.0%	100%
1974	10,146	100.0%	100%
1975	10,146	100.0%	100%
1976	10,146	100.0%	100%
1977	10,146	100.0%	100%
1978	10,146	100.0%	100%
1979	10,146	100.0%	100%
1980	10,146	100.0%	100%
1981	10,146	100.0%	100%
1982	10,146	100.0%	100%
1983	10,146	100.0%	100%
1984	10,146	100.0%	100%
1985	10,146	100.0%	100%

*Part of area under 3:1 randomization.

APPENDIX B: LOG OF NORTH DAKOTA TARGET AREA SEEDING ACTIVITY

			Estimated Percentage of County Area in Seeding Target						Seeding	Seeding		
Year	Class.	Dates	Bowman	Slope	Hettinger	McKenzie	Mountrail	Ward	Agent	Mode	Objectives	Remarks
1952	PS	15 May-31 Jul	10%	0	60%	0	0	0	AgI	GG	PA	
1953	PS	09 Jun-31 Jul	10%	0	60%	0	0	0	AgI	GG	PA	
1954	PS	21 May-28 Jul	0	0	0	0	100%	100%	AgI	GG	PA	
1955	NS		0	0	0	0	0	0				
1956	NS		0	0	0	0	0	0				
1957	NS		0	0	0	0	0	0				
1958	PS	09 Jun-31 Aug	0	0	0	0	10%	20%	AgI	GG	PA	
1959	PS	05 May-13 Aug	0	0	0	0	15%	65%	AgI	GG	PA	
1960	NS		0	0	0	0	0	0				
1961	PS	Autumn	--	--	--	0	25%	0	AgI·NaI	1Air	PA & HS	
		01 Jun-31 Aug	25%	10%	0	--	--	--	AgI·NaI	2Air	- HS	No night seeding.
1962	PS	25 Apr-01 Aug	--	--	--	70%	85%	85%	AgI·NaI	6Air	PA & HS	
		01 Jun-31 Aug	20%	15%	0	--	--	--	AgI·NaI	6Air	- HS	No night seeding.
1963	PS	01 May-01 Aug	--	--	--	0	100%	90%	AgI·NaI	6Air	PA & HS	
		01 Jun-31 Aug	35%	15%	0	--	--	--	AgI·NaI	6Air	PA & HS	
1964	PS	16 Apr-01 Aug	--	--	--	75%	100%	95%	AgI·NaI	6Air	PA & HS	
		01 Jun-31 Aug	100%	20%	0	--	--	--	AgI·NaI	6Air	PA & HS	
1965	PS	~10 May-15 Aug	--	--	--	0	0	90%	AgI·NaI	5Air	PA & HS	
		01 Jun-31 Aug	85%	15%	10%	--	--	--	AgI·NaI	2Air	PA & HS	Radar added.
1966	PS	10 Jun-16 Jul	--	--	--	0	0	65%		Air	PA & HS	
		01 Jun-31 Aug	100%	15%	10%	--	--	--	AgI·NaI	2Air	PA & HS	Radar.
1967	PS	28 May-27 Jul	--	--	--	0	0	80%		Air	PA & HS	
		01 Jun-31 Aug	100%	25%	20%	--	--	--	AgI·NaI	3Air + 20 GG	PA & HS	Radar.
1968	PS	01 May-31 Aug	--	--	--	70%	70%	--		Air	PA & HS	Included in M&F seed.
		12 May-31 Jul	--	--	--	--	--	90%		Air	PA & HS	
		01 Jun-31 Aug	100%	75%	100%	--	--	--	AgI·NaI	4Air	PA & HS	Radar added.

APPENDIX B: LOG OF NORTH DAKOTA TARGET AREA SEEDING ACTIVITY (continued)

			Estimated Percentage of County Area in Seeding Target									
Year	Class.	Dates	Bowman	Slope	Hettinger	McKenzie	Mountrail	Ward	Seeding Agent	Seeding Mode	Objectives	Remarks
1969	PS	15 May-15 Aug	--	--	--	100%	--	--	AgI·NaI	2Air + 9 GG	PA & HS	Begin NDPP. Randomized (3 S to 1 NS). Included in M&F seed.
		01 Jun-31 Jul	--	--	--	--	--	80%		Air	PA & HS	
		01 Jun-31 Aug	100%	100%	100%	--	--	--	AgI·NaI	4Air	PA & HS	
1970	PS	15 Jun-31 Aug	--	--	--	--	100%	100%	AgI·NaI	3Air	PA & HS	Included in M&F seed.
		24 May-15 Aug	--	--	--	100%	--	--	AgI·NaI	2Air	PA & HS	Daylight (10 am-sunset). Random (3 S to 1 NS).
		01 Jun-31 Aug	100%	100%	100%	--	--	--	AgI·NaI	4Air	PA & HS	
1971	PS	15 May-15 Aug	--	--	--	--	100%	100%	AgI·NH_4I	3Air	PA & HS	Included in M&F seed.
		01 May-15 Aug	--	--	--	100%	--	--	AgI + salt	2Air	PA & HS	Sunrise-Sunset. 3 to 1 randomized.
		01 Jun-31 Aug	100%	100%	100%	--	--	--	AgI	2Air	PA & HS	
1972	PS	01 Jun-15 Sep	--	--	--	--	100%	100%	AgI + salt	3Air	PA & HS	(PA Randomized, 3-1). Included in M&F seed.
		01 Jun-31 Aug	--	--	--	100%	--	--	AgI + salt	2Air	PA & HS	Sunrise to sunset. 3 to 1 randomized.
		01 Jun-31 Aug	100%	100%	100%	--	--	--	AgI·NH_4I	4Air	PA & HS	Twin engines. End of NDPP.
1973	PS	01 Jun-31 Aug	--	--	--	100%	100%	100%	AgI·NH_4I	4Air	PA & HS	Included in M&F seed.
		01 May-31 Aug	100%	100%	100%	--	--	--	AgI·NH_4I	4Air	PA & HS	
1974	PS	15 May-31 Aug	--	--	--	100%	100%	100%	AgI·NH_4I	4Air	PA & HS	Included in M&F seed.
		01 May-31 Aug	100%	100%	100%	--	--	--	AgI·NH_4I	4Air	PA & HS	
1975	PS	15 May-15 Sep	--	--	--	--	--	100%	AgI + P	2Air	PA & HS	Included in M&F seed.
		01 Jun-14 Sep	--	--	--	--	100%	--	AgI	1Air	PA & HS	
		01 May-15 Aug	--	--	--	100%	--	--	AgI	1Air	PA & HS	
		01 Jun-31 Aug	100%	100%	100%	--	--	--	AgI	4Air	PA & HS	
1976	S	01 May-31 Aug	100%	100%	100%	100%	100%	100%	AgI + P	8Air	PA & HS	Begin NDCMP.
1977	S	15 May-15 Aug	100%	100%	100%	100%	100%	100%	AgI + P	8Air	PA & HS	
1978	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + P	9Air	PA & HS	
1979	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + P	9Air*	PA & HS	
1980	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + P	9Air*	PA & HS	
1981	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + P	9Air*	PA & HS	

APPENDIX B: LOG OF NORTH DAKOTA TARGET AREA SEEDING ACTIVITY
(continued)

Year	Class.	Dates	Estimated Percentage of County Area in Seeding Target: Bowman	Slope	Hettinger	McKenzie	Mountrail	Ward	Seeding Agent	Seeding Mode	Objectives	Remarks
1982	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + P	8Air*	PA & HS	
1983	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + Dry Ice	8Air*	PA & HS	
1984	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + Dry Ice	8Air*	PA & HS	
1985	S	1 Jun-31 Aug	100%	100%	100%	100%	100%	100%	AgI + Dry Ice	8Air*	PA & HS	

*High performance aircraft included.

GG = Ground Generator Seeding
HS = Hail Suppression
M&F = Miller and Fuhs (1987)
NDCMP = North Dakota Cloud Modification Project
NDPP = North Dakota Pilot Project
NS = Non-Seeded
P = Pyrotechnics
PA = Precipitation Augmentation
PS = Partially Seeded
S = Seeded

APPENDIX C: NORTH DAKOTA HAIL INSURANCE DATA FOR CARD PROJECT

Following are the loss ratio (LR) values (%) for the "combined target" and "west control" areas, as determined by Mike Fuhs. Years are designated as NS = non-seeded, PS = partially seeded (i.e., seeded over some parts of the area) or S = seeded under the NDCMP.

Year	Designation	Combined Target LR (%)	West Control LR (%)	Ratio T/C
1924	NS	8.38	6.22	1.347
1925	NS	2.41	3.59	0.671
1926	NS	7.65	2.30	3.326
1927	NS	11.63	4.67	2.490
1928	NS	12.83	6.30	2.037
1929	NS	2.92	0.61	4.787
1930	NS	3.44	3.53	0.975
1931	NS	2.05	6.79	0.302
1932	NS	4.12	6.59	0.625
1933	NS	2.27	8.73	0.260
1934	NS	M	12.26	--
1935	NS	10.44	13.75	0.759
1936	NS	8.44	3.11	2.714
1937	NS	5.19	12.85	0.404
1938	NS	9.58	6.75	1.419
1939	NS	3.38	3.33	1.015
1940	NS	11.04	14.17	0.779
1941	NS	2.54	6.21	0.409
1942	NS	7.65	9.57	0.799
1943	NS	8.64	6.98	1.238
1944	NS	4.69	13.16	0.356
1945	NS	5.74	5.64	1.018
1946	NS	6.12	7.11	0.861
1947	NS	2.78	3.95	0.704
1948	NS	5.31	4.89	1.086
1949	NS	10.90	2.70	4.037
1950	NS	2.03	0.58	3.500
1951	NS	7.16	4.90	1.461
1952	PS	9.98	3.11	3.209
1953	PS	4.18	4.72	0.886

APPENDIX C: NORTH DAKOTA HAIL INSURANCE DATA FOR CARD PROJECT
(continued)

Year	Designation	Combined Target LR (%)	West Control LR (%)	Ratio T/C
1954	PS	8.75	6.85	1.277
1955	NS	6.78	1.44	4.708
1956	NS	15.22	6.82	2.232
1957	NS	4.01	5.16	0.777
1958	PS	2.95	5.43	0.543
1959	PS	6.19	2.96	2.091
1960	NS	8.77	6.52	1.345
1961	PS	3.09	5.44	0.568
1962	PS	17.95	9.78	1.835
1963	PS	19.63	12.45	1.577
1964	PS	13.24	6.93	1.911
1965	PS	4.33	4.47	0.969
1966	PS	4.89	3.76	1.301
1967	PS	1.47	1.03	1.427
1968	PS	7.40	3.83	1.932
1969	PS	3.69	7.17	0.515
1970	PS	3.19	5.32	0.600
1971	PS	8.58	10.90	0.787
1972	PS	5.12	4.09	1.252
1973	PS	0.99	0.73	1.356
1974	PS	1.12	2.27	0.493
1975	PS	6.57	3.98	1.651
1976	S	3.49	5.06	0.690
1977	S	2.94	3.74	0.786
1978	S	3.83	9.26	0.414
1979	S	2.01	4.13	0.487
1980	S	0.99	4.77	0.208
1981	S	5.35	11.03	0.485
1982	S	4.25	7.96	0.534
1983	S	4.02	6.11	0.658
1984	S	2.17	3.22	0.674
1985	S	1.09	0.49	2.236

APPENDIX D: AUXILIARY MRPP TESTS

A number of MRPP tests were run in addition to those discussed in the body of this report. Table D-1 summarizes the results of the most informative ones.

The tests in Group I show no significant difference between the loss ratio values for the 31 non-seeded years and for the 20 years, prior to the beginning of the NDCMP, when there were some seeding operations in the target area. That justifies pooling the two groups into a common group of 51 years, for the comparisons with the 10 NDCMP years in the text.

The tests in Group II parallel those in Sections 3-4-5 of the text, but use only the 31 non-seeded years in the comparison. The similarity of the P-values indicates that inclusion of the 20 "partially seeded" years, as in the text, made little difference in the results.

The tests in Group III indicate significant differences between the "partially seeded" and NDCMP years. Thus, even though some seeding was going on in the target area during the former period, the results suggest that it had less effect than the NDCMP operations.

TABLE D-1

Summary of Auxiliary MRPP Tests

Group	Area/Data Considered	Basis of MRPP Test	P-Value	Interpretation
I	Control/Historical	31 NS years vs 20 PS years	0.526	No difference
	Target/Historical	31 NS years vs 20 PS years	0.667	No difference
	Target-Control LAD Residuals	31 NS years vs 20 PS years	0.755	No difference
II	Control/Historical	31 NS years vs 10 NDCMP years	0.783	No difference
	Target/Historical	31 NS years vs 10 NDCMP years	0.0030	Significant difference
	Target-Control LAD Residuals	31 NS years vs 10 NDCMP years	0.0039	Significant difference
III	Control/Historical	20 PS years vs 10 NDCMP years	1.000	No difference
	Target/Historical	20 PS years vs 10 NDCMP years	0.019	Significant difference
	Target-Control LAD Residuals	20 PS years vs 10 NDCMP years	0.0025	Significant difference