Results of the Bowman-Slope Hail Suppression Program

A. F. Butchbaker

Faced with high crop-hail insurance rates and large crop losses due to hail, farmers near the Bowman area formed the Bowman-Slope Hail Suppression Association in 1961. The average loss cost in Bowman County exceeds 13 per cent, compared with a state average of approximately five per cent. Crop-hail insurance rates range from 14 to 22 per cent of the insured liability for this area (1).

This southwestern corner of North Dakota lies on the eastern edge of a north-south hail band east of the Rocky Mountains extending from northeastern Montana to southeastern New Mexico in the United States.

No attempts to determine the effectiveness of the Bowman-Slope cloud seeding program or the hailfall climatology of the area were made until 1965, when a preliminary investigation was undertaken (2). More detailed reports have been prepared for each of the years since 1965 (3, 4, 5, 6).

The objectives of the research were: to determine the radar and hailfall climatology of seeded and unseeded storms near the vicinity of a hail suppression project; to determine whether there were significant reductions in hail intensity due to the seeding program; and to determine whether precipitation was altered in the vicinity of the hail suppression program.

Theory of Hail Suppression

There is a variety of storm types by which Nature creates hail. Some are small-scale thunderstorms of short duration; others are quite massive and last several hours. Some of the storms are associated with frontal weather systems and squall lines; others may be isolated cells arising from convective heating of air near the surface of the ground. However, all of them have at least one common characteristic: updraft regions where warm moist air is drawn into the storm. The air cools as it rises and as the rising water vapor condenses it releases latent heat, creating a further unstable condition.

Hailstones are believed to be formed in that part of the storm which possesses a high concentration of supercooled water (water below 32°F that has not frozen). Large hailstones may remain in this environment or cycle between this wet environment and a cooler drier environment until they reach such a size that they can fall through the updrafts and reach the ground. The development of hailstones in a storm are not completely understood.

Most hail suppression programs are based upon the theory of seeding potential hail-producing storms with silver iodide to turn all of the supercooled cloud droplets into ice crystals. By glaciating (turning to ice crystals) the supercooled water in the air parcels through which the hail embryo passes, the hailstone's growth will be inhibited. It is generally assumed that complete glaciation will completely stop the growth.

Another theory suggests that if the number of hail embryos can be sufficiently increased by seeding, there will not be enough supercooled water for any of them to grow large. Thus, many more hailstones may be formed but they will be smaller and perhaps slushy if they reach the ground before melting.

OPERATION OF HAIL SUPPRESSION PROGRAM

Bowman-Slope Hail Suppression Association

After some particularly severe crop hail losses in 1960 (and also for a period of years between 1954 and 1960), Wilbur Brewer, William Fisher, and their farm neighbors organized the Bowman-Slope Hail Suppression Association. The association collected money on a voluntary basis on the seeded

This project was supported by North Dakota Agricultural Experiment Station Project H-4-18, and National Science Foundation Grant NSF GP5485, and NSF GA857.

Dr. Butchbaker was formerly associate professor, Agricultural Engineering Department, North Dakota State University, Fargo, North Dakota, now on the staff of the Agricultural Engineering Department at Oklahoma State University, Stillwater, Oklahoma.

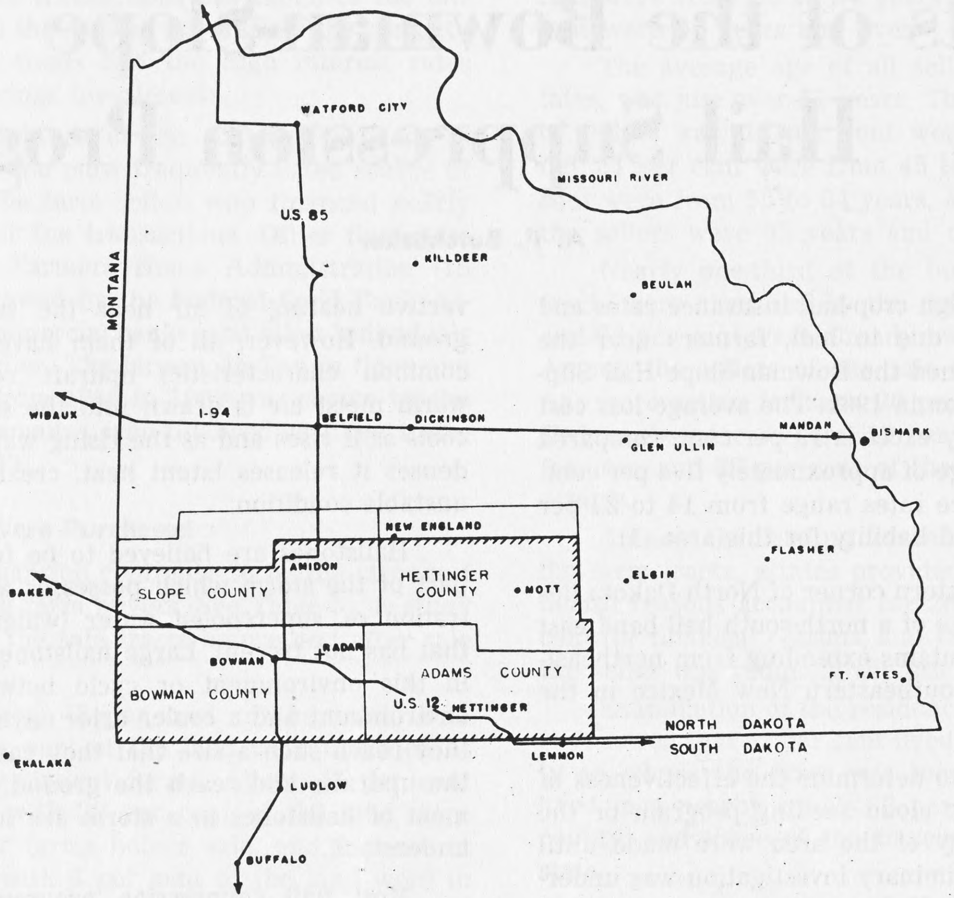

Figure 1. Location of radar site, major towns and boundaries in the study area.

acreage. The original area covered a strip 18 miles wide and 30 miles long. The seeded area expanded from covering portions of Bowman and Slope Counties in 1961 to a four-county area of Bowman, Slope, Adams, and Hettinger Counties in 1968 and 1969, an area of approximately 3,200 square miles. Figure 1 shows the seeded area during 1968.

During the early years of the project, two farmer-pilots, Brewer and Fisher, were contracted by the association to seed the thunderstorms with Lohse wing-tip silver iodide generators. For the first two years, the clouds were aircraft-seeded only during daylight hours. However, there were heavy losses at night, so operations were changed to a 24-hour day, seven-days a week alert, between June 1 and September 1. In addition to the aircraft, 20 Sky-Fire ground generators were located throughout the target area between 1963 and 1967. Between 1961 and 1965, the pilots relied upon their visual observations of storms and telephone reports of incoming hailstorms from people in the western part of the area and also on radio weather reports. Upon observing the likely hail producing clouds, they would fly out to meet the cloud on the edge of the target area, where they would locate the strongest updraft for dispensing the silver iodide into the cloud.

Operation Since 1966

A 3-cm radar system was leased by the association during 1966 to detect thunderstorm cells as they approached the target area. The radar was equipped with planned position indicators (PPI) which permitted the radar operator to observe storm cells and to measure the storm reflectivity. Also, thunderstorm tops were measured by noting the echo range and the antenna tilt angle where a thunderstorm top disappeared on the scope.

Generally, an operational day began with a weather briefing via telephone among personnel of the Institute of Atmospheric Science, South Dakota School of Mines and Technology, Rapid City, and the radar operator at Bowman, North Dakota. On days when thunderstorms were probable, the radar operator maintained close vigilance on latest developments in eastern Montana and western North and South Dakota. Upon noting the minimum gain reading of radar reflectivity, the radar operator would notify the pilots. The pilots would then try to intercept these storms near the target area on either daytime or nighttime flights and seed silver iodide by Lohse-type wingtip generators or pyrotechnic flares at approximately a -4°C level near the cloud base. The radar operator was in radio communication with the pilots during the seeding flights and could direct the pilots to various cells that looked like potential hailers. Table I presents a summary of the seeding activities over a period of three years. A large increase in seeding materials per storm for 1967 and 1968 was due primarily to the increased use of pyrotechnic flares which dispensed the silver iodide from electricity ignited airborne flares.

Table I. Seeding Information

	1966	1967	1968
Number of seeding planes	2	3	4
Seeded area (square miles)	1980	2300	3200
Number of seeded storms	24	19	31
Seeding material used (gms. silver iodide)	29,960*	54,780**	95,710**
Seeding material per seeded storm	1,250	2,880	3,087

* 4% silver iodide-in-acetone burned by wingtip generators

**airborne pyrotechnic devices and wingtip generators

EXPERIMENTAL EQUIPMENT & PROCEDURES

Data acquisition devices for the research program included radar system, aluminum-foil-over-styrofoam hail indicators, rain gages, questionnaires, pilot flight logs, and facsimile weather charts.

Radar. The radar operator took overlays on the radar scope of the echoes and recorded the minimum gain setting before the echo disappeared, the angles to the radar echo cloud top height, and the range of the echo from the radar site. Radar reflectivities and cloud top heights were computed later. Overlays, taken approximately every 15 minutes, permitted the storm paths to be determined.

Ground Indicators. A network of hail indicators and rain gages was located in the target area and in the control areas as shown in Figure 2. The indicators were located at approximately three-mile intervals on easily accessable roads. Dented aluminum foils on the hail indicators were replaced after each hailstorm and were analyzed to obtain hailfall energy values in foot-pounds per square foot, using a calibration method developed by Schleusener and Jennings (7). The rain gages were constructed of quart oil cans and mounted about one foot above the ground. To prevent evaporation between readings light lubricating oil was placed in the rain gages.

Other Data Sources: Questionnaires of the hailfall were distributed to approximately three farmers in each township of the seeded area. The questionnaires were uesd to determine the onset and duration of the hailfall, nature of the hailstorm, and wind velocity in a particular location. The pilots completed flight logs after each seeding

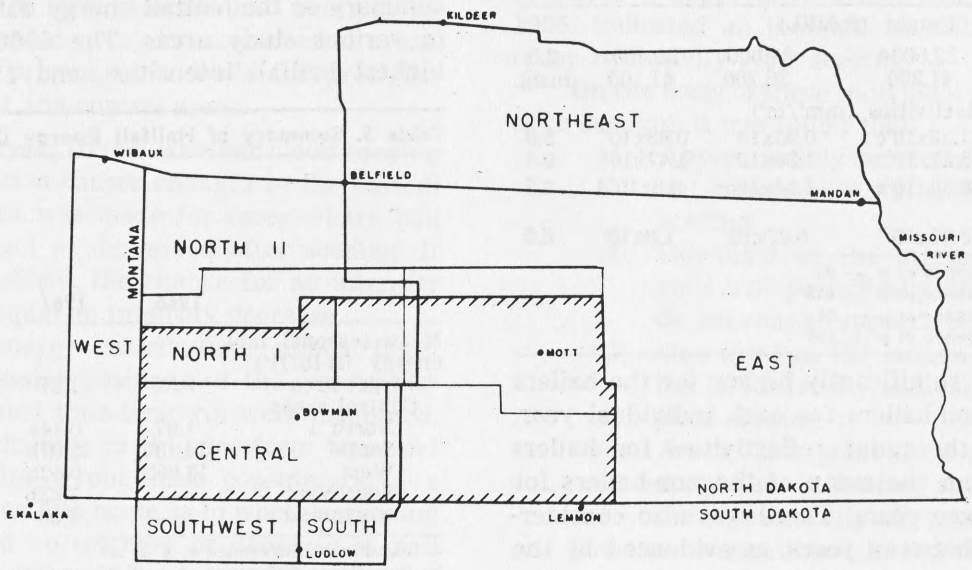

Figure 2. Location of various study areas for hail indicator and raingage sites.

flight, indicating seeding flight paths, time of generator operation, and time pyrotechnic flares were used. Weather Bureau facsimile charts were used to determine the location of major synoptic conditions at the time of occurrence of the hailstorm.

RESULTS

Climatology of Hailstorms.

Occurrences of Hailstorms. Table 2 presents a summary of the storm occurrences for the three years. The 1968 year had the highest number of thunderstorm days and days with cloud seeding.

This was partially due to an increase in size of the seeded area. The 1966 year was also one with considerable hail activity in a study area, which was smaller than for 1967 or 1968.

Table 2. Summary of Storm Occurrences.

	1966	1967	1968
Thunderstorm days	32	20	38
Hailfall days in target or control areas	19	15	19
Days with heavy hail	8	5	5
Days with seeding	20	16	27
Number of storm systems seeded	24	19	31
Seeding days with no hail	7	7	8

Radar Climatology. Table 3 presents a summary of the radar climatology data for cloud top height and maximum radar reflectivity. The mean cloud top height was significantly higher for the hailers than for the non-hailers for each individual year. The mean of the radar reflectivities for hailers was greater than the mean of the non-hailers for each of the three years. There was also considerable variation between years, as evidenced by the statistically significant differences between years for nearly all categories.

Table 3. Summary of Radar Climatology Data.

	1966	1967	1968	Probab. level of which diff. are signi. between years.
Mean Cloud Top Height (ft-MSL)				
Non-hailers	32,600d	34,600	30,400	2.5
Hailers	41,200	36,700	41,100	Insig.
Mean Radar Reflectivities (mm^6/m^3)				
Non-hailers	1.38x10^{7}c	0.95x10^7	0.96x10^7	5.0
Hailers	5.27x10^7	1.30x10^7	1.47x10^7	0.5
Before Seeding	8.30x10^{7}a	1.54x10^{7}c	9.8x10^{7}d	0.5
After	3.97x10^7	0.87x10^7	1.0x10^7	0.5

a Significant difference at p = .05
b Significant difference at p = .025
c Significant difference at p = .01
d Significant difference at p = .005

Hailfall Climatology. Table 4 presents a summary of the hailfall climatology for the three years. Between 50 and 80 per cent of the indicators recording hailfall had less than 10 foot/pounds per square foot of hailfall energy. This represents very little damage to a small grain crop. Between one-sixth and one-third of the indicators recorded 10 to 40 ft-lbs/sq. ft., representing some damage to crops. Only 3 to 6 per cent of the indicators received over 40 ft-lbs/sq. ft. of hail energy, representing serious hail damage to small grains.

Table 4. Summary of Hailfall Climatology Data.

	1966	1967	1968
Per cent of indicators with hail energy in ft-lb/ft^2 between			
0-10	83	80	61
10-40	14	17	33
40+	3	3	6
Time periods having higher frequency of occurrences of storms	1000-1200, 1400-1600 1800-2000MST	1400-1600 MST	1400-1600 MDT
Per cent of storms having hail-fall duration in minutes between			
0- 5	47	65	50
5-20	51	23	30
20+	2	12	20

The time period having the highest occurrence of hailstorms was from 1400 to 1600 MST (2 to 4 p.m.). This suggests that most storms developed in the afternoon from thermal effects.

The hailfall duration at a point location, for about 50 per cent of the storms, lasted five minutes. Less than 20 per cent of the storms had hailfall lasting over 20 minutes. Table 5 presents a summary of the hailfall energy data for each year in various study areas. The 1966 year had the highest hailfall intensities, and 1967 the lowest.

Table 5. Summary of Hailfall Energy Data.

	1966	1967	1968	Probab. level of which diff. are signi. between years.
Mean seasonal hail energy (ft-lb/ft^2)				
Target area	9.22	1.37	2.14	0.5
Control areas				
North I	1.97	0.44a	0.76b	5
South	14.13b	2.07b	4.92c	0.5
West	13.66b	0.42b	4.63a	0.5
Southwest	—	3.63b	8.19d	Insig.
Northwest	—	1.39	2.49	—

a Significant difference at p = .10
b Significant difference at p = .05
c Significant difference at p = .01
d Significant difference at p = .005

There were statistically significant differences between the years for most of the study areas indicating considerable variations from one year to the next.

Precipitation Climatology. Table 6 presents a summary of the precipitation data for the three years. All indicator sites received precipitation during each summer, but not all sites had hail damage. The 1966 year had the highest precipitation of the three years, and also the highest mean hailfall energy. The 1967 year had the lowest precipitation and also the lowest hailfall energy.

Table 6. Summary of Precipitation Data.

	1966	1967	1968	Probab. level of which diff. are signi. between years.
Mean seasonal precipitation (inches)				
Target area	8.95	4.13	5.76	0.5
Control areas				
South	7.33b	4.22	5.20	0.5
West	9.99a	3.59	5.05	0.5
North I	9.41	3.13b	4.83a	0.5
Southwest	—	3.56	6.71c	0.5

a Significant difference at $p = .05$
b Significant difference at $p = .01$
c Significant difference at $p = .005$

Evaluation of Cloud Seeding Effects

Researchers used three methods of analyses trying to detect changes which the cloud seeding for hail suppression might have produced. These included a review of individual storms, a comparison of radar reflectivities before and after seeding, and an analysis of total seasonal hail energies received in the seeded area versus unseeded areas. Additional comparisons were made for precipitation in the target and control areas.

Individual storms. To test whether cloud seeding for hail suppression causes changes in the hailfall intensity, a check was made for cases where hail intensity increased or decreased after seeding. If seeding had no effect, the chance for an intensity increase would equal an intensity decrease.

The hail energy distribution, pilot's flight paths, and successive positions of the severe portion of each seeded thunderstorm were examined, as well as the changes in thunderstorm tops and radar reflectivities. From these considerations, a subjective decision was made as to whether seeding may have caused an increase or decrease in hail intensity at the ground. In cases where hailfall intensity data were lacking, a change in hail intensity did not occur or the storm developed in the target area, no decisions on seeding effects were made. Table 7 presents a summary of the effects of seeding an individual storm system.

Table 7. Summary of Effects of Seeding on Individual Storm Systems.

	1966	1967	1968
Number of seeded cases	24	19	31
Number of seeding days	20	16	27
Number of hail cases	17	9	19
Seeded days with no hail	7	7	8
Days with insufficient data for decision	—	—	3
Seeded cases for comparison	17	9	16
Cases with decreasing reflectivity and hail intensity after seeding	8	6	7
No decision cases with little or erratic changes in hailfall and reflectivity after seeding	8	3	9
Cases with increasing reflectivity and hailfall after seeding	1	0	0
Probability of obtaining combination of numbers of increases and number of decreases	.04	.0156	.0078

The results for the three years indicated that from one-fourth to nearly one-half of the seeded cases had no hailfall. No one knows whether this resulted from cloud seeding for hail suppression or whether hail would not have naturally fallen from these storms. Roughly one-half of the cases where hailfall occurred had definitive changes. The remaining one-half of the hailfall cases had little change in hailfall intensity or radar reflectivity after seeding or had very erratic changes with pulsating effects. No decisions as to the effect of seeding was made for these cases.

Of the cases where well defined changes in hailfall and radar reflectivity occurred, nearly all indicated a suppressive effect. Only one, during 1966, indicated an increase in hail intensity and radar reflectivity after seeding.

On the basis of these individual storm responses to seeding, it was found that:

(1) Approximately one-third of the potential hailers have no hailfall after cloud seeding.
(2) One-third of the storms continue to emit hail periodically after seeding or do not change appreciably.
(3) One third of the storms have decreasing hail intensity and radar reflectivity after seeding.
(4) A very low probability exists for hailers to have increasing hail intensity and radar reflectivity after seeding.

The storms mentioned in the first conclusion may never have hailed naturally. However, based upon the maximum radar reflectivities, cloud top heights, and other features, these storms appeared to have the potential for hail. Therefore, preventive cloud seeding for hail may have been accomplished for these cases. The evaluation of suppressive effects can only take place when hail has fallen.

Radar Reflectivity Changes. To test the hypothesis that seeding causes changes in maximum radar reflectivity of the individually seeded storms, a comparison of reflectivity observations taken before seeding and those after seeding can be made.

Table 3 presents the means of the radar reflectivity for before and after seeding for each of the three years. There were statistically significant differences between the before and after seeding cases for each of the years. There was also a significant difference between years, indicating considerable variation between years.

Comparison of Total Hail Energies. If cloud seeding effectively reduced the hail, the total seasonal hail energy received in the target area should be lower than comparable control areas. To test this hypothesis, the total June, July, and August hail energy at each indicator location was computed and the energy totals for each area statistically compared.

Table 5 presents a summary of the mean seasonal hailfall energy for each study area. The target area had significantly less hailfall energy than the south and southwest unseeded control areas. Except for the 1967 year, the target area also had significantly less hail energy than the west control areas. The North I area had significantly less hail energy for each of the three years than the target area. Many of the storms passing over the North I area had been seeded previously over the target area. There were significant differences between years for each study area, indicating considerable variation in hailfall energy from year-to-year.

In addition to hail energy comparisons, seasonal precipitation was compared between the target area and the control areas (Table 6). In general, there were little significant differences in precipitation between the target area and the various control areas each year. However, significant differences between years existed for each study area.

The results of these comparisons indicate that hailfall energy is less in the target area than nearby unseeded control areas, particularly the south and southwest areas. The areas downwind from the target area either had no difference in hailfall energy or less hailfall energy than the target area. In general, little differences in seasonal precipitation were found between the target area and unseeded control areas or control areas contaminated from the seeding.

The results of this investigation suggest that hail is suppressed in a seeded area compared with nearby unseeded areas without significantly changing the precipitation in the seeded or unseeded areas. Also, a low probability exists for increases in hail intensity after seeding and a relatively high probability exists for either no hail or decreasing hail intensity after seeding potential hailers or storms already hailing.

Summary of Results

The results of this investigation indicated: (1) a 30 to 60 per cent reduction in hail intensity in the target area compared with the south and west control areas. (2) significant differences in storm characteristics between before and after seeding and in seasonal hail energy between seeded and unseeded areas, (3) a low probability was found for increases in hail intensity after seeding, (4) one-third of the seeded storms did not hail, one third had decreasing hail intensity after seeding, and one-third did not change appreciably in hail intensity after seeding, (5) the southwestern North Dakota area had thunderstorm days between one-fourth and one-third of the days between 1 June and 1 September with potential hailstorms on about three-fourths of these days, (6) the cloud top heights and maximum radar reflectivities were significantly higher for hailers than for non-hailers, and (7) hailstorms occurred most frequently between 1400-1600 (2 to 4 p.m.) MST with most storms having a hailfall duration of less than five minutes and hailfall energy less than 10 ft-lb/sq. ft.

REFERENCES

1. **North Dakota 1966 Crop-Hail Insurance Statistics.** Crop-Hail Insurance Actuarial Association, Chicago, Illinois, 1967.
2. Flannagan, M. J., A. F. Butchbaker, et. al., **Observations of Convective Storms in Connection with a Hail Suppression Project,** Joint report by Institute of Atmospheric Science, S. Dak. School of Mines and Technology, Rapid City, South Dakota and Agricultural Engineering Department, N. Dakota State University, Fargo, N. Dak., 1966.
3. Hagen, L. A., **Climatology of Hailstorms and Evaluation of Cloud Seeding for Hail Suppression in South-Western North Dakota,** unpublished M. S. thesis, NDSU, Fargo, N. Dak., May 1967.
4. Butchbaker, A. F., **Results of 1967 Hail Suppression Program in Southwestern North Dakota,** Agricultural Engineering Department Report, North Dakota State University, Fargo, North Dakota 1969.
5. Butchbaker, A. F., **Results of 1968 Hail Suppression Program in Southwestern North Dakota,** Agricultural Engineering Department Report, North Dakota State University, Fargo, North Dakota, 1969.
6. Butchbaker, A. F., **Summary of the Results of a Hail Suppression Program in Southwestern North Dakota,** Agricultural Engineering Department Report, North Dakota State University, Fargo, North Dakota, 1969.
7. Schleusener, R. A. and P. C. Jennings, "An Energy Method for Relative Estimates of Hail Energy," **Bull. of Am. Meteor. Soc.,** 41: 372-376, July, 1960.