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A TARGET-CONTROL ANALYSIS OF WHEAT YIELD DATA FOR THE NORTH DAKOTA CLOUD MODIFICATION PROJECT REGION

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ABSTRACT

A combined historical/target-control analysis of annual wheat yield data for western North Dakota provides indications of possible seeding effects in the target areas of the North Dakota Cloud Modification Project (NDCMP). The basic analysis procedure comparing post-1975 seeded-period data with pre-1961 non-seeded data gives an estimated yield increase of about 6% in the NDCMP target areas, relative to the control area, during the NDCMP operational period. However, the statistical (P-value) indications of the significance of the difference are somewhat equivocal. The historical increase in yields in all the areas due to improvements in agricultural technology apparently contributes to this difficulty, by tending to obscure any incremental change associated with the cloud seeding operations, but an attempt to resolve the issue by redefining the historical reference period to reduce the time gap was unsuccessful. An economic analysis of the effects of such a yield increase suggests an average annual economic impact in the NDCMP target areas of about 19 million dollars.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The State of North Dakota has a long history of cloud seeding for the purposes of hail suppression and rainfall increase; a variety of seeding techniques have been used for these purposes. The State-managed North Dakota Cloud Modification Project (NDCMP) was established in 1976, and the treatment strategy has varied little in succeeding years. (There have been some variations in the details of the seeding technology.) Current operational practice is for aircraft to deliver glaciogenic seeding materials to summertime convective clouds using the guidance of land-based radar (*Boe et al.,* 1990). The NDCMP target area has varied over the years, but from 1976 through 1988, the continuously-participating area included six counties in two districts in western North Dakota.

To ascertain the effectiveness of an operational cloud seeding project is difficult (*Hsu et al.,* 1981). Data acquired during the project specifically to determine effectiveness are often quite limited. Operational project design usually does not include an experimental target-control arrangement or randomized seeding techniques to facilitate statistical evaluation. One must generally make do with the kinds of data available from other sources, and conduct exploratory analyses to find any indications of seeding effects. This typically involves data not only from the target area for the seeding project but also from a historical non-seeded period and/or a nearby area that can function as a control. The latter types of data provide a basis of comparison to help adjust for factors other than cloud seeding (such as natural variations in the weather or developments in agricultural technology) that might also produce changes in the seeded target area.

Such an evaluation of the hail suppression effects for the North Dakota operational project was reported by *Smith et al.* (1987). They based their investigation, hereinafter designated the Hail Analysis, upon long-term crop-hail insurance data and subjected them to statistical methods advocated by *Mielke et al.* (1982). The statistical approach used requires a target and a control area as well as a historical record for each area that extends many years before cloud modification started. This provides a comparison of each area's record during the operational years with the historical record, which helps to mitigate the effect of any long-term trend in either climatic conditions or agricultural technology. The target area for the Hail Analysis was taken to be the same six counties considered in this report, while the control area used was the eastern tier of 12 counties in Montana.

Some type of analysis involving precipitation data for the NDCMP operations area would also be desirable. However, the climatic rain gage network in the region is sparse; some counties have only a single station, and there are currently only 18 climatic gages in the six NDCMP target counties of interest. The NDCMP operates a much more dense volunteer-observer gage network, but no historical record preceding the 1976 initiation of the NDCMP is available. Consequently, we turned to crop data as an alternative source of relevant information.

After a working data base was established (Sec. 2), wheat yield data for western North Dakota were subjected first to historical (NDCMP-period versus non-seeded period) analyses for the control and target areas separately (Sec. 3), and then to a combined historical/target-control analysis like that described in *Mielke et al.* (1982; Sec. 4). Complications that arose in the course of the latter gave rise to a perceived need to try to incorporate some years with limited seeding prior to the NDCMP operational period (Sec. 5). An attempt to do this (Sec. 6) led to slightly different numerical results but did little to clear up the initial complications. An economic analysis conducted by North Dakota State University (Sec. 7) provides a basis for estimating the benefits of the indicated seeding effects.

2. NORTH DAKOTA CROP DATA

The crop data were provided by the North Dakota Agricultural Experiment Station, Department of Agricultural Economics, North Dakota State University. The basic data were arranged in files by crop variety. Annual variables reported for each county were total acres planted, total acres harvested, and bushels produced for each crop variety. Fallowed durum and spring wheat are the dominant crops in western North Dakota, with durum and spring wheat acreage being roughly comparable in the NDCMP target areas and spring wheat predominating elsewhere. Variations among years of 50% or more in planted acreage have occurred in every variety. The present analysis concentrates on total wheat yield, which was determined by combining records from the fallow and continuously-cropped files for spring wheat, durum, and winter wheat. No irrigated-acreage reports were included in the study. The annual average wheat yield for each county was calculated by dividing production (bu) by acres harvested. Any differences in the yield values attributable to the effects of cloud seeding would be expected to reflect the combined results of both hail suppression and rainfall enhancement activities.

Figure 1 is a map of North Dakota indicating the target and control areas for this analysis. The target area comprises the continuously-participating counties of NDCMP District I (McKenzie, Mountrail, and Ward Counties) and District II (Bowman, Hettinger, and Slope Counties). The control area was defined as the remainder of western North Dakota, excluding Adams and McLean Counties (which were part of the NDCMP for some, but not all, of the years included in this study). The total area of the combined target districts is 26,749 km^2, while the control area covers 61,776 km^2. The available records provide no indication of any cloud seeding activity in the control area. However, parts of the control area lie downwind of the target area, so any apparent seeding effects indicated by target-control comparisons may be somewhat diluted by contamination due to seeding materials or seeded clouds drifting into the control area. We elected not to bring in data from upwind areas in Montana, because of differences in crop-reporting procedures between the states. Appendix A gives a table of the annual yield values for the control and target areas.

The years 1935-1951 were initially selected to represent the historical non-seeded period. Limited cloud seeding in the target area was reported for years 1952-1967, with more extensive seeding and even some randomization during the period 1968-1975. The NDCMP operational years include 1976-1988. The years 1952-1975 were not included in the historical analysis (Sec. 3), where the NDCMP years were first compared to a historical record from non-seeded years, or in a preliminary target-control

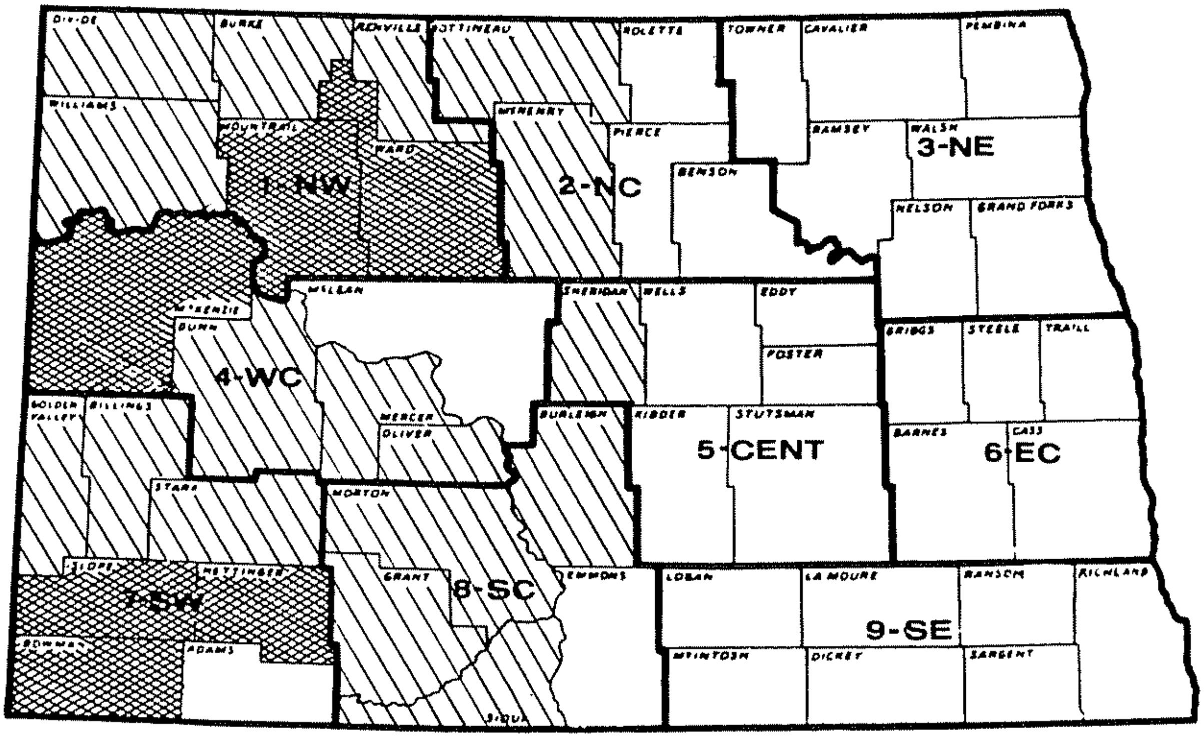

Fig. 1. A map of North Dakota showing the location and size of the target area and the control area . Unhatched areas were not included in the analyses. Heavy lines delineate climatic divisions of the State.

analysis conducted before all of the data became available in a usable format (see Appendix B). An initial target-control analysis (Sec. 4) incorporated four additional years (1955, 1956, 1957, and 1960) when no seeding took place. However, in each case the analysis appeared to be confounded by trends in yield associated with the changes in agricultural technology over the period involved. Further examination (Sec. 5) indicated that including at least some of the remaining intermediate years may be necessary to deal with these trends and isolate any signal that could be associated with the seeding operations. A target-control reanalysis of that kind was therefore made (Sec. 6), but the results did not differ greatly from those of the initial analysis.

3. HISTORICAL ANALYSIS

Figure 2 illustrates the historical trends in wheat yield for the target and control areas. A general rising trend for both areas (and therefore probably associated mainly with improvements in agricultural technology and practices) is evident; the correlation of yield with time is 0.73 (control) or 0.74 (target). However, there appears to have been a marked overall increase in yields beginning in 1962. This increase, averaging on the order of 10 bu/acre, was sustained through the succeeding years, except for particularly dry ones (1980, 1988).

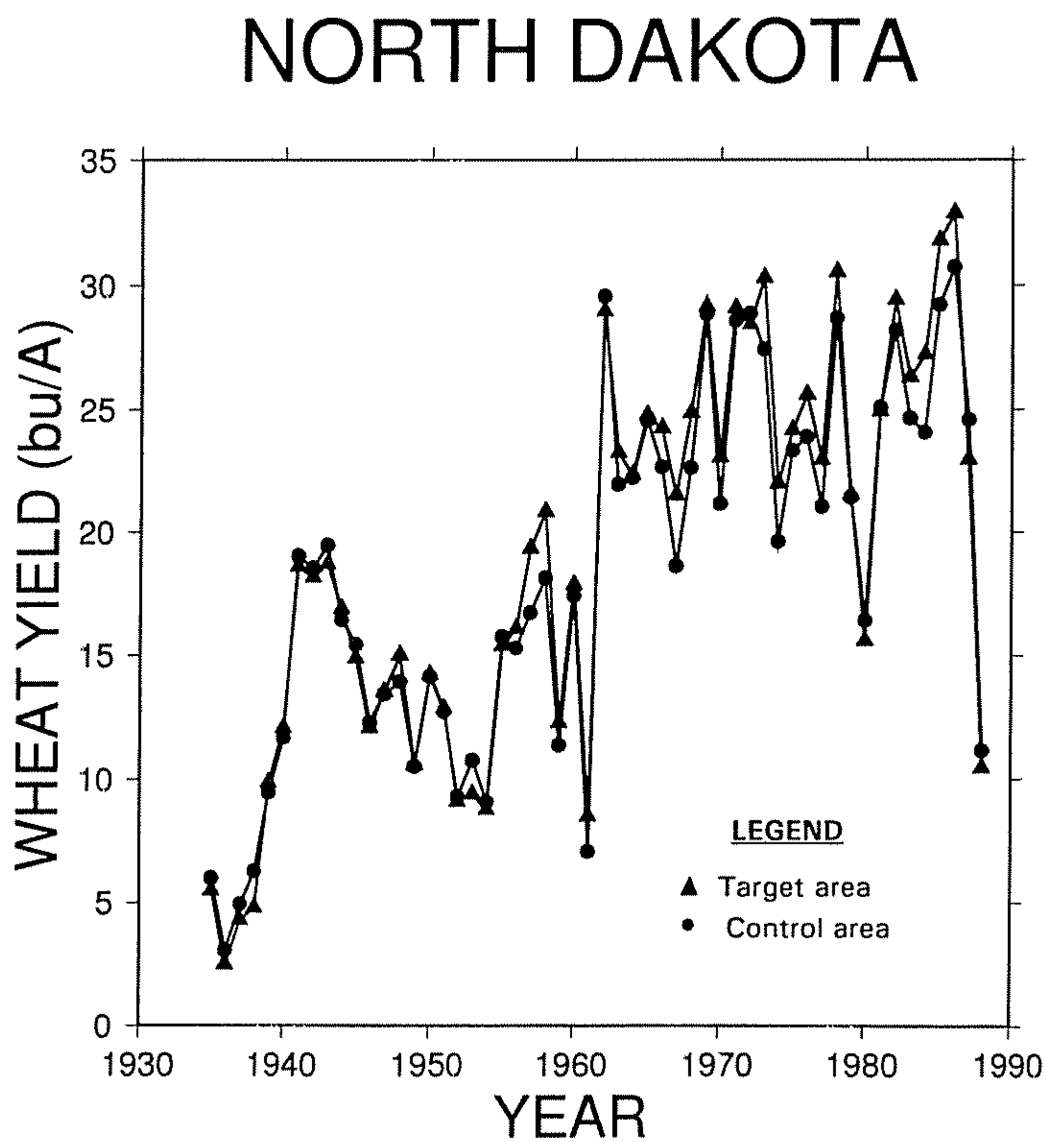

Fig. 2: Historical plot of annual wheat yield values for the target area (▲) and control area (•). Basic data appear in Appendix A.

The control and target values follow each other quite closely for years 1935-1951. Some more substantial differences appear in the intermediate years (1952-1975), with the larger ones generally favoring the target area. The differences show no clear trend for years 1952-1965. From 1966 to 1975, yields of the target area substantially surpass the control yields in six of the ten years; the remaining four years have yields very similar in magnitude. Thus the overall tendency is for target and control yields to continue to follow one another in the earlier part of the intermediate period, even though some type of cloud modification was being attempted in portions of the target area (except for the four years previously mentioned). From 1966 to 1975, it is clear that target yields predominate. For the NDCMP years 1976-1988, target yields are greater than control yields in eight of the thirteen years. Only in three of the years (1980, 1987, 1988) did control yields exceed target yields, and only the 1987 difference was substantial.

An initial historical comparison of yield values from the non-seeded period (1935-1951) and the NDCMP operational period (1976-1988) utilized a Multi-Response Permutation Procedure (MRPP) test (*Mielke et al.,* 1982a,b) similar to that applied in the Hail Analysis. In a test of this sort, data for all the years involved are combined into a common pool. Samples of size equal to the number of NDCMP years (13) are then repeatedly drawn at random from the pool (without replacement) and compared to the actual data for the NDCMP years. The result is expressed in a statistical quantity called a "P-value", which represents the probability of drawing at random a set of values as extreme (either high or low) as, or more extreme than, the actual data. For example, a historical test for the target area would consider the pool of target-area wheat yield values for the years 1935-51 plus 1976-88; Fig. 2 shows that the latter clearly have higher yields. The P-value indicates the probability of drawing at random from the combined pool of 30 years of data a set of 13 values that are as high as, or higher than, the actual 1976-88 data. A small P-value, say less than 0.05 (or 0.10), indicates that such a result is unlikely to occur by chance. In that event, one could have some confidence that the difference between the NDCMP years and the non-seeded years is due to some factor, or combination of factors, rather than to mere random variations. The MRPP test says nothing about what those factors are, and it may or may not be possible to identify a specific factor (such as cloud seeding) that could be responsible for the indicated difference.

Separate historical comparisons were made for the target and control areas. In both instances, the resulting P-value was less than 0.00001, which indicates that the probability of drawing a set of values similar to those of the NDCMP period at random from the composite group is extremely small. Thus the changes in yield in a given area over time can be considered significant. However, the observed historical changes show up in both areas and so cannot be ascribed primarily to the effects of cloud seeding in the target area. Some other factor must be responsible for the main historical trend. In this historical analysis, the well-known contributions of advances in agricultural technology are a major contributing factor which tends to obscure any superimposed effects that might be attributed to the NDCMP seeding operations. The historical trends apparent in Fig. 2 could be attributed to those advances without invoking any potential effect of cloud seeding. Consequently, this historical analysis (in contrast to that for the Hail Analysis) provides no clear-cut indications of possible seeding effects. We therefore turned to target-control comparisons as a potential means of compensating for the technological factor and isolating any incremental changes that might be due to the NDCMP seeding operations.

4. INITIAL TARGET-CONTROL ANALYSIS

The next analysis involved a target-control comparison like that used in the Hail Analysis; the procedure is described in *Mielke et al.* (1982). These analyses involve MRPP tests of residuals (differences between predicted and observed values) about regression lines on target-control scatter plots. The scatter plot is employed in an effort to use the control-area data to compensate for differences (including the historical trend) caused by factors other than cloud seeding in the target area. A regression line on the scatter plot provides a way of describing an apparent relationship between wheat yields in the target and control areas. The basic analysis employed here uses the least absolute deviation (LAD) regression line constrained to pass through the origin; this facilitates development of a point estimate for the magnitude of any target-control difference that may be indicated as significant. Similar MRPP analyses were also completed for residuals about the unconstrained LAD line and the least-squares regression line.

Each MRPP test in this analysis compares residuals about the composite regression line for two groups of points, corresponding to the respective time periods (instead of comparing actual yield values as in the historical analysis in Sec. 3). If a low P-value results, it is unlikely that the NDCMP-period residual values correspond to a random selection from the composite group. In such cases, separate constrained LAD regression lines are determined for the two time periods. The ratio of the slopes of these two lines provides a point estimate of the target/control differential change in wheat yield (assumed to be a multiplicative factor) between the two periods. The difference can be regarded as an indication of a possible seeding effect. Here, too, other factors may contribute to the difference, and their contributions would be combined with the seeding effect; the methodology does not permit separating out the individual contributions of any relevant factors. However, we have not identified any factor other than cloud seeding that would be likely to have effects differing between the control and target areas and also differing between the two time periods.

The initial target-control scatter plot for wheat yield is demonstrated in Fig. 3. This figure includes data for all the non-seeded years (1935-51 plus 1955-57 and 1960) and for the NDCMP period (1976-88). The MRPP test on the residuals about the composite constrained LAD regression line gave $P = 0.015$. This is small enough to justify determination of separate constrained LAD lines for the two time periods; those two lines are shown in the figure. The slope of the line for the non-seeded years is very near unity; if soil conditions, weather events, and agricultural practices were uniformly distributed across the control and target areas, the idealized slope

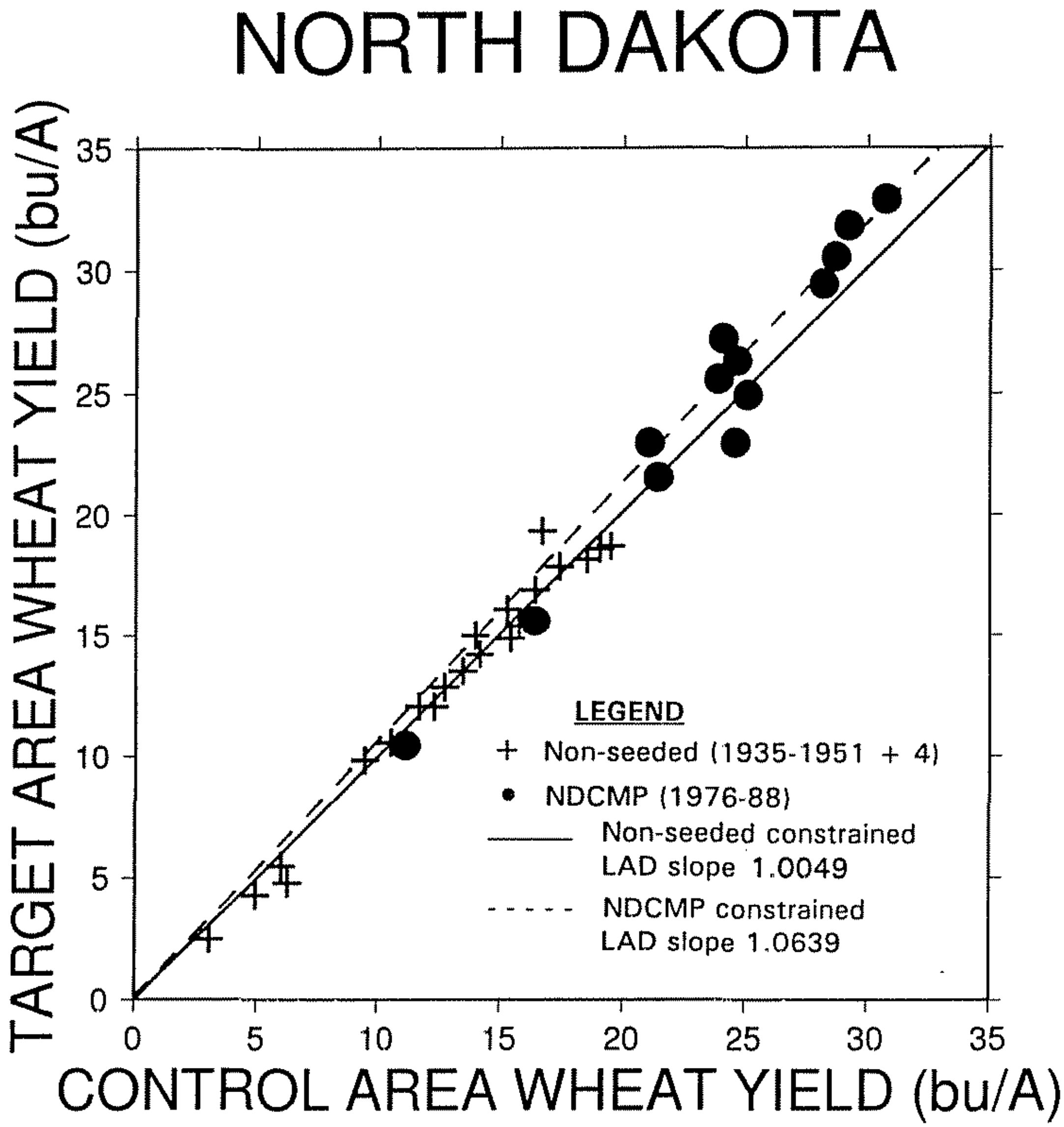

Fig. 3: Scatter plot of target vs. control area wheat yields. NDCMP data (1976-88) are indicated by ● and constrained LAD regression line is dashed (-------). Non-seeded period data (1935-51 plus 1955-57 and 1960) are indicated by + and constrained LAD regression line is solid (——).

would be 1.0. Furthermore, the constrained LAD intercept of zero would be physically significant as well; if crop yields in the control area were nil, the same would be expected in the target area. The slope of the line for the NDCMP years is somewhat greater; the ratio of the slopes is 1.0639/1.0049 = 1.059, which suggests a relative increase of 5.9% in wheat yield for the target area (as compared to the control area) during the NDCMP treatment period.

However, similar MRPP tests on residuals about the unconstrained LAD line and the least-squares regression line do not indicate any significant difference, with the P-values being approximately 0.57. This is not consistent with the first result, and yet there is little difference among the three regression lines. That causes concern about the sensitivity of the analysis procedure to small differences in residuals that are already small because of the extreme linearity of the scatter plot. (In the Hail Analysis, the corresponding plot exhibited much greater scatter and the P-value was small no matter which regression analysis was employed.)

Referring again to Fig. 3, it is evident that the ranges of yield values for the two time periods are essentially separated. Only two of the NDCMP-period points overlap those from the non-seeded period; they correspond to drought years during the NDCMP. The separation is due primarily to the advances in agricultural technology, as discussed in Sec. 3. The consequence is that the two groups of points in essence lie at opposite ends of the regression line. Small changes in the line used (and especially in its slope) therefore can have different effects on the already small residuals for the different groups. The linear correlation in Fig. 3 is quite high ($r=0.99$), but the extreme linearity of the data in this case may be detrimental to stability in the residuals under different regression procedures and in the corresponding calculation of the P-value. A possible means for overcoming this complication would be to enhance the overlap between the two data groups on the scatter plot.

5. REDEFINITION OF THE HISTORICAL PERIOD

It appeared plausible that the general separation of the data groups appearing in Fig. 3 could be mitigated by including some further data from the intermediate years between 1951 and 1976 in the "non-seeded" set. The lack of non-seeded data points above 20 bu/A is a significant feature in that figure. The frequency distributions of wheat yields for the control and target areas for all years 1935-1988 are presented in Fig. 4 as histograms. Extreme values are more prevalent for target yields, but most of the yield values fall between 10 and 30 bu/A. The frequency distributions show that 48% of the target yields and 43% of the control yields are greater than 20 bu/A. Figure 2 shows that all but one of those cases occurred in the post-1961 period. Thus, including additional intermediate years (especially ones from 1962 onward) would provide greater overlap between historical and NDCMP years, which might mitigate the apparent sensitivity of the analysis procedure to small changes in the regression line used.

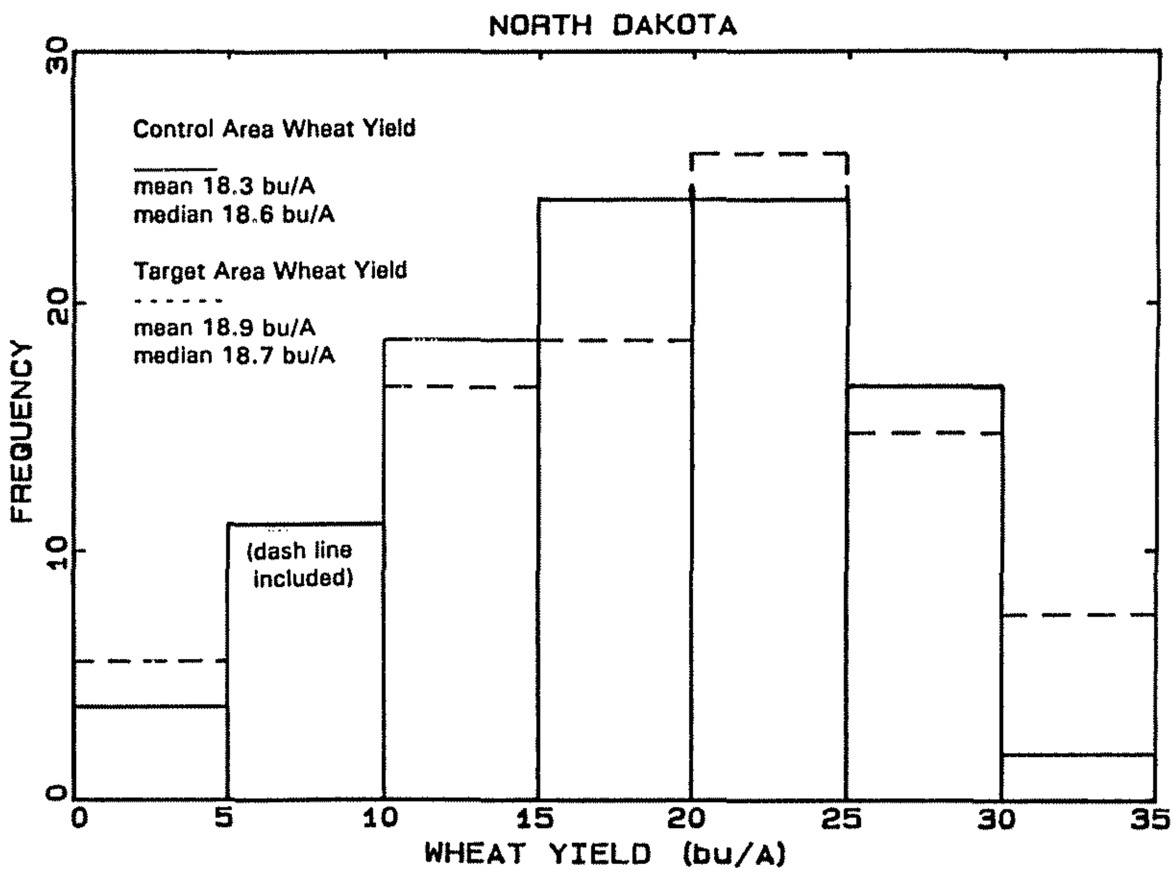

Fig. 4: Histograms of wheat yields for the control area (———) and target area (-------) for years 1935-88. Control area mean is 18.3 bu/A and median is 18.6 bu/A; target area mean is 18.9 bu/A and median is 18.7 bu/A.

Some seeding to modify clouds occurred in most of the intermediate years between 1951 and 1976, with the level of activity building up erratically over the period. Appendix A of the report by *Smith et al.* (1987b) gave numerical values for the fraction of the target area actually seeded. These values are reproduced in Fig. 5, where they are represented by the dashed line. Because some seeding was accomplished during the intermediate years, including these years into the historical (and ideally non-seeded) set could have the effect of diluting any statistical differences

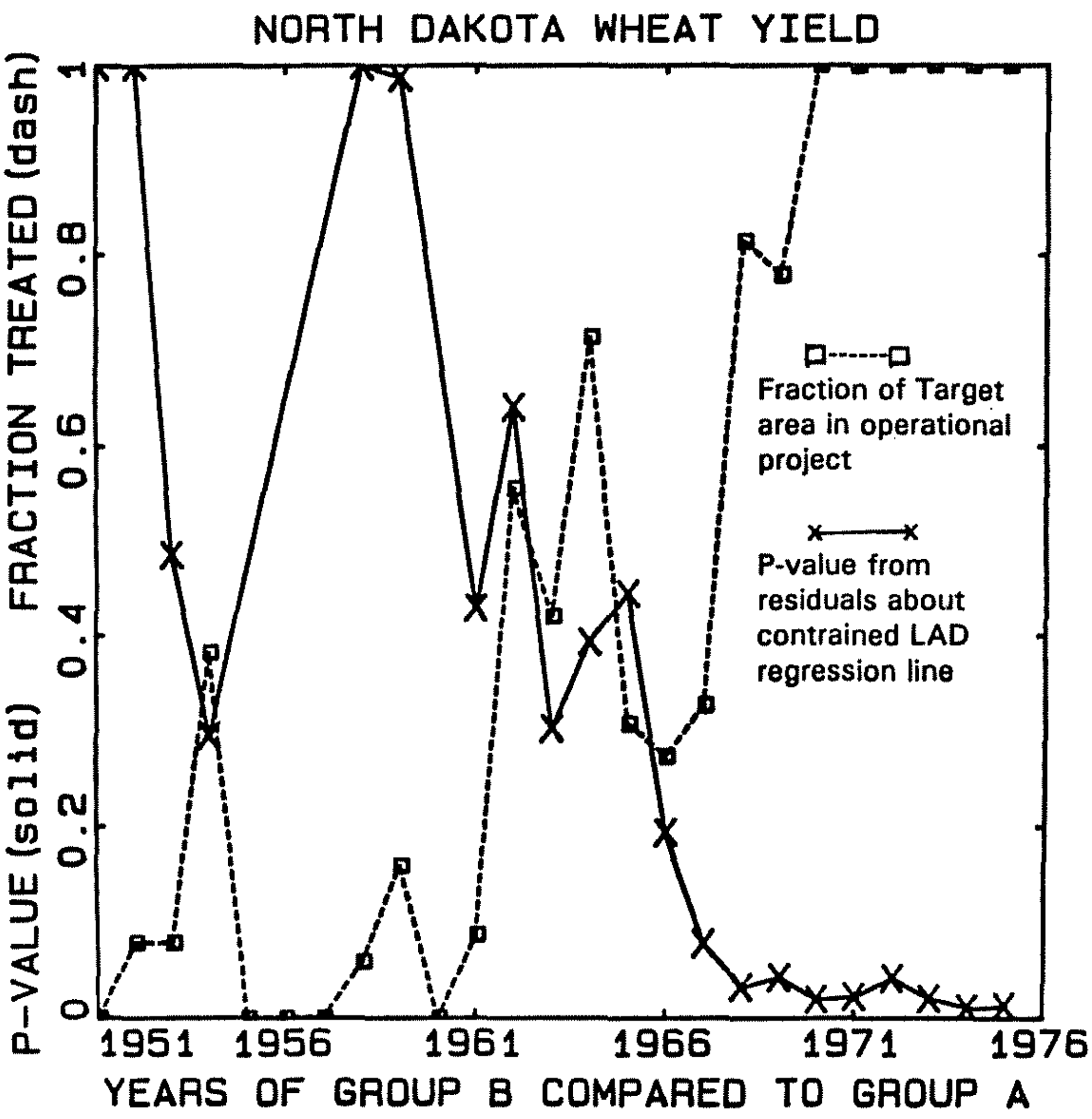

Fig. 5: Plot of P-value (x____x) from MRPP test based on residuals about constrained LAD regression line vs. cumulative years of intermediate set considered, in comparison to the non-seeded group. The dashed line (------) represents the fraction of the target area seeded, by year.

between NDCMP and historical sets. Therefore, only those intermediate years that are not statistically different from the ones known to be non-seeded were incorporated into the redefined "historical" data set.

The dividing point was established by making a running determination of another P-value based on residuals about a LAD regression line constrained to pass through (0,0). The wheat yields for 21 non-seeded years were compared to yields from subsets of the remaining intermediate years (1952-1975 minus the four non-seeded years). This comparison began by using a subset consisting of the yields for just the year 1952, and determining the constrained LAD line for the 22 data points of target versus control wheat yields. The P-value was determined from an MRPP test based upon the residuals about that line, with comparison of the 21 non-seeded years to the one-year subset from the remaining years. The process was then repeated with the subset incremented through addition of the wheat yields from the next intermediate year (1953). This procedure was continued, incrementing the intermediate subset one year at a time, through year 1975.

The resultant series of P-values is represented in Fig. 5 by the solid line. A general downward trend in the P-value is apparent as additional years are incorporated into the subset of intermediate years. This implies that the subset becomes noticeably different from the non-seeded years as additional intermediate years are brought in -- an indication already apparent from Fig. 2. Any selection of a demarcation point is somewhat arbitrary, but we chose the point where the P-value drops below 0.1 for this purpose. Using $P \geq 0.1$ as the criterion results in eleven intermediate years (1952-1966, except for the four non-seeded years) being grouped with the 21 non-seeded years into the redefined historical group. The remaining nine intermediate years (1967 and beyond) correspond to increasing seeding effort in the target area and are hereafter referred to as the "mid years"; the fraction of the target area seeded increased to 100% during this period.

It is the cumulative effect and not the contribution from any one year that determines the P-value. Thus yields for 1966 and perhaps a preceding year or two may more appropriately belong to the mid year subset rather than to the "non-seeded" intermediate subset. In this sense, the present analysis procedure is somewhat conservative in that it will tend to dilute rather than enhance any indications of seeding effects.

6. TARGET-CONTROL REANALYSIS

The combination of target and control wheat yield values for years 1935-1966 is henceforth taken to represent the historical trend for the scatter plots. This redefined historical period was compared to the NDCMP years (1976-1988) and also to the remaining mid years (1967-1975). Table 1 gives the results of the various regression analyses and comparative P-values from MRPP tests of the appropriate groups of residuals. For the truly non-seeded years (1935-1951 plus 1955-57 and 1960), the constrained LAD regression for target versus control yielded a slope of 1.00494. Adding the subset of intermediate years to the historical set changed the constrained LAD slope only slightly, to 1.00743.

Three types of regression analysis were again applied in all cases: the LAD line constrained to pass through the origin, a free LAD line, and traditional least-squares regression. The comparison of the NDCMP to the historical period in Table 1 shows a significant (i.e., small) P-value for the constrained LAD analysis, but unconstrained LAD and least-squares results indicate that in those cases the two groups of residuals belong to a common class. Essentially the same finding resulted from the initial target-control analysis in Sec. 4, so adding the eleven years of data from the intermediate period to the historical group has not clarified the results in this respect.

Figure 6 illustrates the NDCMP versus historical comparison. Including the subset of intermediate years in the historical set has indeed increased the overlap between the two groups of years on the scatter plot. Again, the historical constrained LAD line (solid) is very near the 1:1 line, while the constrained LAD line for the NDCMP years (dashed) has a greater slope. The ratio of the slopes (1.0639/1.0074 = 1.056) indicates a 5.6% relative yield increase in the target area for the NDCMP years. Thus including the subset of intermediate years (which involved some seeding activity) succeeded in reducing the separation between the groups, and the magnitude of the apparent target-control difference obtained from the basic constrained-LAD analysis remained essentially unchanged. As noted above, however, it did not succeed in producing consistent P-values for the comparisons of residuals about the different regression lines.

The comparison between the historical period and the remaining nine years of the intermediate period is also interesting. Those "mid years" (1967-1975) are apparently distinguishable from the historical set, as indicated by the magnitudes of the P-values in Table 1. No matter which regression line is used to calculate the residuals, the P-value remains below 0.1. Figure 7 presents the historical and mid year data sets with their respective constrained LAD lines. The MRPP P-value is small (0.009), yet the slopes of the two lines differ only slightly. The ratio of the slopes

TABLE 1

Regression Parameters and Comparative P-values for Various Target-Control Comparisons

COMPARISON	(NDCMP)	(Mid)	(Historical)	NDCMP / Historical	Mid / Historical	NDCMP / Mid	Mid + NDCMP / Historical
No. of Years	13	9	32	45	41	22	54
Least Absolute Deviation (through origin)							
Intercept	0	0	0	0	0	0	0
Slope	1.06387	1.03614	1.00743	1.02589	1.01778	1.06387	1.02675
Σ Res	13.35	11.01	22.59	40.66	35.27	24.36	52.11
P-value				0.047	0.009	0.538	0.007
Least Absolute Deviation (free)							
Intercept	-2.31588	6.71746	-0.71375	-1.07264	-0.78337	0.52243	-0.94373
Slope	1.14492	0.77795	1.05535	1.09195	1.06973	1.04567	1.08008
Σ Res	11.19	4.77	22.02	35.73	34.09	24.33	47.77
P-value				0.846	0.096	0.562	0.175
Least Squares							
Intercept	-2.63342	6.44146	-0.39248	-0.82823	-0.43961	-0.13958	-0.68366
Slope	1.15277	0.79677	1.04076	1.07342	1.05546	1.05587	1.07039
Σ Res	11.52	5.22	22.54	35.89	35.13	25.09	48.55
r	0.98	0.97	0.99	0.99	0.99	0.97	0.99
P-value				0.453	0.058	0.558	0.106

NDCMP: 1976-88
Mid: 1967-75
Historical: 1935-66

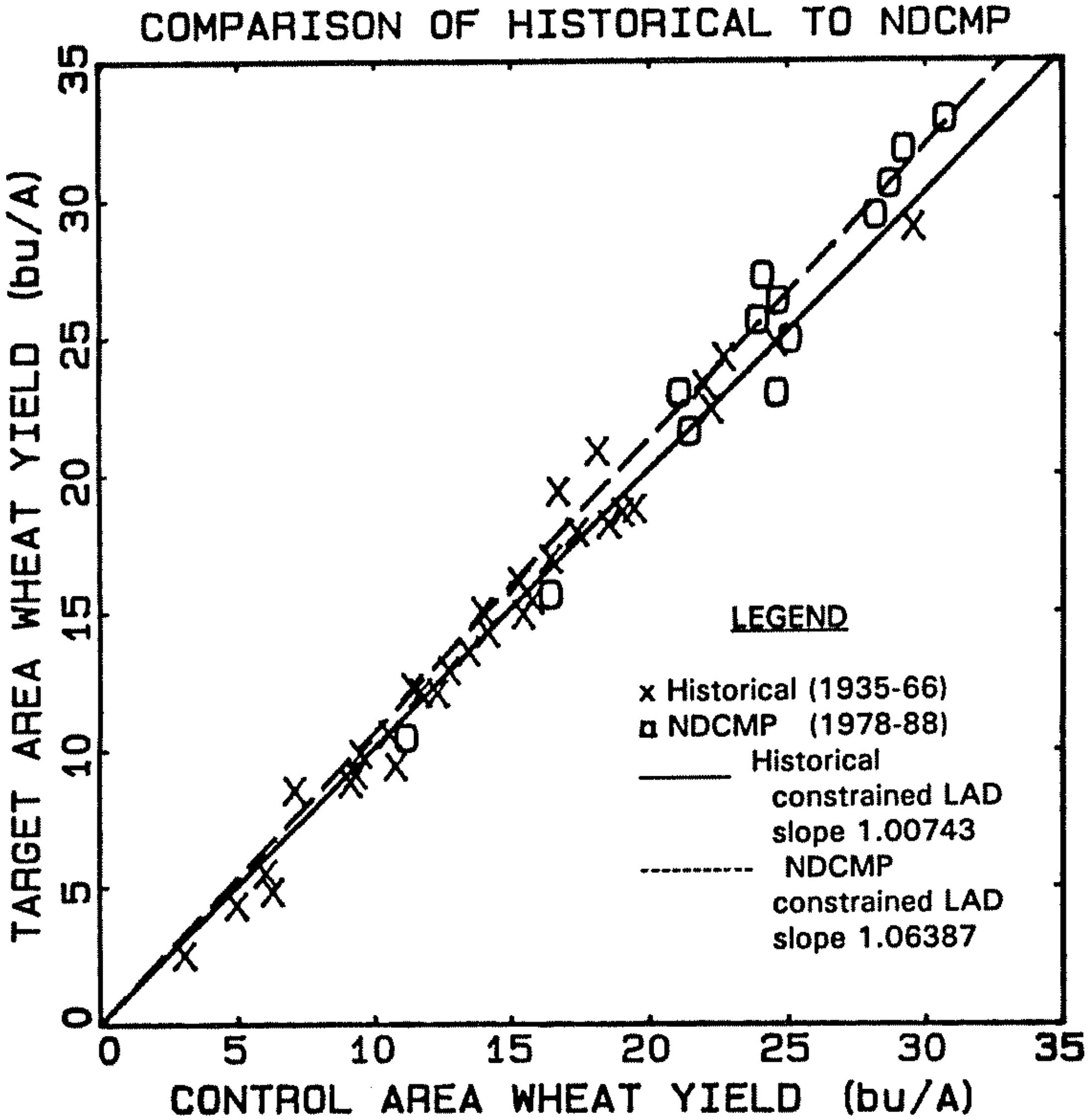

Fig. 6: Scatter plot of target vs. control area wheat yields. NDCMP data (1976-88) are indicated by □ and constrained LAD regression line is dashed (------). The data for the expanded historical set (1935-66) are indicated by X and constrained LAD regression line is solid (______).

(1.0361/1.0074 = 1.028) indicates a relative wheat yield increase in the target area of about 2.8% for the nine mid years. Thus for this comparison we find a stronger and more consistent statistical indication of a difference, even though the apparent difference is smaller in magnitude. The latter would be consistent with the lower level of seeding activity during the mid years (Fig. 5) and with a general improvement of operational procedures during the NDCMP period. The strength of the analysis method is indicated by the fact that such a small difference is found to be significant.

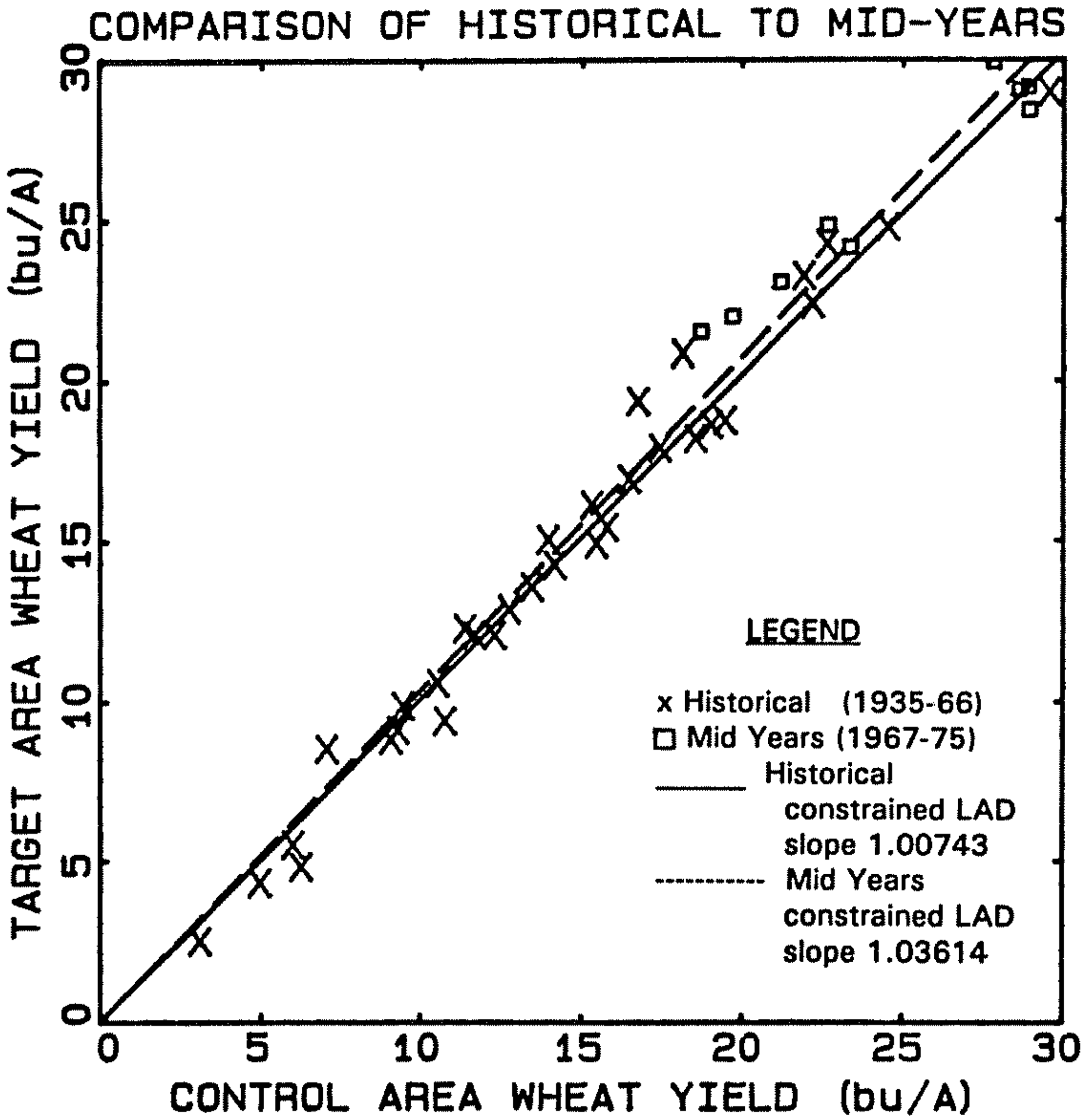

Fig. 7: Scatter plot of target vs. control area wheat yields. Data for mid years (1967-75) are indicated by □ and constrained LAD regression line is dashed (------). Data for expanded historical set (1935-66) are indicated by X and constrained LAD regression line is solid (_____).

For completeness, two further comparisons were made. First, the NDCMP years were compared to the mid years to evaluate any difference between the two periods, each of which involved fairly extensive seeding activity in the NDCMP target areas. Again Table 1 shows similar, but this time large, P-values no matter which type of regression is used. (It is also interesting to note that the constrained LAD line slope is identical to that for the NDCMP years by themselves.) Thus the nine mid years cannot be distinguished from those of the NDCMP according to this test. This finding is not incompatible with the fact that the point estimates of target-control differences in yield for the two periods are not the same; the confidence intervals for those estimates (which cannot be determined by the present analysis procedure) may well overlap.

All of the seeded years (1967-1988) were then compared to the historical set; the last column of Table 1 presents the results. The basic results are similar to those for the NDCMP-vs.-historical comparison (fourth column of the table), although the P-values in the last column are all lower. The disparity among P-values for the various regressions of NDCMP versus historical time periods may be due to the effects of some especially dry years during the NDCMP. According to Fig. 2, yields from the target area were less than those from the control area for NDCMP years 1980, 1987, and 1988. The years 1980 and 1988 were extremely dry in western North Dakota and the yields were low, being comparable to those from the period before 1962. Typically during the NDCMP, when the yields are higher, the target yields exceed those of the control area. The drought in 1980 and 1988 may have affected the target area more strongly than the control area, perhaps by restricting the number of opportunities for effective cloud seeding.

Appendix C summarizes the results of several additional exploratory analyses that were carried out during the course of this investigation.

7. ECONOMIC IMPACTS OF CLOUD SEEDING ON WHEAT PRODUCTION

(by Randal C. Coon and Jerome E. Johnson*)

Cloud seeding may provide additional needed rainfall for growing crops. This appears particularly attractive considering the widespread droughts that affected North Dakota in recent years (see *Johnson et al.,* 1989). In fact, in any given year, some parts of the state repeatedly suffer from low rainfall conditions. In addition, studies of crop-hail insurance statistics indicate that cloud seeding may be partially effective in suppressing hail (*Smith et al.,* 1987b).

Additional rainfall usually means bigger crop yields. The size of the crop yield increase is an indication of the economic benefits of cloud seeding or the economic impact. Economic impact includes both direct economic benefits received due to cloud seeding plus all the indirect and induced benefits (i.e., the additional revenues generated through the subsequent rounds of spending and re-spending of the original benefits). Economic impact is the net increase or decrease in economic activity resulting from expansion or shrinkage of a particular firm, industry, or sector in the area economy. For a complete discussion of economic impact, see *Coon et al.* (1985).

7.1 Methodology

Drought conditions are common in one degree or another in some areas of North Dakota in most years. This study does not specifically examine the economic benefits of cloud seeding for the 1988-1990 drought years. The economic impact analysis is for the same study period (1976-1988) and counties used in this report to measure the effects of cloud seeding on crop yields in western North Dakota. The counties of interest are the six target counties in North Dakota (Fig. 1).

A preliminary target-control analysis (Appendix B) indicated an 8.5 percent increase in wheat yields per harvested acre in the cloud seeded target areas during the 1976-1988 period. [The economic analysis was conducted on that basis, and so results below should be reduced by about one-third to account for the lower final estimate of the seeding effects.]

This economic study calculates the value of added production for all wheats (spring wheat on fallow, spring wheat-continuous, durum wheat on fallow, durum wheat-continuous, and winter wheat) for the 1976-1988

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period. This value is based on the weighted annual average values of increased yields for the six targeted counties using county crop production data published by the National Agricultural Statistical Service (1976-1990). Revised data for all years were used in the economic analysis.

These **direct economic benefits** per acre then were processed in the North Dakota Input-Output Model (Table 2) (*Coon et al.* 1989) to obtain the **economic impacts** per acre. Per acre direct benefits and economic impacts were multiplied by the county weighted acreage to determine the individual and six-county totals.

Direct benefits and economic impacts also were estimated for the control counties in western North Dakota. These values represent the impacts that would result if all wheat acres in each county obtained the estimated yield increases resulting from cloud seeding.

The specific steps in the economic analysis are:

1) Assemble crop data (acres harvested, production, and prices) for each county in western North Dakota for the years 1976-1988 for the five classes of wheat (spring wheat on fallow, spring wheat-continuous, durum wheat on fallow, durum wheat-continuous, and winter wheat).

2) For each county the weighted annual average acres harvested for all wheats were calculated as were the 1976-1988 weighted average acreage (Table 3). Weighted averages were used so an extreme year would not unduly skew the results as could result if using simple averages. Weighted average returns per acre were calculated by multiplying production times price and dividing by number of harvested acres (Table 4).

3) Returns per acre for the treated counties were multiplied by 7.834 percent to obtain the per acre direct benefits resulting from cloud seeding. The 8.5 percent yield increase for the treated counties is already included in the data for the 1976-1988 period. Thus, the increase for the treated counties was:

$$1 - \frac{1}{1.085} = 1 - 0.92166 = 0.07834$$

Nontreated counties' returns were multiplied by 8.5 percent to obtain the direct economic benefits that could be realized if cloud seeding were to be used.

4) Direct benefits of cloud seeding (i.e., the added returns per acre resulting from increased yields due to cloud seeding) were processed by the

TABLE 2

Input-Output Interdependence Coefficients, Based on Technical Coefficients for 17-Sector Model for North Dakota

	Sector	(1) Ag. Lvstk	(2) Ag Crops	(3) Nonmetallic Mining	(4) Const	(5) Trans	(6) Comm Pub Util	(7) Ag Proc & Misc Mfg	(8) Retail Trade	(9) FIRE
(1)	Ag. Livstock	1.2072	0.0774	0.0445	0.0343	0.0455	0.0379	0.1911	0.0889	0.0617
(2)	Ag. Crops	0.3938	1.0921	0.0174	0.0134	0.0178	0.0151	0.6488	0.0317	0.0368
(3)	Nonmetallic Mining	0.0083	0.0068	1.0395	0.0302	0.0092	0.0043	0.0063	0.0024	0.0049
(4)	Construction	0.0722	0.0794	0.0521	1.0501	0.0496	0.0653	0.0618	0.0347	0.0740
(5)	Transportation	0.0151	0.0113	0.0284	0.0105	1.0079	0.0135	0.0128	0.0104	0.0120
(6)	Comm & Public Util	0.0921	0.0836	0.1556	0.0604	0.0839	1.1006	0.0766	0.0529	0.1321
(7)	Ag. Proc & Misc Mfg	0.5730	0.1612	0.0272	0.0207	0.0277	0.0239	1.7401	0.0452	0.0704
(8)	Retail Trade	0.7071	0.8130	0.5232	0.4100	0.5475	0.4317	0.6113	1.2734	0.6764
(9)	Fin, Ins, Real Estate	0.1526	0.1677	0.1139	0.0837	0.1204	0.1128	0.1322	0.0577	1.1424
(10)	Bus & Pers Services	0.0562	0.0684	0.0430	0.0287	0.0461	0.0374	0.0514	0.0194	0.0766
(11)	Prof & Soc Services	0.0710	0.0643	0.0559	0.0402	0.0519	0.0526	0.0530	0.0276	0.0816
(12)	Households	1.0458	0.9642	0.8424	0.6089	0.7876	0.7951	0.7859	0.4034	1.2018
(13)	Government	0.0987	0.0957	0.0853	0.0519	0.2583	0.0999	0.0796	0.0394	0.1071
(14)	Coal Mining	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
(15)	Thermal-Elec. Generation	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
(16)	Pet Exp/Ext	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
(17)	Pet Refining	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gross Receipts Multiplier		4.4931	3.6851	3.0284	2.4430	3.0534	2.7901	4.4509	2.0871	3.6778

TABLE 2 (continued)

	Sector	(10) Bus & Pers Service	(11) Prof & Soc Service	(12) Households	(13) Govt	(14) Coal Mining	(15) Therm-Elec Generation	(16) Pet Exp/Ext	(17) Pet Refining
(1)	Ag. Livstock	0.0384	0.0571	0.0674	0.0000	0.0376	0.0251	0.0159	0.0145
(2)	Ag. Crops	0.0152	0.0229	0.0266	0.0000	0.0285	0.0321	0.0062	0.0057
(3)	Nonmetallic Mining	0.0043	0.0050	0.0057	0.0000	0.0032	0.0019	0.0045	0.0037
(4)	Construction	0.0546	0.0787	0.0902	0.0000	0.0526	0.0328	0.1148	0.0929
(5)	Transportation	0.0118	0.0100	0.0093	0.0000	0.0084	0.0048	0.0180	0.0172
(6)	Comm & Public Util	0.1104	0.1192	0.1055	0.0000	0.0712	0.0378	0.0510	0.0444
(7)	Ag. Proc & Misc Mfg	0.0237	0.0362	0.0417	0.0000	0.0618	0.0782	0.0097	0.0089
(8)	Retail Trade	0.4525	0.6668	0.7447	0.0000	0.3995	0.2266	0.1838	0.1675
(9)	Fin, Ins, Real Estate	0.1084	0.1401	0.1681	0.0000	0.0771	0.0977	0.0388	0.0358
(10)	Bus & Pers Services	1.0509	0.0455	0.0605	0.0000	0.0289	0.0201	0.0139	0.0127
(11)	Prof & Soc Services	0.0497	1.1026	0.0982	0.0000	0.0493	0.0301	0.0210	0.0195
(12)	Households	0.7160	1.0437	1.5524	0.0000	0.6666	0.3973	0.3205	0.2951
(13)	Government	0.0774	0.0881	0.1080	1.0000	0.0511	0.0444	0.0280	0.0285
(14)	Coal Mining	0.0000	0.0000	0.0000	0.0000	1.0000	0.1582	0.0003	0.0002
(15)	Thermal-Elec Generation	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
(16)	Pet Exp/Ext	0.0000	0.0000	0.0000	0.0000	0.0138	0.0084	1.0981	0.8227
(17)	Pet Refining	0.0000	0.0000	0.0000	0.0000	0.0168	0.0102	0.0000	1.0000
Gross Receipts Multiplier		2.7133	3.4159	3.0783	1.000	2.5664	2.2057	1.9245	2.5693

TABLE 3

Acres of Wheat Harvested in Western North Dakota Counties, 1976-1988
(1976-1988 Weighted Average)

County[1]	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Wtd Ave
							-acres-							
Adams	136,600	117,900	125,600	127,500	77,200	151,500	136,000	89,600	104,200	115,000	114,300	117,000	58,900	113,177
Billings	29,200	34,800	38,100	42,500	15,500	37,300	35,600	29,400	32,300	23,000	35,400	30,400	21,200	31,131
Bottineau	364,200	257,600	293,200	276,500	346,700	381,800	339,000	235,200	293,700	276,300	326,500	306,000	294,700	307,031
Bowman	130,400	126,300	123,400	119,500	87,000	123,000	121,300	76,600	100,900	95,700	98,800	106,000	59,400	105,254
Burke	183,900	180,200	175,500	182,700	197,100	203,400	182,900	139,400	154,500	144,500	161,200	154,700	136,900	168,992
Burleigh	204,500	102,400	172,000	179,600	99,750	202,700	155,800	108,100	139,700	157,000	159,100	133,800	48,500	143,304
Divide	268,300	231,400	213,700	238,400	252,800	257,800	232,500	177,100	177,400	162,900	198,200	196,600	173,500	213,892
Dunn	125,500	117,200	132,100	134,800	72,600	136,700	125,000	94,900	118,800	104,300	107,000	101,500	47,800	109,092
Emmons	208,300	180,700	200,000	219,500	95,500	231,200	214,000	136,300	181,200	181,600	178,000	174,400	39,400	172,323
Golden Valley	72,200	75,800	74,500	91,000	49,000	98,700	83,000	53,100	66,400	67,000	67,500	80,000	37,200	70,277
Grant	157,800	115,800	130,700	117,600	94,100	185,600	124,100	84,600	99,500	111,000	106,300	105,000	57,700	111,523
Hettinger	248,700	216,300	222,700	222,000	165,000	260,800	228,300	153,800	202,800	210,500	238,000	201,100	152,000	209,385
McHenry	250,200	200,500	223,900	207,800	225,800	241,600	213,500	138,300	164,800	176,800	182,500	172,400	133,100	194,708
McKenzie	164,100	148,200	167,100	178,100	113,300	192,200	159,000	133,400	123,800	125,200	138,100	140,100	88,700	143,946
McLean	369,900	362,800	378,100	374,500	364,700	402,900	329,400	243,200	285,600	304,100	344,800	326,300	246,700	333,308
Mercer	94,700	91,200	91,700	98,800	78,900	101,000	95,800	55,000	76,900	80,200	83,400	76,200	48,100	82,454
Morton	142,200	115,100	144,400	141,000	79,000	154,800	149,500	89,600	128,700	130,600	123,600	127,700	66,000	122,477
Mountrail	281,100	246,600	261,500	263,400	268,000	294,500	243,800	202,000	204,200	203,500	232,500	223,400	194,800	239,946
Oliver	60,800	40,500	48,100	57,300	42,000	59,800	55,400	40,000	42,300	49,900	46,600	49,800	29,700	47,862
Renville	212,700	176,000	174,800	179,800	179,700	229,700	209,000	140,000	172,000	170,000	181,900	179,000	172,500	182,854
Sioux	46,900	42,800	46,100	41,900	31,900	52,700	41,900	27,000	35,300	37,000	41,600	28,000	11,600	37,285
Slope	115,500	101,100	95,900	96,000	58,800	116,700	116,500	62,600	88,200	85,600	92,500	89,500	74,600	91,808
Stark	191,800	150,500	65,400	179,500	139,000	203,000	178,300	124,900	165,100	150,200	151,300	162,000	98,600	158,431
Ward	450,800	359,500	382,100	370,500	354,100	438,700	405,400	281,700	357,500	348,300	370,900	339,400	325,900	368,062
Williams	359,800	337,600	313,700	338,500	328,500	371,000	341,200	286,900	267,700	258,700	294,100	281,000	257,500	310,477

[1] Underlined counties represent the treated counties and remaining ones are the control counties.

TABLE 4

Average Return Per Acre For All Wheat, Western North Dakota Counties, 1976-1988
(1976-1988 Weighted Average)

County[1]	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Wtd Ave
							dollars per acre							
Adams	54.78	46.81	69.40	64.81	40.95	59.11	81.69	93.81	112.40	82.61	61.98	80.62	27.23	68.61
Billings	72.70	52.47	75.91	71.14	39.03	50.93	78.46	77.81	75.31	44.73	64.72	69.26	25.96	63.89
Bottineau	59.39	67.14	90.19	84.84	88.85	96.07	122.00	115.34	98.56	137.40	92.14	75.02	65.57	91.21
Bowman	63.96	45.89	69.56	70.32	46.30	54.51	80.38	86.71	93.94	62.59	61.23	74.58	33.14	65.51
Burke	68.03	62.97	90.57	68.60	94.83	86.16	93.99	97.71	80.74	85.11	87.14	70.98	65.72	81.08
Burleigh	43.14	30.11	69.08	62.58	44.44	81.37	95.47	80.41	89.18	94.10	63.50	68.22	24.99	68.28
Divide	70.51	61.03	92.96	97.05	110.43	94.31	103.13	91.42	54.70	36.53	88.50	95.60	53.24	82.60
Dunn	65.51	54.16	79.99	74.62	40.19	69.45	91.79	83.48	87.07	91.52	73.45	63.52	28.67	72.32
Emmons	27.01	31.00	61.20	57.48	35.31	78.43	79.45	74.73	99.71	81.85	53.63	67.72	20.22	62.44
Golden Valley	80.68	60.27	88.43	77.76	44.48	67.67	89.41	73.82	82.10	52.68	61.41	83.55	25.64	71.05
Grant	56.28	50.77	59.56	66.75	44.60	79.65	88.79	99.05	91.75	96.05	63.12	72.65	30.51	70.08
Hettinger	65.27	59.98	75.00	83.17	41.50	74.82	92.49	102.68	120.53	104.61	79.32	77.33	34.96	78.56
McHenry	57.51	45.21	77.96	91.23	69.07	104.75	114.46	100.33	90.22	122.15	72.60	58.95	37.88	80.59
McKenzie	69.99	49.62	85.53	75.96	43.46	79.12	108.65	88.33	70.47	55.07	71.26	69.84	30.65	71.51
McLean	66.45	61.46	91.01	91.40	75.60	94.45	116.45	99.46	96.95	122.84	87.34	67.71	39.64	85.56
Mercer	60.64	52.14	76.42	85.71	56.59	95.88	108.45	96.42	92.04	129.86	80.44	73.84	37.54	81.58
Morton	57.07	50.39	73.01	81.55	51.89	82.10	98.39	87.76	89.90	97.32	77.06	79.08	29.67	76.12
Mountrail	58.71	62.50	93.49	81.50	98.66	93.73	119.23	93.31	79.13	100.77	99.09	64.04	49.94	84.48
Oliver	79.00	42.38	72.68	87.37	49.59	85.16	113.59	93.10	96.98	117.48	75.07	66.99	30.49	80.23
Renville	62.69	68.54	94.55	85.77	89.33	103.23	122.55	111.34	114.68	141.97	95.64	71.02	68.77	94.29
Sioux	36.90	38.98	59.81	57.28	45.92	57.13	76.34	76.49	102.62	85.16	51.10	60.85	20.45	60.11
Slope	71.18	40.99	76.51	78.95	45.90	79.86	103.28	92.77	104.93	83.54	67.01	85.68	35.50	75.46
Stark	69.23	16.63	75.31	81.25	48.75	62.49	85.24	94.59	98.36	90.00	72.53	76.53	29.53	70.57
Ward	69.40	63.42	99.85	95.73	89.29	107.21	120.70	117.54	104.67	137.53	95.91	63.01	51.28	93.50
Williams	69.12	54.24	87.30	81.65	70.15	99.68	108.05	82.26	54.96	45.09	79.94	71.83	32.30	73.61

[1] Underlined counties represent the treated counties and remaining ones are the control counties.

North Dakota Input-Output Model's agriculture-crops sector to determine the economic impacts per acre.

5) Per acre direct benefits and economic impacts were multiplied by the 1976-1988 weighted average wheat acres to get total direct benefits and economic impacts at the county level.

7.2 Results

Economic impacts are presented for all counties in western North Dakota (Table 5). Impacts were determined for the six cloud-seeded counties and the remaining counties in western North Dakota. These impacts are **only** for wheat acres and assume that each acre of all wheats produces the increased yields associated with the added rainfall and/or decreased hail damage. For the nontreated counties, the impacts also include added levels of business activity that could have resulted from the additional rainfall or reduced hail damage achieved by cloud seeding.

TABLE 5

Annual Per Acre Direct Benefits and Economic Impacts for Treated and Untreated Wheat Acres in Western North Dakota Counties (Weighted 1976-1988 Averages)

County[1]	Direct Benefits	Economic Impacts	County[1]	Direct Benefits	Economic Impacts
	-- dollars per acre --			*-- dollars per acre --*	
Adams	5.83	21.48	McKenzie	5.60	20.64
Billings	5.43	20.01	McLean	7.27	26.79
Bottineau	7.75	28.56	Mercer	6.93	25.54
Bowman	5.13	18.90	Morton	6.47	23.84
Burke	6.89	25.39	Mountrail	6.62	24.40
Burleigh	5.80	21.37	Oliver	6.82	25.13
Divide	7.02	25.87	Renville	8.01	29.52
Dunn	6.15	22.66	Sioux	5.11	18.83
Emmons	5.31	19.57	Slope	5.91	21.78
Golden Valley	6.04	22.26	Stark	6.00	22.11
Grant	5.96	21.96	Ward	7.32	26.97
Hettinger	6.15	22.66	Williams	6.26	23.07
McHenry	6.85	25.24			

[1]Underlined counties represent treated counties, and remaining ones are the control counties.

Direct benefits and economic impacts are presented on a per acre basis to provide a common base for comparisons. Treated counties had increased returns per acre ranging from $5.13 for Bowman County to $7.32 for Ward County. Economic impacts resulting from these per acre revenue increases amounted to $18.90 per acre for Bowman and $26.97 for Ward County. On a per acre basis, all counties in western North Dakota could increase their returns per acre of wheat by at least $5.00 if those acres produced increased yields via cloud seeding. This direct benefit in turn, when applied to the economic multiplier process, would generate nearly $20 or more of economic activity on a per acre basis in western North Dakota if yields were increased by cloud seeding.

Table 6 presents the total direct benefits and economic impacts for counties in western North Dakota. Direct benefits and economic impacts on a county-wide basis were obtained by multiplying the values in Table 5 by the annual weighted average number of wheat acres for each county to determine the magnitude of the economic impacts if the yields were

TABLE 6

Annual Total County Direct Benefits and Economic Impacts for Treated and Untreated Western North Dakota Counties (Weighted 1976-1988 Averages)

County[1]	Direct Benefit	Economic Impact	County	Direct Benefit	Economic Impact
	--- *$ 1,000* ---			--- *$ 1,000* ---	
Adams	660	2,431	<u>McKenzie</u>	806	2,971
Billings	169	623	McLean	2,423	8,929
Bottineau	2,379	8,769	Mercer	571	2,106
<u>Bowman</u>	540	1,989	Morton	792	2,920
Burke	1,164	4,291	<u>Mountrail</u>	1,588	5,855
Burleigh	831	3,062	Oliver	326	1,203
Divide	1,502	5,533	Renville	1,465	5,398
Dunn	671	2,472	Sioux	191	702
Emmons	915	3,372	<u>Slope</u>	543	2,000
Golden Valley	424	1,564	Stark	951	3,503
Grant	665	2,449	<u>Ward</u>	2,694	9,927
<u>Hettinger</u>	1,288	4,745	Williams	1,944	7,163
McHenry	1,334	4,914			

[1] Underlined counties represent treated counties, and remaining ones are the control counties.

increased through cloud seeding. Ward County could realize a nearly $10 million increase in county-wide economic activity. Cloud seeding all wheat acres could give each county in western North Dakota a significant economic impact, with total economic activity increasing from about $623,000 for Billings County to the $9,927,000 impact for Ward County. Totaling the annual economic impact for the six treated counties resulted in over a $27 million annual increase in total business activity (Table 7). The magnitude of these impacts indicates the potential economic benefits that could be realized by cloud seeding.

[To be consistent with the final estimate of seeding effect on wheat yield, the economic impacts estimated here should be multiplied by about 0.7. Thus the total economic impact for the six NDCMP target counties is about $19 million.]

TABLE 7

Annual Economic Impacts of Cloud Seeding All Wheat Acres for Six Western North Dakota Counties Using Weighted 1976-1988 Averages (in $1,000)

County	Econ. Impacts
Bowman	1,989
Hettinger	4,745
McKenzie	2,971
Mountrail	5,855
Slope	2,000
Ward	9,927
Total	27,487

8. CONCLUSIONS

1) The comparison shown in Fig. 3 for the NDCMP years versus the non-seeded years indicates a 5.9% wheat yield increase in the target area (as compared to the control area) for the NDCMP years. The non-seeded set for this comparison specifically excluded years with any known cloud modification treatments. The MRPP P-value for the basic constrained-LAD regression analysis was 0.015, which suggests a significant difference between the two groups of years. However, much higher P-values resulted when other regression lines were used in a similar type of analysis, so the statistical support for a difference is somewhat equivocal.

2) While the basic target-control analysis indicates that the wheat yields have increased more in the NDCMP target area than in the control area, the general increase in wheat yields over the years (due primarily to advances in agricultural technology) complicates the problem of isolating differences that could be related to the cloud seeding. Because of this trend, the yield values for the non-seeded and NDCMP years are almost completely separated on the target-control scatter plot of Fig. 3. That may contribute to the lack of consistency in the P-value determinations under different regressions.

3) Expanding the historical data set to include a subset of the intermediate years, when limited seeding activity was being carried out in the target area, had the expected effect of increasing the overlap between historical and NDCMP-period yields. The point estimate of the apparent seeding effect for the NDCMP was essentially unchanged, but the statistical support for a difference was not clarified as had been hoped.

4) The scatter plots for these analyses are extremely linear, with target-control correlation coefficients ranging from 0.97 to 0.99. The residuals, which are calculated as the differences between regression-predicted and observed values, are correspondingly small. Thus, the P-values resulting from the MRPP tests are based upon small differences among small residuals. Even so, the analysis method was able to provide statistical support for a 2.8% target-area yield increase for the mid years when compared to the expanded historical data set. Thus, the method can be sensitive to small differences.

5) Substantial economic benefits would be associated with wheat yield increases of the magnitudes estimated herein. For example, the average annual economic impact of cloud seeding in the six NDCMP target counties is estimated to be of the order of 19 million dollars.

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REFERENCES

Boe, B. A., R. L. Rose, M. C. Williams, P. St. Amand, R. Elliott, C. Wisner, J. Pellet, J. A. Donnan, D. R. Booker, L. F. Ritter, M. Schock, J. R. Miller, Jr., J. Thompson, M. L. Schultz and J. A. Jung, 1990: *North Dakota Cloud Modification Project Operations Manual.* ND Atmos. Res. Brd., Bismarck, ND. 67 pp.

Coon, Randal C., F. Larry Leistritz, Thor A. Hertsgaard and Arlen G. Leholm. 1985: *The North Dakota Input-Output Model: A Tool For Analyzing Economic Linkages.* Agricultural Economics Report. No. 107. Fargo: Department of Agricultural Economics, North Dakota State University.

Coon, Randal C., F. Larry Leistritz and Thor A. Hertsgaard, 1989: North Dakota Input-Output Economic Projection Model Documentation And User's Guide Version 2.0. *Agricultural Economics Software Series No. 4.* Fargo: Department of Agricultural Economics, North Dakota State University.

Hsu, C-F., K. R. Gabriel and S. A. Changnon, Jr., 1981: Statistical techniques and key issues for the evaluation of operational weather modification. *J. Wea. Modif.,* **13**, 195-199.

Johnson, Jerome E., Randal C. Coon and John W. Enz, 1989: *Economic Benefits of Crop-Hail Reduction Efforts in North Dakota.* Agricultural Economics Report No. 247. Fargo: Department of Agricultural Economics, North Dakota State University.

Mielke, P. W., Jr., K. J. Berry, P. J. Brockwell and J. S. Williams, 1981a: A class of nonparametric tests based on multi-response permutation procedures. *Biometrika,* **68**, 720-724.

Mielke, P. W., Jr., K. J. Berry and G. W. Brier, 1981b: Application of multi-response permutation procedures for examining seasonal changes in monthly sea-level pressure patterns. *Mon. Wea. Rev.,* **109**, 120-126.

Mielke, P. W., Jr., K. J. Berry and J. G. Medina 1982: Climax I and II: Distortion resistant residual analyses. *J. Appl. Meteor.,* **21**, 788-792.

National Agricultural Statistics Service, 1976-1990: *North Dakota Agricultural Statistics.* [Various annual issues of Ag Statistics.] Fargo: issued cooperatively by North Dakota State University and the U.S. Department of Agriculture.

Smith, P. L., J. R. Miller, Jr., R. L. Rose and P. W. Mielke, Jr., 1987a: An exploratory study of North Dakota crop-hail insurance data for evidence of seeding effects. Preprints, *11th Conf. Wea. Modif.,* Edmonton, Alberta, Canada, Amer. Meteor. Soc., 86-89.

Smith, P. L., J. R. Miller, Jr., and P. W. Mielke, Jr., 1987b: An exploratory study of crop-hail insurance data for evidence of seeding effects in North Dakota. Report SDSMT/IAS/R-87/01, Institute of Atmospheric Sciences, S. D. School of Mines and Technology, Rapid City, SD. 21 pp.

APPENDIX A

Annual Wheat Yield Values (bu/A) for Control and Target Areas

Year	Control	Target
1935	6.01	5.49
1936	3.06	2.49
1937	4.95	4.30
1938	6.27	4.80
1939	9.47	9.85
1940	11.68	12.07
1941	19.04	18.59
1942	18.55	18.16
1943	19.48	18.72
1944	16.45	16.89
1945	15.44	14.89
1946	12.30	12.06
1947	13.45	13.55
1948	13.96	15.01
1949	10.54	10.57
1950	14.16	14.23
1951	12.73	12.87
1952	9.30	9.10
1953	10.77	9.40
1954	9.10	8.79
1955	15.77	15.40
1956	15.30	16.08
1957	16.73	19.34
1958	18.14	20.82
1959	11.38	12.27
1960	17.42	17.87
1961	7.07	8.50
1962	29.56	28.96
1963	21.96	23.23
1964	22.22	22.34
1965	24.54	24.76
1966	22.67	24.24
1967	18.65	21.52
1968	22.64	24.85
1969	28.84	29.16
1970	21.16	23.06
1971	28.56	29.07
1972	28.87	28.43

APPENDIX A (continued)

Year	Control	Target
1973	27.42	30.30
1974	19.64	21.99
1975	23.32	24.17
1976	23.90	25.59
1977	21.06	22.96
1978	28.70	30.53
1979	21.42	21.55
1980	16.43	15.62
1981	25.09	24.91
1982	28.18	29.42
1983	24.64	26.30
1984	24.08	27.21
1985	29.22	31.79
1986	30.73	32.86
1987	24.58	22.96
1988	11.15	10.45

APPENDIX B

Preliminary Target-Control Analysis

In the initial stages of this project, the data for years 1935-1951 first became available in usable form for comparison with the NDCMP years 1976-88. We wanted to get a preliminary feeling for the analysis procedure and typical results, and there was also some reluctance to incorporate a broken series of years. Therefore a preliminary target-control analysis was carried out using just the aforementioned sets of years.

The preliminary target-control scatter plot for wheat yield appears in Fig. B-1. The MRPP test on the residuals about the composite constrained LAD regression line gave P = 0.005. This is clearly small enough to justify determination of separate constrained LAD lines for the two time periods. Those two lines are shown in the figure; the ratio of the slopes is 1.0639/0.9805 = 1.085. This suggested an increase of 8.5% in wheat yield for the target area during the NDCMP treatment period. That figure was used as the basis for the economic analysis presented in Sec. 7.

However, similar tests on residuals about the unconstrained LAD line and the least-squares regression line in this case also do not indicate any significant difference, with the P-values being approximately 0.4. As found in Sec. 4, this is inconsistent with the first result, and yet there is little difference among the three regression lines. That causes similar concern about the sensitivity of the analysis procedure to small differences in already small residuals.

The comparison between this result and that obtained in Sec. 4 may give some indication of the noise level in the analysis here. Comparing Fig. B-1 with Fig. 3 suggests that the difference between the LAD regression lines for the two sets of non-seeded years (1935-51, and the same plus 1955-57 and 1960) is due largely to a single "outlier" year (it happens to be 1957). Such sensitivity to the data for a single year is disconcerting. On the other hand, adding in a further set of years with another similar "outlier" year (this one happens to be 1958) produces essentially no further change (as indicated by comparison of Figs. 3 and 4).

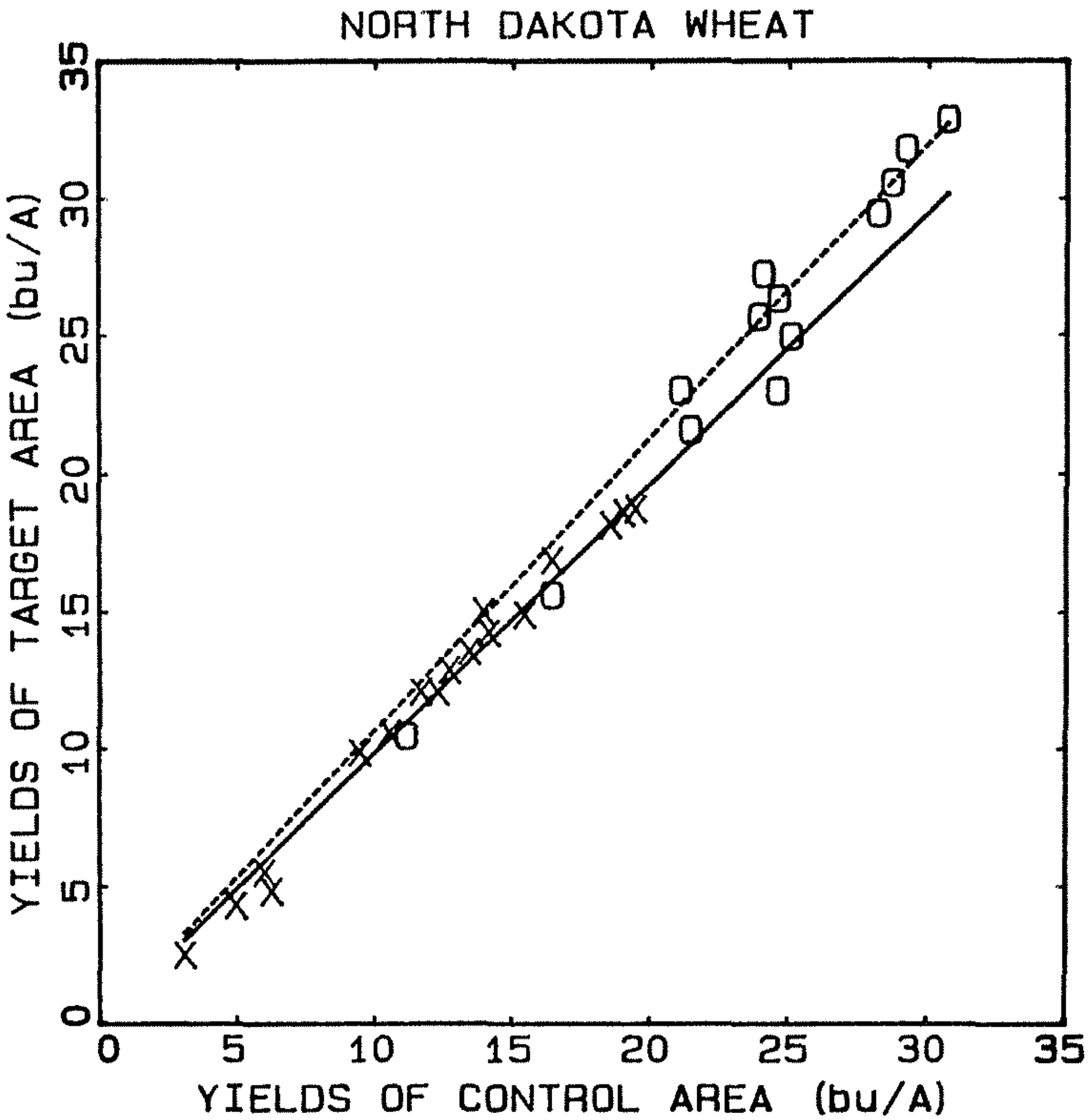

Fig. B-1: Scatter plot of target vs. control area wheat yields. NDCMP (1976-88) are O and constrained LAD regression line is dashed (-----). Historical period (1935-51) are X and constrained LAD regression line is solid (_____).

APPENDIX C

Other Wheat Yield Analyses

This appendix summarizes results of some additional analyses that were carried out in the course of this project.

C.1 Ratio of Harvested to Planted Acres

An analysis of the annual ratios of harvested to planted acreage might indicate the effects of cloud seeding for hail suppression in reducing damaged acreage, and for rainfall enhancement in making additional acreage suitable for harvest (particularly in drought years). These ratios for the target and control areas were therefore examined for the preliminary unseeded years (1935-1951) and for the NDCMP operational years (1976-1988). The great majority of the ratios were found to be very close to unity; 78% of the ratios were greater than 0.92, and the lower values occurred primarily in drought years. Moreover, there was fairly good correlation between target-area and control-area ratios for the years with low values. Consequently the constrained LAD regression line on the target-control scatter plot was forced to be just the 1:1 line, and the methodology used here does not work in that case. The other regression lines on the target-control scatter plot were dominated by the small number of years (usually drought years) with low harvested-to-planted acreage ratios. Consequently this line of investigation proved unproductive.

C.2 "Harvested" vs. "Planted" Yields

The wheat yield values could be calculated by dividing the total production (bushels) by either the number of acres harvested, as in the body of this report, or the number of acres planted. One could argue that the latter might reflect more fully the effects of cloud seeding operations. An analysis comparable to that discussed in Appendix B was carried out using the "planted" yield values. The results, which are illustrated in Fig. C-1, were quite similar to those given in Appendix B: the indicated relative yield increase in the target area during the NDCMP years was 9.3%, with an associated P-value for the basic constrained LAD regression of 0.0052. Here, too, higher P-values (greater than 0.15) resulted when the other regression analyses were used.

It could be argued that the slightly-higher estimate of the yield increase for the planted-acre basis reflects a ratio of harvested to planted acres that must be slightly higher in the target area than in the control area.

PLANTED WHEAT YIELD

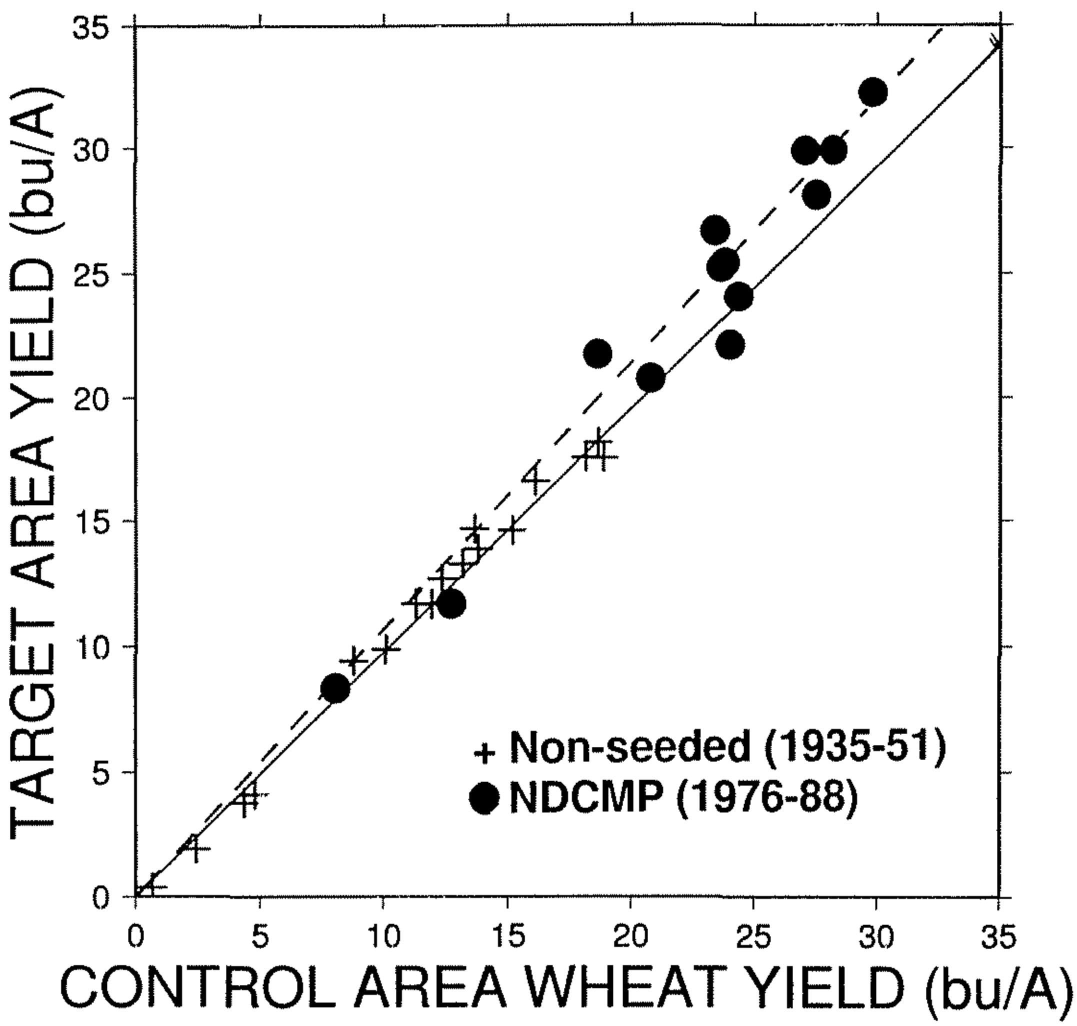

Fig. C-1: Scatter plot of target versus control area "planted" wheat yields. NDCMP period data (1976-88) are indicated by ● and constrained LAD regression line is dashed (-----). The data for the non-seeded years are indicated by X and constrained LAD regression line is solid (_____).

This would be a plausible outcome of effective cloud seeding in the target area.

Because the results for "harvested" and "planted" yields looked essentially the same for this case, no further use was made of the "planted" yield values in subsequent analyses.

C.3 Analyses by Individual Crop Variety

As the working database was being constructed, some preliminary analyses like that reported in Appendix B were conducted using the data for individual crop varieties. Except for the dominant crops discussed in Section 2 of this report, the acreages involved were generally small and there were substantial year-to-year variations in the acreage planted to individual varieties. Consequently the decision was later made to combine all the wheat varieties into the total-yield analysis which is summarized in the body of this report.

For the record, a significant P-value (P = 0.023) was found only for the spring wheat target-control comparison based on the 1935-51 non-seeded versus the 1976-88 NDCMP-period yield values. The indicated relative yield increase in the NDCMP target area for this variety was 3.2%. The P-value for the spring wheat free LAD regression analysis was higher (0.18) here again, so the ambiguity regarding the statistical significance of the result is also present in this case.

C.4 Target/Control Yield Ratio Analysis

Some statisticians favor the use of target/control ratios in evaluating the results of weather modification projects. These ratios have particular meaning if the effects of seeding are expected to be multiplicative (e.g., a 10% increase would be represented by a ratio of 1.10). On the other hand, ratio statistics can be somewhat misleading; a target/control yield ratio of (22 bu/A)/(20 bu/A) = 1.10 is the same as the ratio of (2.2 bu/A)/(2.0 bu/A) = 1.10. However, the significance in terms of agricultural or economic impacts is clearly not the same.

Target/control wheat yield ratios for the non-seeded years (1935-51 plus 1955-57 and 1960) and for the NDCMP period (1976-88) were examined. Figure C-2 shows a "box and whisker" plot indicating the extremes and quartile values for these ratios. Remembering that the sample sizes are relatively small, one can infer that the NDCMP seeding operations had little effect on the first quartile or the upper extreme. However, they seem to have raised the median and third-quartile values as well as the lower extreme yield ratio.

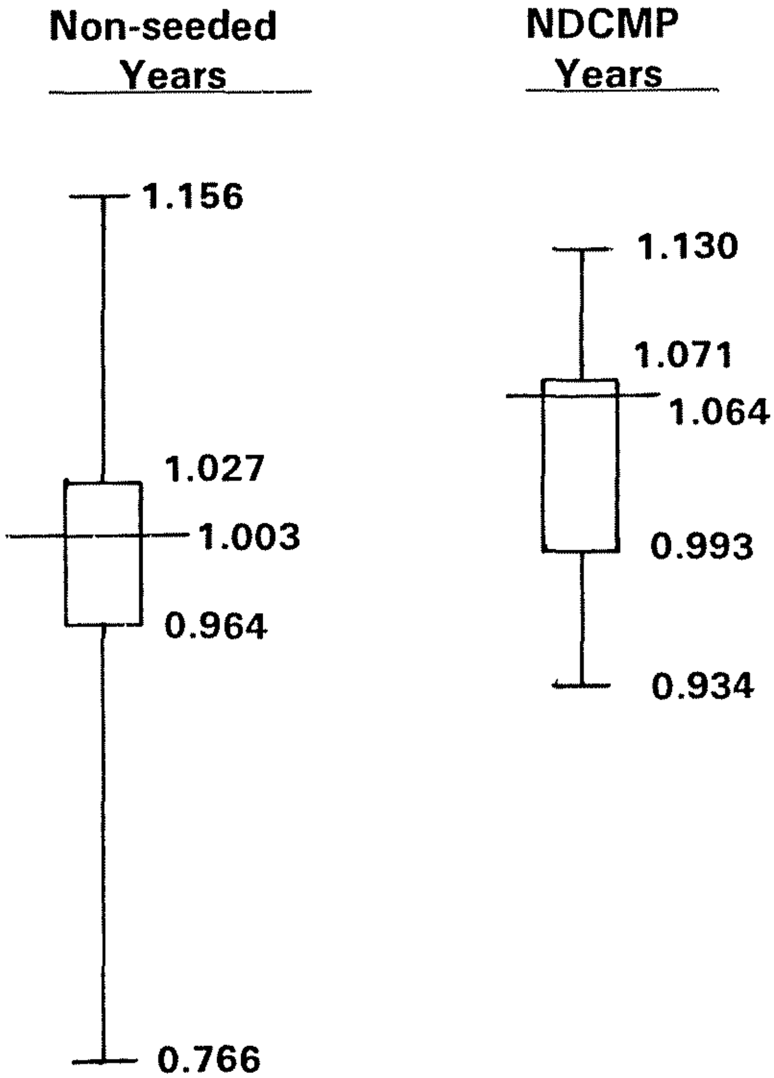

Fig. C-2: Box-and-whisker plot comparing target/control wheat yield ratios for the non-seeded years (1935-51 plus 1955-57 and 1960) vs. the NDCMP period (1976-88).

A Mann-Whitney rank test (results provided by James R. Miller, Jr.) on these yield ratios leads to a P-value of 0.034. This is small enough to suggest a significant difference associated with the NDCMP seeding operations. Such a test, however, provides no estimate of the magnitude of the apparent seeding effect. Mean ratios, which might be used to develop such an estimate, are understood by most weather modifiers to be poorly behaved, in a statistical sense, because their frequency distributions tend to be highly skewed. However, the difference between the median ratios, here 0.061 or 6.1%, can also provide a rough estimate of the effect. This value is quite comparable to the 5.9% estimate obtained from the target-control analysis discussed in Section 4 of this report.