E83-10041

YM-U2-04286
JSC-18233
CR-169549

AgRISTARS

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

JANUARY 1982

Yield Model Development

EVALUATION OF THE WILLIAMS-TYPE SPRING WHEAT MODEL IN NORTH DAKOTA AND MINNESOTA

(E83-10041) EVALUATION OF THE WILLIAMS-TYPE SPRING WHEAT MODEL IN NORTH DAKOTA AND MINNESOTA (National Oceanic and Atmospheric Administration) 45 p HC A03/MF A01 CSCL 02C

N83-13535

Unclas

G3/43 00041

RM. 200, FEDERAL BLDG.
600 E. CHERRY ST.
COLUMBIA, MO 65201

Lyndon B. Johnson Space Center
Houston, Texas 77058

1. Report No. YM-U2-04286 JSC-18233	2. Government Accession No.	3. Recipient's Catalog N
4. Title and Subtitle Evaluation of the Williams-type Spring Wheat Model in North Dakota and Minnesota		5. Report Date January 1982
		6. Performing Organization Code
7. Author(s) Sharon LeDuc		8. Performing Organization Report No YM 1-4-4 (80-01.1)
9. Performing Organization Name and Address NOAA Rm 200, Federal Bldg 600 E. Cherry St. Columbia, MO 65201		10. Work Unit No.
		11. Contract or Grant No
12. Sponsoring Agency Name and Address NOAA JSC/SK Houston, TX 77058		13. Type of Report and Period Covered Technical Report
		14. Sponsoring Agency Code SK
15. Supplementary Notes		

16. Abstract

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This research was conducted as part of the AgRISTARS Yield Model Development Project. It is part of Task 4 (Subtask 1) in Major Project Element Number 1.

17. Key Words (Suggested by Author(s)) Model evaluation yield modeling test criteria		18. Distribution Statement	
19. Security Classif. (of this report) Unclass.	20. Security Classif. (of this page) Unclass.	21. No. of Pages 44	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

EVALUATION OF THE WILLIAMS-TYPE SPRING WHEAT MODEL IN NORTH DAKOTA AND MINNESOTA

by

SHARON LEDUC

This research was conducted as part of the AgRISTARS Yield Model Development Project. It is part of task 4 (subtask 1) in major project element number 1, as identified in the 1981 Yield Model Development Project Implementation Plan. As an internal project document, this report is identified as shown below.

AgRISTARS
Yield Model Development
Project

YMD 1-4-1 (82-01.1)

Evaluation of the Williams-Type Spring Wheat Model in North Dakota and Minnesota. By Sharon LeDuc, Center for Environmental Assessment Services, Environmental Data and Information Services, National Oceanic and Atmospheric Administration, Columbia, Missouri, January, 1982.

ABSTRACT

The Williams-Type Model was developed similarly to previous models of G.V.D. Williams. The models use monthly temperature and precipitation data as well as soil and topological variables to predict the yield of the spring wheat crop. The models are statistically developed using the regression technique. Eight model characteristics are examined in the evaluation of the model. Evaluation is at the crop reporting district level, the state level and for the entire region. A ten year bootstrap test was the basis of the statistical evaluation. The accuracy and current indication of modeled yield reliability could show improvement. There is great variability in the bias measured over the districts, but there is a slight overall positive bias. The model estimates for the east central crop reporting district in Minnesota are not accurate. The estimates of yield for 1974 were inaccurate for all of the models.

Key words: Model evaluation, yield modeling, test criteria.

Acknowledgements

The author wishes to thank Tom Barnett, who developed the models, for his cooperation and help. Comments and reviews from members of the Modeling Center were incorporated. Leslie Wolk is commended for her art work. My sincere appreciation is extended to Susan Conrad for her fine typing and patience.

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SUMMARY

The Williams-type model is derived from a stepwise regression approach using yield for individual crop reporting districts as the dependent variable combined in the same model and monthly weather variables and crop district specific soil texture and topography variables as the independent variables. Functions of the year surrogate variables, to account for technological changes, were also incorporated as explanatory variables. The model is objective, adequate, timely, simple and low in cost. The relation between yield and the predictor variables is consistent with scientific knowledge. The accuracy and current indication of modeled yield reliability could use improvement. There is a slight overall positive bias but quite a large range of values over the CRDs. The model estimates for Minnesota CRD 40 were not accurate. The yield estimate for 1974 was not accurate for any of the areas.

Description of Model

A model for analyzing the effects of weather and soil variables on Canadian spring wheat yields was described by Williams, et. al. (1975). The model falls under the general classification of "statistical - empirical regression models." The models for Canadian wheat, barley, and rye pooled crop district weather and agronomic data to larger soil-color regions and incorporated soil texture and topographic information along with trend and weather.

A predictive yield model for spring wheat in North Dakota and Minnesota, based on the concepts outlined by Williams, et. al., was developed and tested by the Yield Model Development group. This Williams-type model incorporated CRD-level weather (monthly mean temperature and total precipitation), soil texture, and topography in a manner as similar as possible to that used by Williams. The CRD-level data were pooled to the following two more-or-less environmentally homogeneous regions:

(a) Red River Valley consisting of ND CRD's 30 & 60 and MN CRD's 10 & 40;

(b) North Dakota remainder consisting of ND CRD's 10, 20, 40, 50, 70, 80 & 90.

Separate models were developed for the two regions to provide predictions of CRD yields using individual CRD weather/soil data with coefficients from the pooled model. Models were also developed for the two states, ND and MN, based on state-aggregated data for weather.

Models were developed on the basis of data available, i.e., 1932 through 1979 for North Dakota and 1936 through 1979 for Minnesota. The number of observations were similar for the two regions. The terms were selected from stepwise regressions from which the first ten (or fewer) terms entered by stepwise selection were retained for each region. A limit of 10 terms had been used by Williams et. al., and seemed to be a reasonable upper limit here as well. Selected variables and the range of the coefficients are given in Appendix 2. The basic variables which differ slightly from those considered by Williams were:

(1) monthly mean temperature;

(2) total monthly precipitation;

(3) percent of soils in the CRD in textural classes coarse, medium, and fine;

(4) percent of CRD area in the topographic classes level to gently undulating;

(5) year as surrogate for technological, etc., trend.

These basic inputs are used to calculate the possible model variables:

Trend 1, linear between 1955 and 1966;

Trend 2, linear between 1955 and 1978;

TX = .75 (% fine soil) + .65 (% medium textured soil) + .35 (% coarse-textured soil); and were determined by scientist at Johnson Space Center through Buck Rogers, USDA;

TXSQ = TX squared;

Tp = % of area level to gently undulating;

TOPSQ = Tp squared;

C = precipitation Sept. - Apr.;

C squared;

E5, E6, E7 = potential evapotranspiration calculated by the Thornthwaite method (1948) for May PET5, June PET6, July PET7

E5, E6, E7 squared, i.e. PET5SQ,

D6, D7* = moisture deficits = E - precip. for June, July;

D5, D6, D7 squared, i.e., DEF6SQ, DEF7SQ;

DEFSEA = seasonal deficit = D5 + D6 + D7 - C: or potential evapotranspiration May through July minus the precipitation from September through July.

DEFSEASQ = DEFSEAS squared;

TXDS = (TX times DEFSEA) squared

* D5 not used since D5, D6, D7, C and DEFSEAS are not all linearly independent. Of these, the stepwise regression selected 10 terms or less for each region. Variables E6, E7, D5 and C were not in Williams' model. The cumulative precipitation was for the 21 months prior to planting.

Ten years (1970-79) were used for testing each model's predictive performance in a manner similar to the way the models are applied in practice. All years following and including the test year were not used in calculating the regression coefficients. This was done for each successive test year. Appendix 2 shows the terms included in each model and the range of coefficients as estimated from the 10 trials. There are some general patterns but wide diversity in detail, reflecting both real and random region-to-region variations. "Growing conditions during these ten years are shown in Appendix 3.

Only end-of-season models were tested, although "truncated" models providing yield estimates at the end of each month throughout the growing season were developed.

Variables selected included one trend for all models. The range on these coefficient estimates is shown in Appendix 2 variables selected are also shown there. Variables in the state models differed from those in CRD models since texture variables were constant in state models. The estimates of the coefficients for the meteorological variables showed stability in the ten year test period.

EVALUATION METHODOLOGY

Eight Model Characteristics to be Discussed

The document, Crop Yield Model Test and Evaluation Criteria, (Wilson, et al., 1980), states:

> The model characteristics to be emphasized in the evaluation process are: yield indication reliability, objectivity, consistency with scientific knowledge, adequacy, timeliness, minimum costs, simplicity, and accurate current measures of modeled yield reliability.

Each of these characteristics will be discussed with respect to the Williams-type spring wheat model.

Bootstrap Technique Used to Generate Indicators of Yield Reliability

Indicators of yield reliability (reviewed below) require that the parameters of the regression model be computed for a set of data and that a yield prediction be made based on that data for a given "test" year. The values required to generate indicators of yield reliability include the predicted yield, $\hat{Y}$, the actual (reported) yield, Y, and the difference between them, $d = \hat{Y}-Y$, for each test year. It is desirable that the data used to generate the parameters for the model not include data from the test year.

In order to accomplish this, the "bootstrap" technique is used. Years from an earlier base period are used to fit the model and obtain a prediction equation. The values of the independent variables for the test year immediately following the base period are inserted into the equation and a predicted yield is generated. Then, the base period is shifted one year forward and the process is repeated. Continuing in this way, ten (1970-1979) predictions of yield are obtained, each independent of the data used to fit the model. Results are shown in Appendix 1 and growing conditions are included in Appendix 4.

The $\hat{Y}$ and d values for each year and for each CRD are obtained from models derived at this level. A $\hat{Y}$ and d value for the state yield is derived from a state level model. Another set of $\hat{Y}$ values are obtained at the state level by using a weighted average of the predicted yields from the CRD models. Predicted yields for the region are also obtained using a weighted average of the predicted yields from the CRD models and from the state models. The weighting factor used is harvested acreage for the year of the prediction.

For North Dakota and Minnesota, data prior to 1969 (39 years) are used to fit prediction models for 1970, etc. The yield of all spring wheat is used as the dependent variable, i.e., durum plus other spring wheat. The average and percent production and the yield over the ten year test period are listed in Table 1 for each geographic region. The percentage of regional production contributed by each CRD is shown graphically in Figure 1. Darker shades indicate higher production. Historic yields are in Appendix 5.

Review of Indicators of Yield Reliability

The Y, $\hat{Y}$ and d values for the ten-year test period for each geographic area may be summarized into various indicators of yield reliability.

Indicators Based on the Differences between Y and $\hat{Y}$ (d) Demonstrate Accuracy, Precision and Bias

From the d value, the mean square error (root and relative root mean square error), the variance (standard deviation and relative standard deviation), and the bias (its square and the relative bias) are obtained.

The root mean square error (RMSE) and the standard deviation (SD) indicate the accuracy and precision of the model and are expressed in the original units of measure (quintals/hectare). It is about 68% probable that the absolute value of d for a future year will be less than one RMSE and 95% probable that it will be less than twice the RMSE. So, accurate prediction capability is indicated by a small RMSE.

A non-zero bias means the model is, on the average, overestimating the yield (positive bias) or underestimating the yield (negative bias). The SD is smaller than the RMSE when there is non-zero bias and indicates what the RMSE would be if there were no bias. If the bias is near zero, the SD and the RMSE will be close in value. We prefer an unbiased model, i.e., bias close to zero.

Indicators Based on Relative Differences Between Y and $\hat{Y}$ (rd) Demonstrate Worst and Best Performance

The relative difference, rd=(100d/Y), is an especially useful indicator in years where a low actual yield is not predicted accurately. This is because years with small observed actual yields and large differences often have the largest rd values.

Several indicators are derived using relative differences. In order to calculate the proportion of years beyond a critical error limit, we count the number of years in which the absolute value of the relative difference exceeds the critical limit of 10 percent. Values between 5 and 25 percent were investigated and a critical limit of 10 percent was found most useful in describing model performance. The worst and next to worst performances during the test period are defined as the largest and next to largest absolute value of the relative difference. The range of yield indication accuracy is defined by the largest and smallest absolute values of the relative difference.

Indicators Based on Y and $\hat{Y}$ Demonstrate Correspondence Between Actual and Predicted Yields

Another set of indicators demonstrates the correspondence between actual and predicted yields. It would be desirable for increases in actual yield to be accompanied by increases in predicted yields. It would also be desirable for large (small) actual yields to correspond to large (small) predicted yields.

Two indicators relate the change in direction of actual yields to the corresponding change in predicted yields. One looks at change from the previous year (nine observations) and the other at change from the average of the previous three years (seven observations). A base period of three years is used since a longer base period would further decrease the number of observations, while a shorter period would not be very different from the comparison to a single previous year.

Finally, the Pearson correlation coefficient, r, between the set of actual and predicted values for the test years is computed. It is desirable that $r(-1 \leq r \leq +1)$ be large and positive. A negative r indicates smaller predicted yields occurring with larger observed yields (and vice versa).

Spring Wheat Production contributed by individual CRDs (1970-79 average). Darker shades indicate higher production.

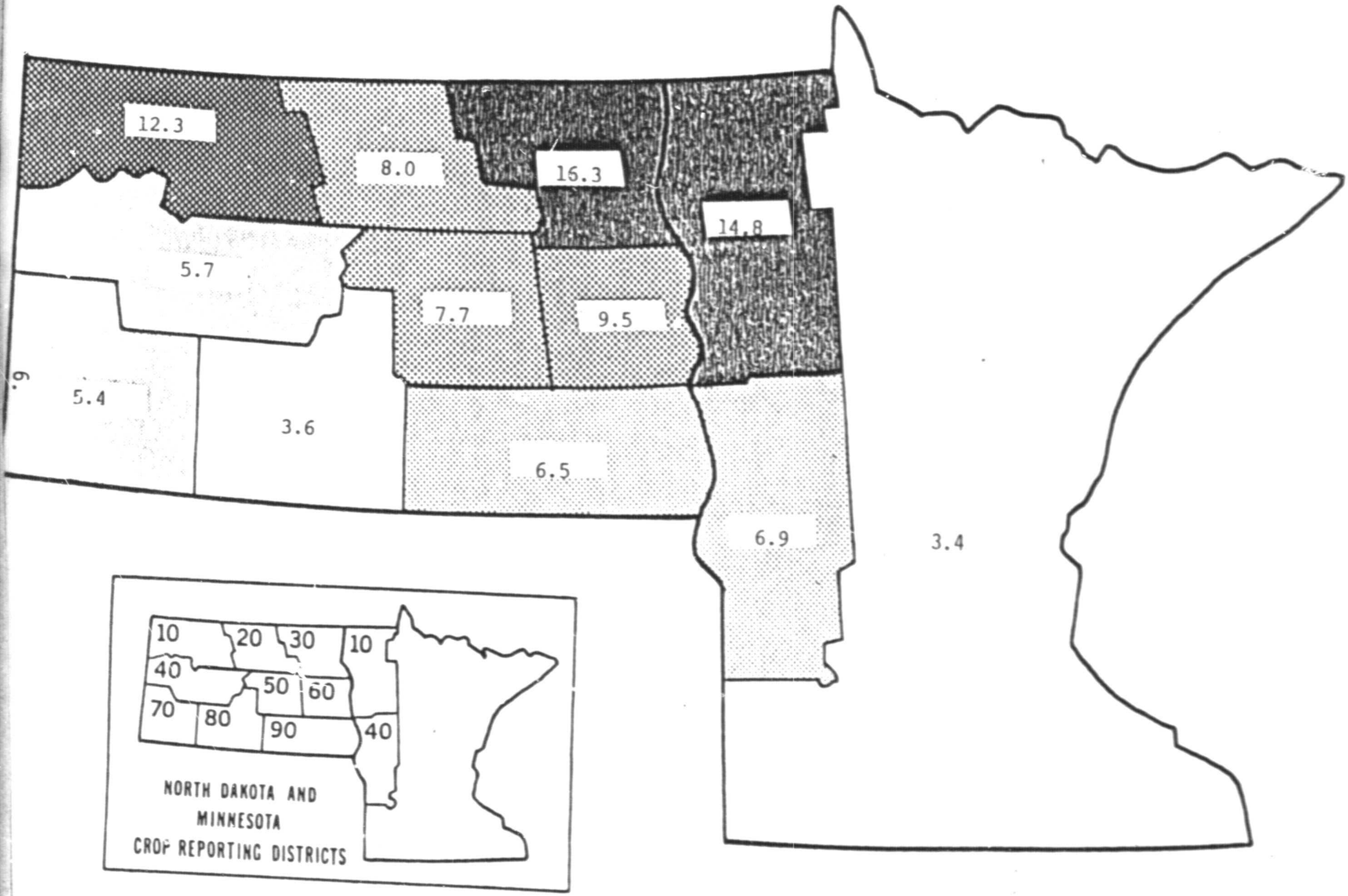

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TABLE 1
AVERAGE PRODUCTION AND YIELD
FOR TEST YEARS 1970-79

SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	PRODUCTION (1,000) QUINTALS	BUSHELS	PERCENT OF STATE	REGION	YIELD QNTL/HA	BU/ACRE
N.DAKOTA	10	10,803	39,693	16.5	12.3	17.8	26.5
	20	6,985	25,664	10.6	8.0	17.1	25.5
	30	14,255	52,378	21.7	16.3	20.7	30.8
	40	4,965	18,242	7.6	5.7	16.7	24.8
	50	6,769	24,873	10.3	7.7	16.7	24.8
	60	8,280	30,422	12.6	9.5	20.3	30.3
	70	4,756	17,474	7.2	5.4	16.4	24.3
	80	3,123	11,473	4.8	3.6	13.1	19.5
	90	5,676	20,855	8.7	6.5	16.1	23.9
STATE		65,611	241,075		74.9	17.7	26.4
MINNESOTA	10	12,984	47,707	59.0	14.8	23.7	35.2
	20	131	480	0.6	0.1	19.4	28.8
	30	4	14	0.0	0.0	17.9	26.6
	40	6,025	22,136	27.4	6.9	20.6	30.6
	50	1,231	4,523	5.6	1.4	22.7	33.7
	60	43	158	0.2	0.0	20.0	29.7
	70	660	2,424	3.0	0.8	21.9	32.6
	80	664	2,441	3.0	0.8	24.2	35.9
	90	255	936	1.2	0.3	22.0	32.7
STATE		21,996	80,820		25.1	22.8	33.9
REGION		87,607	321,894			18.8	27.9

Current Measure of Modeled Yield Reliability Defined by a Correlation Coefficient

One of the model characteristics to be evaluated is its ability to provide an accurate, current measure of modeled yield reliability. Although a specific statistic was not discussed in the paper, Crop Yield Model Test and Evaluation Criteria (Wilson, et al., 1980), it was stated that:

> This 'reliability of the reliability' characteristic can be evaluated by comparing model generated reliability measures with subsequently determined deviation between modeled and 'true' yield.

For regression models, this suggests the use of a correlation coefficient between two variables generated for each test year. One variable is an indicator of the precision with which a prediction for the next year can be made. It is based on the model development base period as applied to test year independent variable values. The other variable (obtained retrospectively) is an indicator of how close the predicted value for the next year actually is to the "true" value. The estimate of the standard error of a predicted value from the base period model as applied to the test year is used for the first value, s_y, and the absolute value of the difference between the predicted and actual yield in the test year is used as the second variable, $|d|$.

A non-parametric (Spearman) correlation coefficient, r, is employed since the assumption of bivariate normality cannot be made. A positive value of r(-1   r+ 1) indicates agreement between s_y is associated with a small (larger) value $|d|$. An r value close to +1 is desirable since it indicates that a small standard error pf prediction (and therefore a narrow confidence interval about the predicted yield) is associated with small discrepancies between predicted and actual yields. If this were the case, one would have confidence in s_y as an indicator of the accuracy of Y.

MODEL EVALUATION

Indicators of Yield Reliability Based on Differences Between Y and Y (d) Show Wide Range in Bias and Root Mean Square Error

The CRD, state and region values of indicators of yield reliability based on d for this simple linear model are given in Table 2. The bias for CRDs is less than one quintal per hectare with the exception of the two Minnesota crop reporting districts and 80 in North Dakota. The CRDs have a relative bias of less than ten percent with the exception of the south central CRD in North Dakota and in Minnesota the northwest crop reporting districts.

The root and relative root mean square error values (RMSE and RRMSE) are worse for CRDs in Minnesota and the Southern CRDs, Central and North Central CRDs in North Dakota. Values for RMSE range from 1.49 to 2.76 (Figure 2). Values for RRMSE range from 8.5 percent to 18.3 percent. Generally, the bias is closer to zero but the RMSE in ND is larger for the aggregated CRD estimates than for the state estimates. In Minnesota the state model is better in both respects. The CRD model estimates aggregated to the regional level have a similar RMSE and show more bias than the aggregated state model estimates.

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TABLE 2
INDICATORS OF YIELD RELIABILITY
BASED ON D = PREDICTED - ACTUAL YIELD

WILLIAMS TYPE MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

MSE, VAR, B-SQR (QUINTALS/HECTARE SQUARED)
RMSE, SD, BIAS (QUINTALS/HECTARE)
RRMSE, RSD, RB (PERCENT OF AVERAGE YIELD)

STATE	CRD	MSE	RMSE	RRMSE	VAR	SD	RSD	B-SQR	BIAS	RB
N.DAKOTA	10	2.68	1.64	9.2	2.16	1.47	8.6	0.52	-0.72	-4.0
	20	4.01	2.00	11.7	3.33	1.83	11.2	0.67	-0.82	-4.8
	30	3.67	1.91	9.3	3.50	1.87	9.2	0.17	-0.41	-2.0
	40	2.22	1.49	8.9	2.12	1.45	8.9	0.10	-0.32	-1.9
	50	5.90	2.43	14.6	5.07	2.25	14.3	0.83	-0.91	-5.5
	60	3.02	1.74	8.5	2.20	1.48	7.6	0.83	-0.91	-4.5
	70	2.93	1.71	10.5	2.91	1.71	10.3	0.02	0.15	0.9
	80	5.77	2.40	18.3	2.16	1.47	9.8	3.61	1.90	14.5
	90	4.11	2.03	12.6	4.11	2.03	12.6	0.00	0.01	0.1
STATE MODEL		2.52	1.59	9.0	2.51	1.59	9.0	0.01	-0.09	-0.5
CRDS AGGR.		1.95	1.40	7.9	1.82	1.35	7.8	0.12	-0.35	-2.0
MINNESOTA	10	8.52	2.92	12.3	2.66	1.63	7.7	5.86	-2.42	-10.2
	40	14.15	3.76	18.3	11.81	3.44	18.1	2.34	-1.53	-7.4
STATE MODEL		3.63	1.90	8.4	3.09	1.76	7.5	0.53	0.73	3.2
CRDS AGGR.		7.60	2.76	12.2	3.11	1.76	8.6	4.49	-2.12	-9.4
REGION										
CRDS AGGR.		2.15	1.47	7.9	1.64	1.28	7.1	0.50	-0.71	-3.8
STATES AGGR.		2.07	1.44	7.7	2.06	1.44	7.6	0.01	0.09	0.5

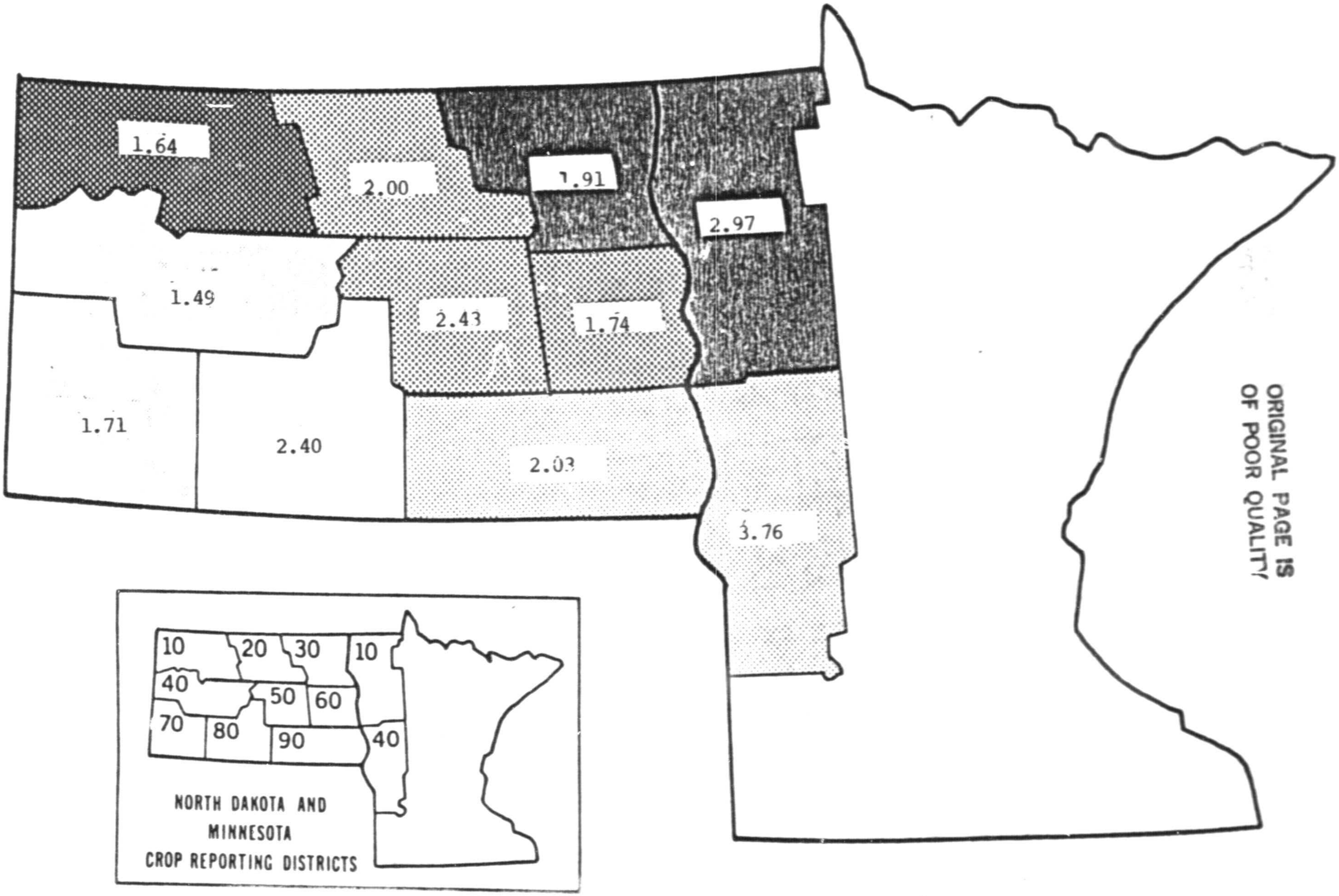

Figure 2. Root mean square error (RMSE) for Spring Wheat, quintals per hectare, based on test years 1970-79. Darker shades indicate CRDs with higher production.

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TABLE 3
INDICATORS OF YIELD RELIABILITY
BASED ON RD = 100 * ((PREDICTED-ACTUAL YIELD)/ACTUAL YIELD)

WILLIAMS TYPE MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	PERCENT OF YEARS |RD|>10%	LARGEST |RD| RD	(YEAR)	NEXT LARGEST	SMALLEST |RD|	RANGE |RD|
N.DAKOTA	10	30	-17.9	(1973)	-11.0	-1.7	16.2
	20	40	23.3	(1974)	-16.2	0.0	23.3
	30	30	21.6	(1974)	-16.0	-0.5	21.1
	40	30	24.1	(1974)	-11.3	0.0	24.1
	50	40	32.5	(1974)	-24.4	-2.2	30.3
	60	30	-13.7	(1979)	-13.5	-2.2	11.5
	70	50	-15.7	(1973)	12.8	3.9	11.8
	80	70	47.1	(1974)	28.2	5.3	41.8
	90	40	21.7	(1974)	-19.5	-4.2	17.5
STATE MODEL		30	23.4	(1974)	-11.4	0.5	22.9
CRDS AGGR.		20	17.5	(1974)	-13.1	-1.3	16.3
MINNESOTA	10	50	-16.7	(1971)	-15.0	0.5	16.2
	40	50	-29.7	(1977)	-24.3	-2.7	27.0
STATE MODEL		20	12.8	(1978)	10.0	2.7	10.1
CRDS AGGR.		40	-18.3	(1973)	-18.0	-0.5	17.7
REGION							
CRDS AGGR.		30	-13.2	(1971)	12.2	-1.2	11.9
STATES AGGR.		30	19.5	(1974)	-10.5	0.0	19.5

Figure 3. Percent of test years (1970-79) the absolute value of the relative difference is greater than ten percent for spring wheat. Higher production is indicated by darker shades.

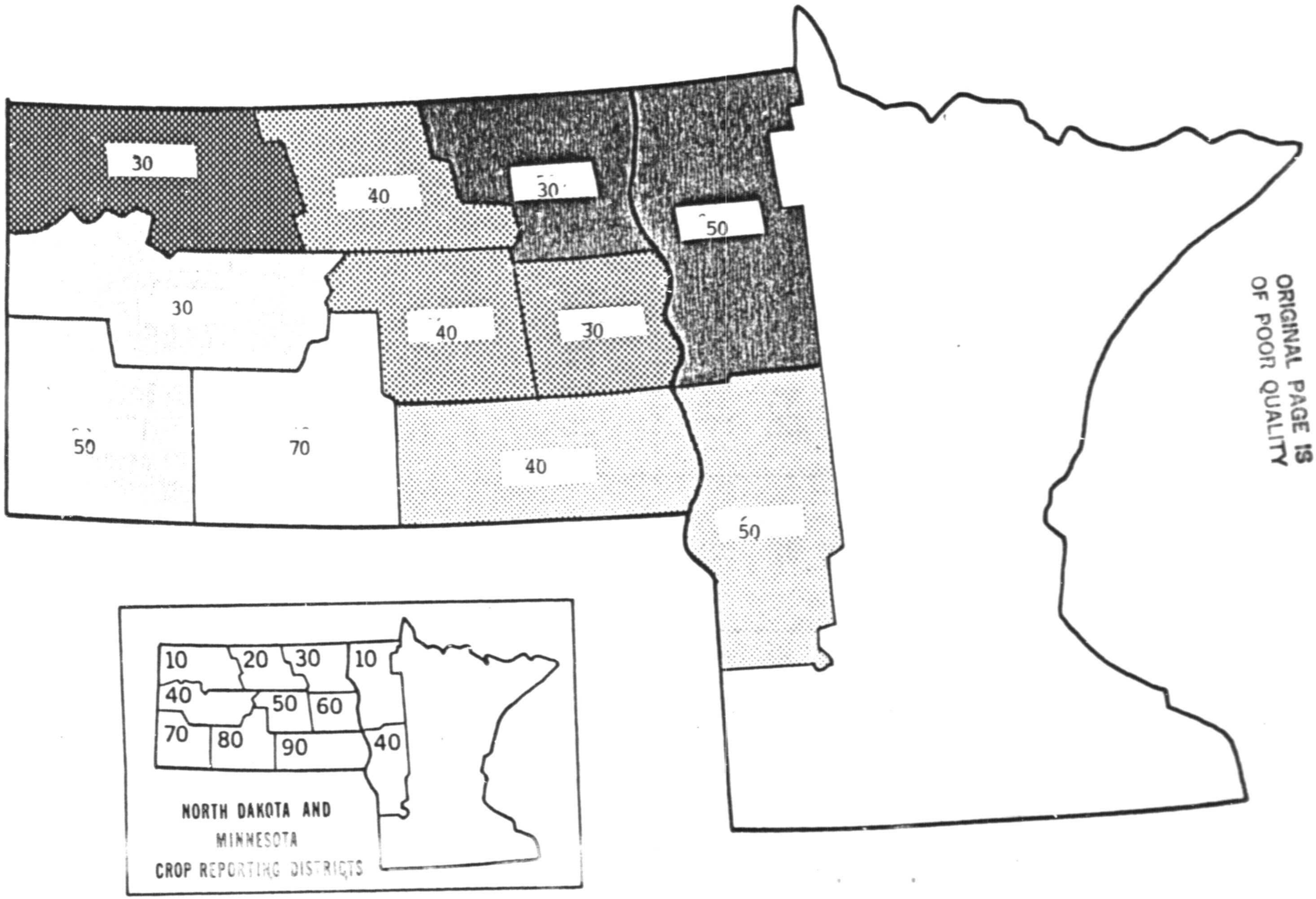


Figure 4. Largest absolute value of the relative difference for Spring Wheat during the test years 1970-79. Darker shades indicate higher production.

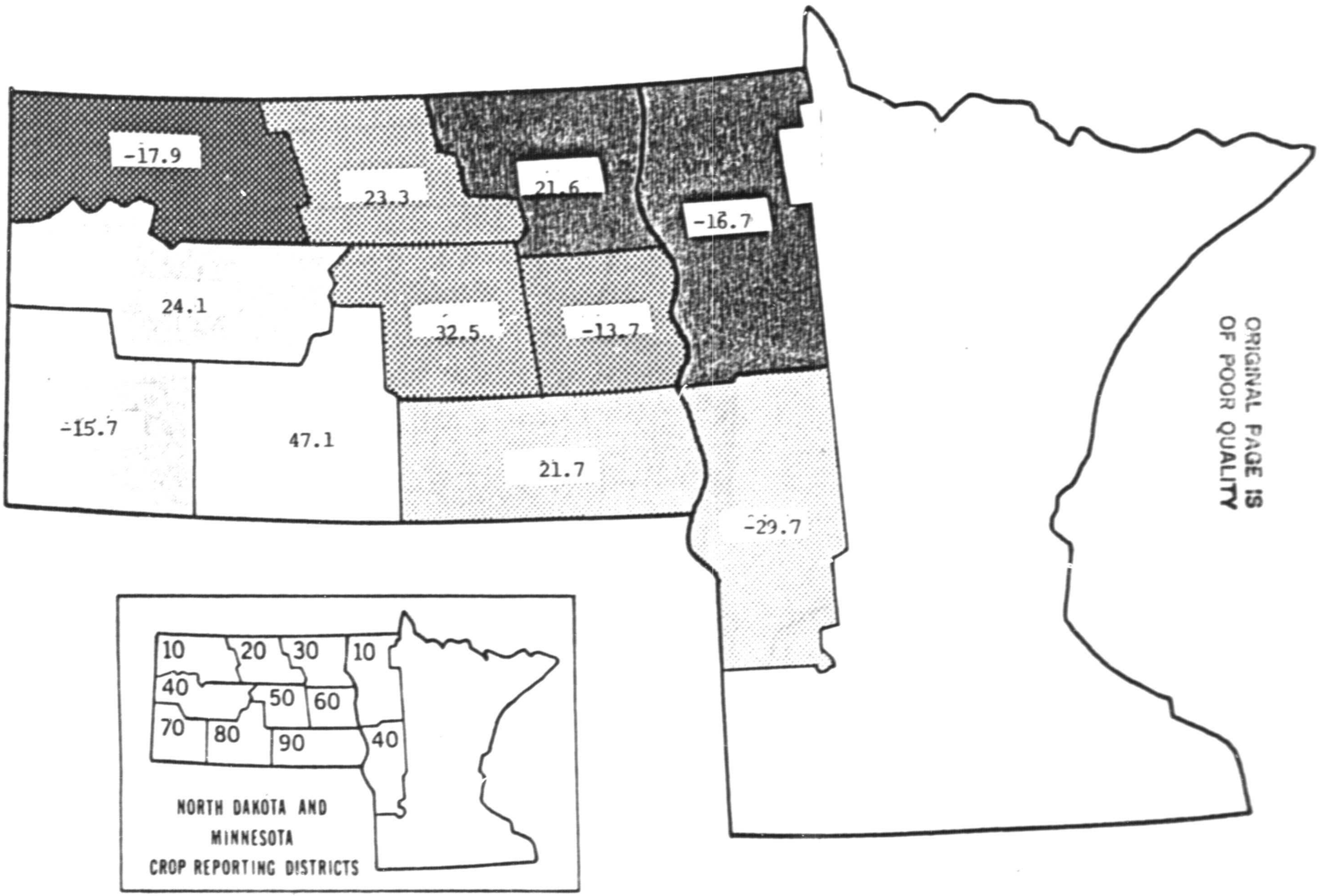
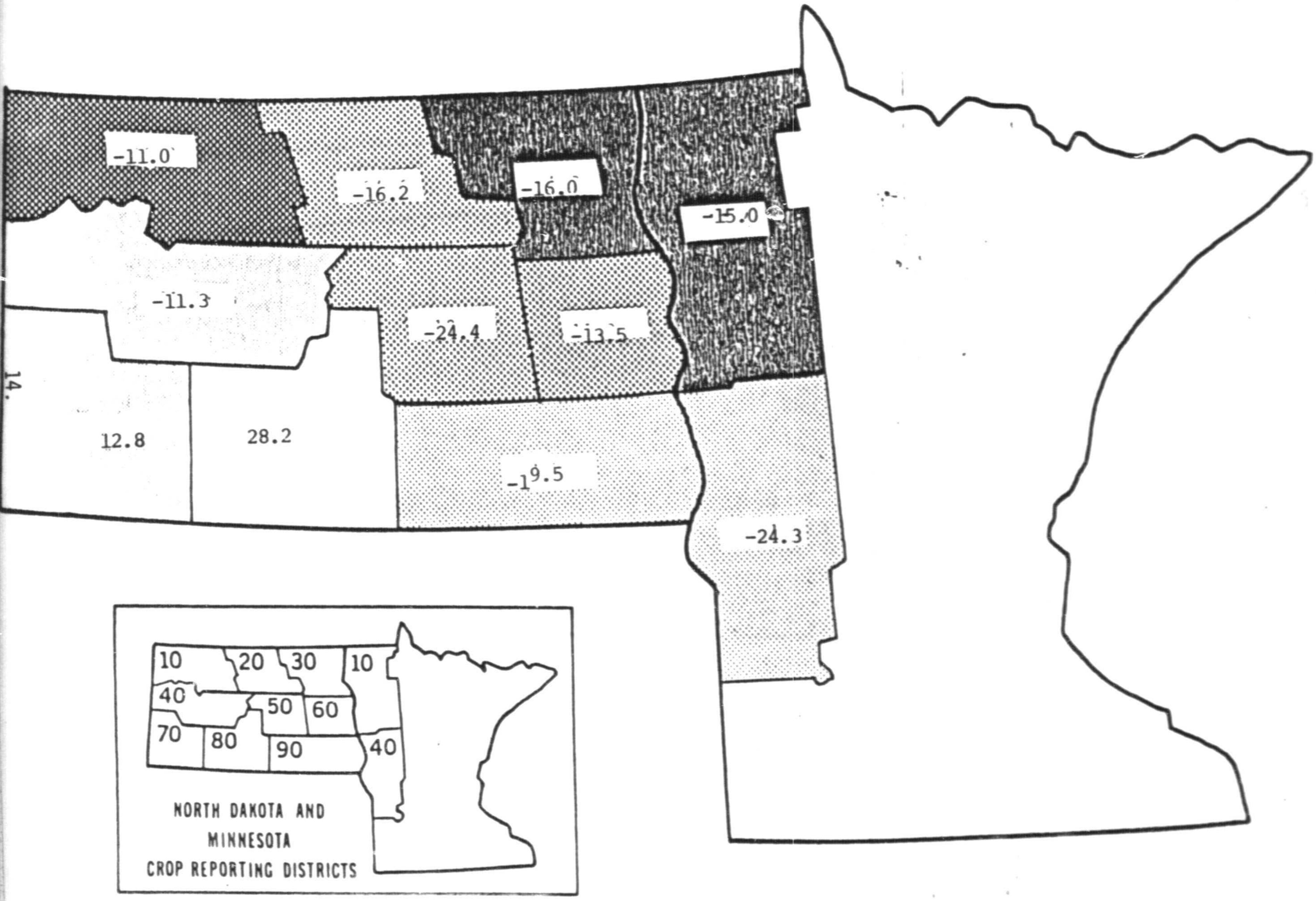


Figure 5. Next largest absolute value of the relative difference for Spring Wheat during the test years 1970-79. Darker shades indicate CRDs with high production.



Indicators of Yield Reliability Based on Relative Differences Between Y and Y (rd) Show 1974 as Worst Year and 20-70 Percent of the Years have rd Greater than 10 Percent

The CRD, state and region values for indicators of yield reliability based on rd are given in Table 3. CRD values are shown in Figures 3-5. Two to six of the ten test years have absolute relative differences greater than 10 percent in most (10 out of 11) of the CRDs. Failure in predicting very low yield in 1974 caused the largest absolute relative difference for most CRD's. The largest absolute relative difference ranged from 16.7 percent to 47.1 percent and next largest from 11.0 to 28.2 percent. The smallest absolute relative difference is sometimes zero (two CRDs) and ranged up to 5.3 percent.

As compared to the aggregated CRD results, the state model values for the largest absolute relative differences are somewhat lower in Minnesota but much larger in North Dakota. There are similar number of years with absolute relative differences greater than 10 percent with the aggregation of CRDs and of states to regional level.

Indicators of Yield Reliability Based on Y and $\hat{Y}$ Show Correct Direction of Change Over Half the Time in Comparing Predicted to Actual Yields

Plots of the actual and predicted yields over the ten-year test period using state level models are displayed in Figures 6 and 7. Estimates have little bias in ND. The estimates for Minnesota are better in later year. The CRD, state and region values for indicators of yield reliability based directly on actual and predicted yields are given in Table 4.

In all the CRDs the change in direction of predicted yields agrees with the change in direction of actual yields from the previous year in over half of the test years (Figure 8). When the direction of change is from the average of the three previous years, the direction of change is again in agreement over half the time in all CRDs (Figure 9). Results for the state are mixed. For comparison with the previous year the ND state model is not as good as the aggregated CRDs, but the two methods are similar when comparing to base period. CRDs aggregated are not as good as MN state model but are similar to the state models aggregated to the region. The Pearson r (Figure 10) is positive for all the CRDs. The range of the positive r's is 0.62 to 0.90. State results are worse and regional CRD's aggregated results are better. This indicates that the model will give the correct direction of change over half the time. Only the final yield estimate was tested, thus change of predicted yield from previous forecasts within the current year were not investigated.

Base Period Indicates More Precision Than Independent Tests Can Confirm

Certain statistics generated from the regression analysis of the base period data are often used to provide some indication of expected yield reliability. However, these statistics only reflect how well the model describes the data used to generate the model, i.e., fit of the model, rather than how well the model can predict from independent data. Therefore, it is important to compare these indicators of fit of the model to the independent indicators of yield reliability discussed in the preceding sections. In this way, one can see how these base period indicators of fit of the model do or do not correspond to independent test indicators of yield reliability.

FIGURE 6

NORTH DAKOTA
State Model

Actual and Predicted Yields for
the Test Years 1970-1979

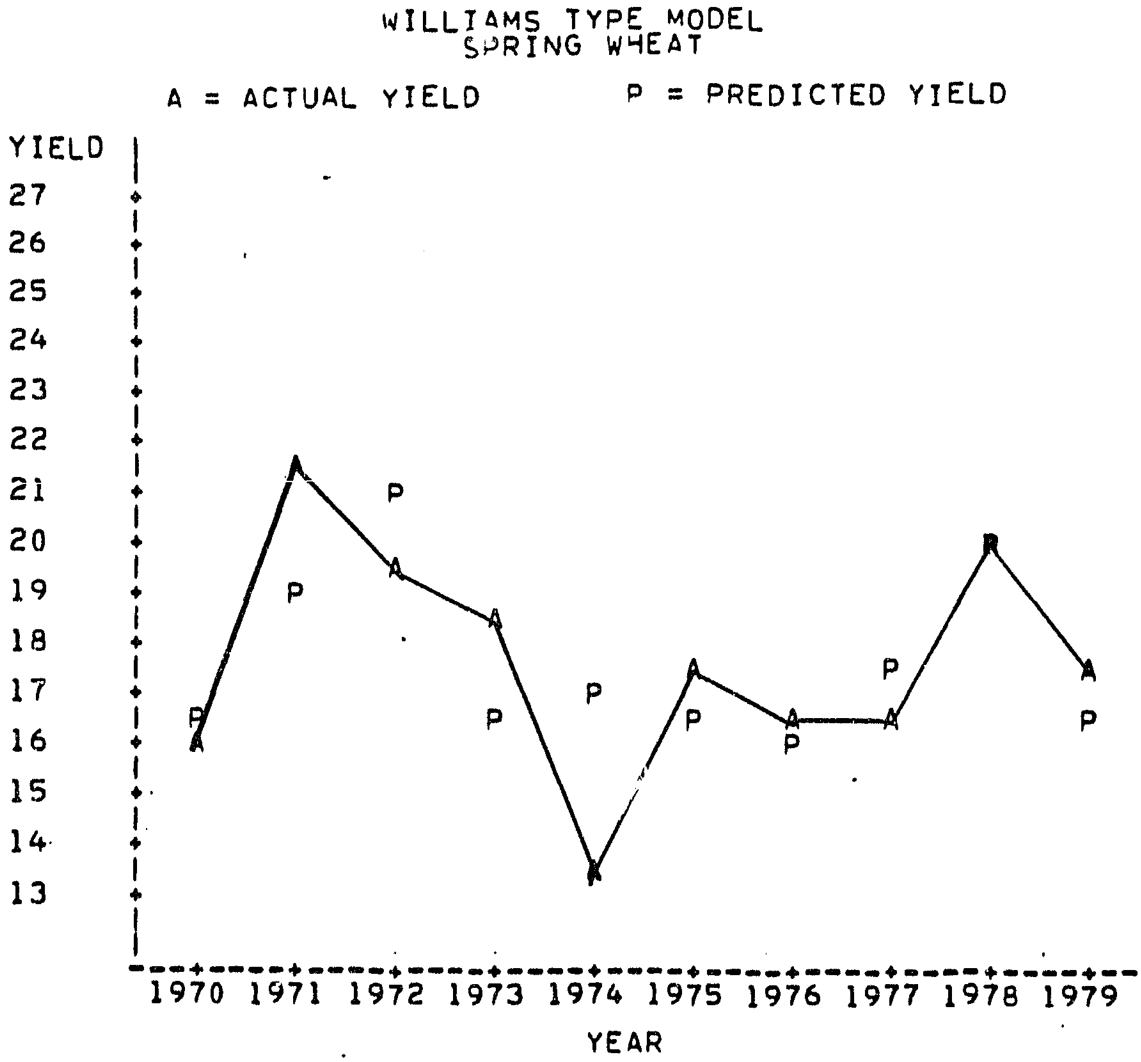


FIGURE 7

MINNESOTA
State Model

Actual and Predicted Yields for the Test Years 1970-1979

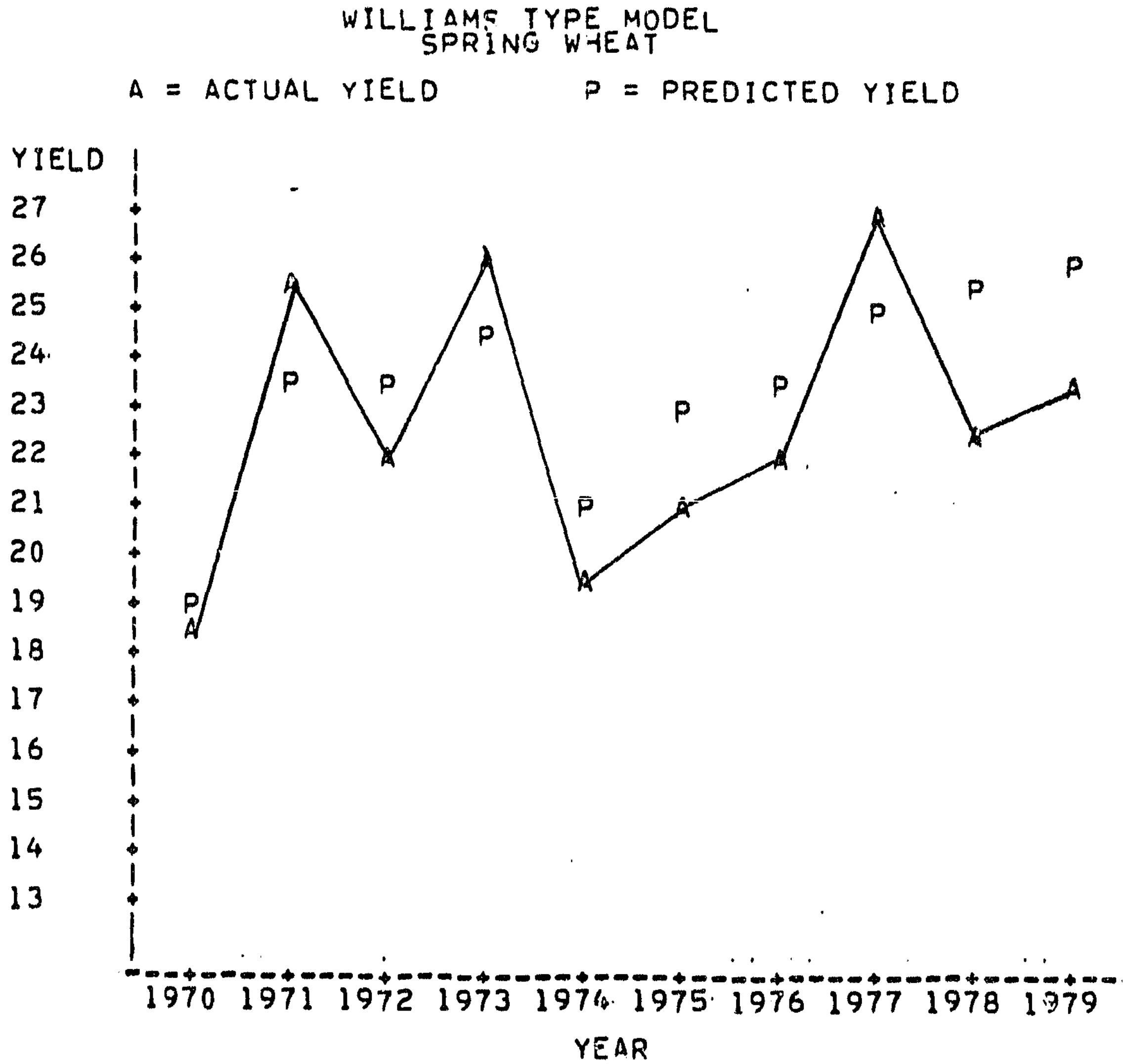


TABLE 4
INDICATORS OF YIELD RELIABILITY
BASED ON ACTUAL AND PREDICTED YIELDS

WILLIAMS TYPE MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE CRD	PERCENT OF YEARS DIRECTION OF CHANGE IS CORRECT FROM PREVIOUS YEAR	FROM BASE PERIOD	PEARSON CORR. COEF.
N.DAKOTA 10	78	71	0.79
20	56	86	0.67
30	67	71	0.62
40	89	71	0.83
50	56	71	0.60
60	89	57	0.82
70	67	57	0.66
80	78	86	0.84
90	67	86	0.64
STATE MODEL	67	71	0.67
CRDS AGGR.	89	71	0.77
MINNESOTA10	67	100	0.90
40	78	86	0.77
STATE MODEL	78	57	0.75
CRDS AGGR.	44	86	0.83
REGION			
CRDS AGGR.	78	86	0.79
STATES AGGR.	78	86	0.70

Figure 8. Percent of test years (1970-79) the direction of change in predicted yield from the previous year agrees with the direction of change in actual Spring Wheat yield. Darker shades indicate CRDs with higher production.

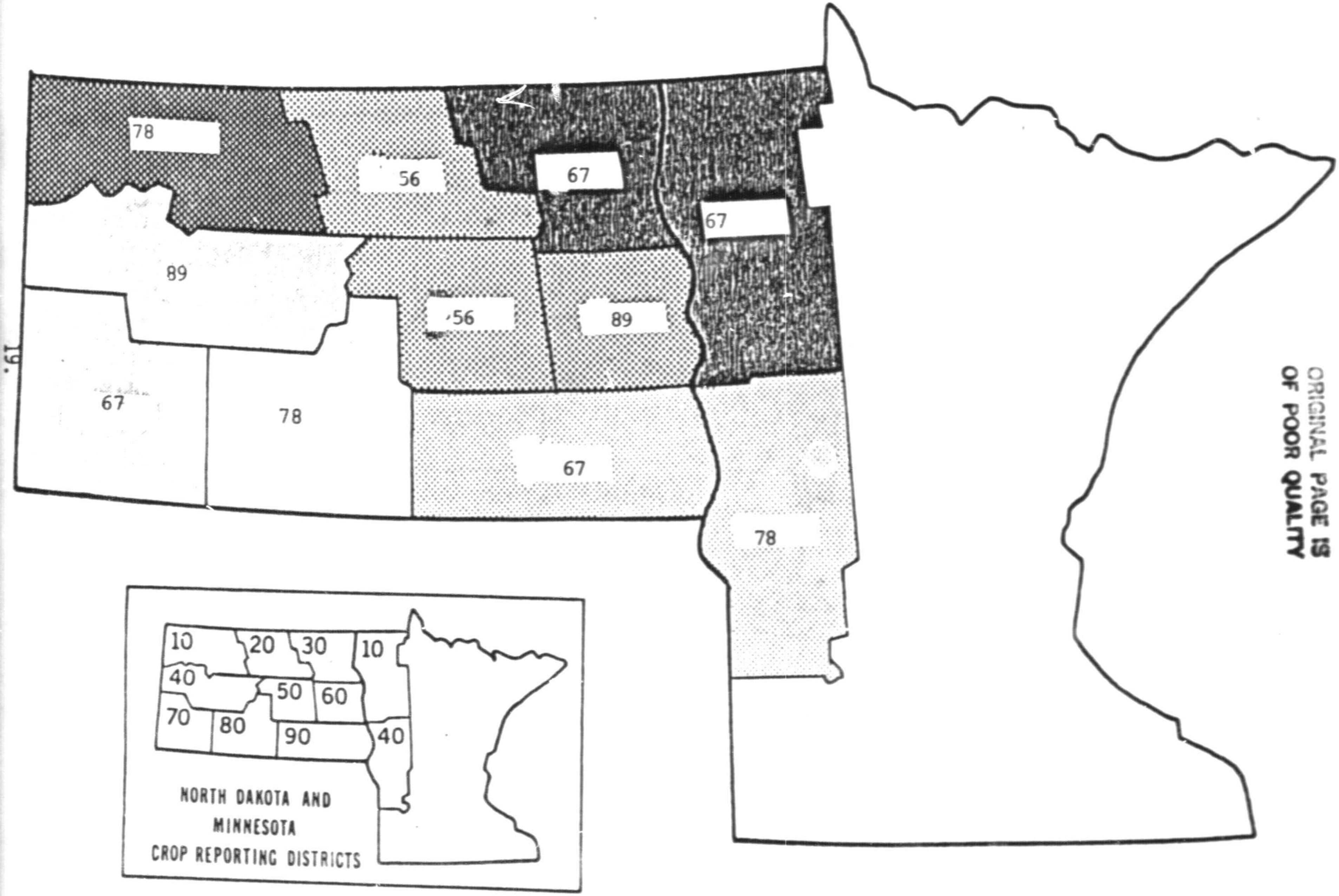
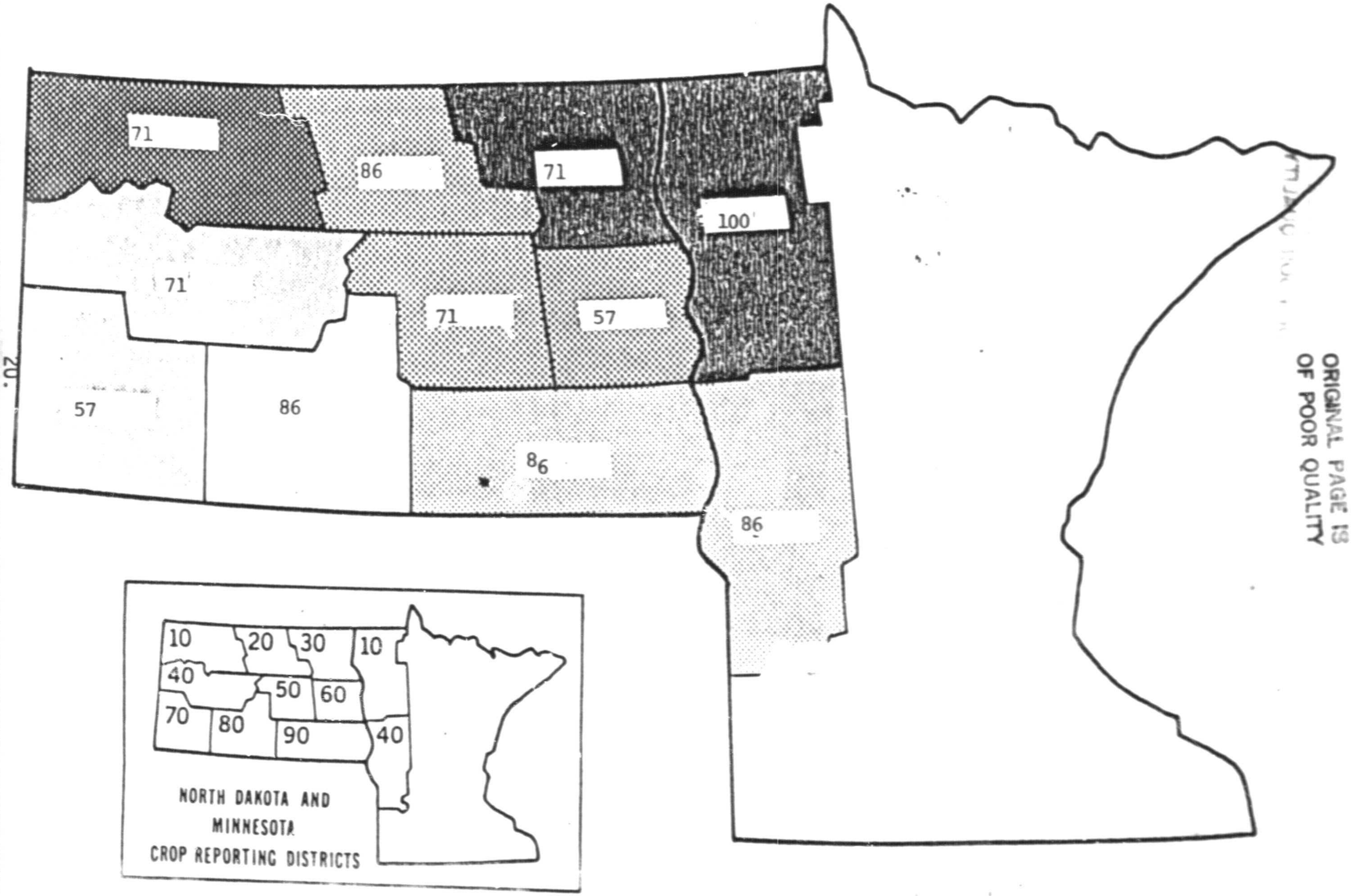


Figure 9. Percent of test years (1970-79) the direction of change in predicted yield from the previous three year average agrees with the direction of change in actual spring wheat yield. Darker shades indicated CRDs with higher production.



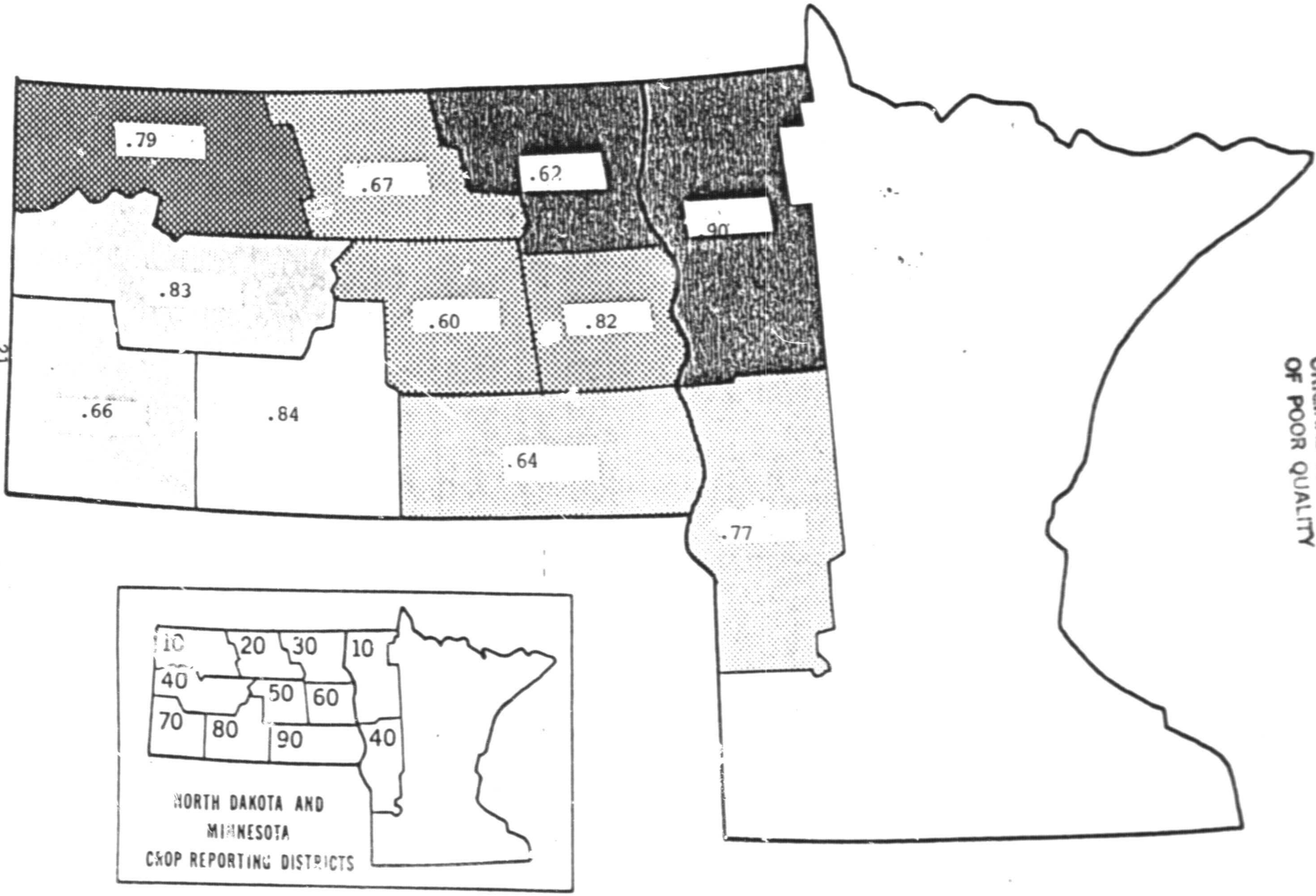


Figure 10. Pearson correlation coefficient between actual and predicted spring wheat yields in test years (1970-79). Darker shades indicate higher production.

TABLE 5
RESIDUAL MEAN SQUARE AS AN
INDICATOR OF THE FIT OF THE MODEL
BASED ON THE MODEL DEVELOPMENT BASE PERIOD

WILLIAMS TYPE MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	BASE PERIOD RESIDUAL MEAN SQUARE LOW	HIGH	AVERAGE	INDEPENDENT TEST MSE
N.DAKOTA	10	4.72	4.98	4.88	2.68
	20	4.72	4.98	4.88	4.01
	30	4.65	5.07	4.83	3.67
	40	4.72	4.98	4.88	2.22
	50	4.72	4.98	4.88	5.90
	60	4.65	5.07	4.83	3.02
	70	4.72	4.98	4.88	2.93
	80	4.72	4.98	4.88	5.77
	90	4.72	4.98	4.88	4.11
STATE MODEL		3.18	3.49	3.36	2.52
MINNESOTA	10	4.65	5.07	4.83	8.52
	40	4.65	5.07	4.83	14.15
STATE MODEL		3.27	3.58	3.37	3.63

TABLE 6
CORRELATION BETWEEN OBSERVED AND PREDICTED YIELDS AS AN
INDICATOR OF THE FIT OF THE MODEL
BASED ON THE MODEL DEVELOPMENT BASE PERIOD

WILLIAMS TYPE MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

TEST STATE	CRD	BASE PERIOD CORRELATION COEF. LOW	HIGH	AVERAGE	INDEPENDENT CORR. COEF.
N.DAKOTA	10	0.88	0.91	0.90	0.79
	20	0.88	0.91	0.90	0.67
	30	0.89	0.92	0.91	0.62
	40	0.88	0.91	0.90	0.83
	50	0.88	0.91	0.90	0.60
	60	0.89	0.92	0.91	0.82
	70	0.88	0.91	0.90	0.66
	80	0.88	0.91	0.90	0.84
	90	0.88	0.91	0.90	0.64
STATE MODEL		0.92	0.94	0.93	0.67
MINNESOTA	10	0.89	0.92	0.91	0.90
	40	0.89	0.92	0.91	0.77
STATE MODEL		0.90	0.94	0.93	0.75

One indicator of yield reliability, the mean square error (MSE), is the sum of squared d values (d = Y-Ŷ) for the independent test years divided by the number of test years (Table 2). The direct analogue for the model development base period is the residual mean square. The residual mean square is obtained by first generating the usual least squares prediction equation using the base period years. Then instead of predicting the yield for the following test year, yields are predicted for each of the base period years. The residual mean square is the sum of squared d values for these base period years divided by the appropriate degrees of freedom (number of years minus number of parameters estimated in fitting the model). Whereas one value of MSE is generated for each geographic area over the entire test period, a value of the residual mean square is generated for each base period corresponding to a test year in that area. The low, high, and average of the base period values for each area are given in Table 5. Values for CRD's in pooled regions are the same.

The MSE values in Table 2 are also given in Table 5. The average residual mean square from the fit of the equation is less than the MSE, except for CRDs in Minnesota and two in North Dakota. In fact, the smallest residual mean square is more than the MSE in all except those four. Minnesota CRD 40 is the outlier whose independent test MSE is much larger than the largest residual mean square from the base period.

Another indicator of yield reliability is the correlation coefficient, r, between the observed and predicted yields for the independent test years (Table 4). It is desirable for r to be close to +1, even though it can be negative. The analogue for the model development base period is the square root of R^2, the coefficient of multiple determination. The square root of R^2 expressed as a proportion, R ($0 \leq R \leq 1$), may be interpreted as the correlation between observed and predicted values for the base period years. The low, high and average values of R for each geographic area are given in Table 6. Values for CRD's in the same pooled region are the same.

The Pearson correlation coefficient values in Table 4 are also given in Table 6. The highest positive value of r is 0.84 and one r value is .60. Average CRD values of R are from 0.90 to 0.91. The values of r from the independent tests are certainly much lower than the values of r from the base period. It is obvious that levels of R (or alternatively R^2) for a model development base period are of no value in indicating independent performance of this model. In fact, the base period R or R^2 can be very misleading as is the case with Minnesota CRD 40.

Model is Objective

Since the independent variables are objectively defined no subjective inputs are required to run the model.

Results might differ if the set of years used to generate the models were changed. Different independent variables might possibly have been selected with a different time period. Once the decisions on the time period to use for model development and the variables to be used in the regression are fixed, the operation becomes completely objective. The variables to estimate the time trends and soil texture required subjective decisions.

Model Considers Known Scientific Relationships

The models consider factors which have a statistically significant relationship with crop yield. Some known relationships between weather and crop yield may be lacking in the models because the base period did not contain evidence of this relationship or the weather variables were not formulated to detect the relationship. Non-climatic, technological causes of yield variation are not included even though it is known that such relationships exist. Trend is a problem since changes are impossible to detect from year to year as being caused by the components of trend. Soil variables for the state model are nearly constant through the years and are therefore of questionable value.

Model is Adequate

The model can provide estimates for any geographic area and soils having historic yield and monthly temperature and precipitation information. This basic information would be required for any modeling effort. Models would have to be redeveloped for specific areas.

Model is Timely

As soon as reliable figures are available for monthly temperature and precipitation through the growing season models can be developed for estimating the current yield. "End-of-season" models can provide yield estimates as soon as weather data for the final required month are available.

Model is Not Costly

The only data required are the historic monthly temperature and precipitation and actual yield. These data are readily available. The least squares regression model can be fit using any standard statistical package program. Estimates for the current year require the monthly temperature and precipitation data and derived variables soon after the end of the month. Soils data are required for pooling CRD's but not for state models.

Model is Simple

The model is simple. Users can clearly understand the basis of predicted yields. The model is easy to use. The independent variable values in the model are simply functions of the year, predetermined texture and topological variables, and transformations of the monthly temperature and precipitation. To estimate the yield for a current year one would need complete information on the transformations used to derive the weather variables and the pre-determined variables.

Model has Poor Current Measure of Modeled Yield Reliability

The CRD, state and region values for the Spearman correlation coefficient between the estimate of the standard error of a predicted yield value and the absolute value of the difference between the predicted and actual yield are computed. They are given in Table 7 and shown in Figure 11. In 7 of 11 CRDs, the correlation is negative. The largest positive value is 0.39. Thus, the model does not provide a good measure as to how close the predicted values will be to the actual values. Instances of years with smaller (larger) confidence intervals about the true predicted value are all too often associated with larger observed discrepancies between the actual and predicted values. The accuracy of a predicted yield cannot be reliably judged using information provided by the model. The state model in North Dakota is better than the individual CRDs. None of the indicators for CRDs or for the state in Minnesota are good. The value of the standard error of a predicted yield is a function of the residual mean square and the distance of the independent variable values in the prediction year from their average during the base period.

CONCLUSIONS

Williams-type spring wheat models for North Dakota and Minnesota utilize monthly temperature and precipitation, predetermined texture and topography variables, and piecewise linear trend to estimate yield. Indicators of yield reliability obtained from a ten year bootstrap test are examined to determine strengths and weaknesses of the models. The bias and root mean square error show quite a range over the various CRDs, but the overall bias in Minnesota is negative, i.e., the models tend to under estimate the actual yield. Minnesota CRDs and several in North Dakota have a very high root mean square error. The 1974 spring wheat yield was the most difficult for the models to estimate. The direction of change was correct but the magnitude was underestimated. Absolute relative differences were greater than 10 percent anywhere from 2 to 7 times during the 10 year test period. The models showed some capability in indicating the direction of change in yield from the previous years and also from a base period. Precision indicated by the R^2 value and the residual mean square errors does not agree with model performance for the independent 10 year bootstrap test.

The biggest weakness seems to be with the Minnesota CRD estimates. Models are objective, adequate, timely, simple and not costly. It considers some known scientific relationships.

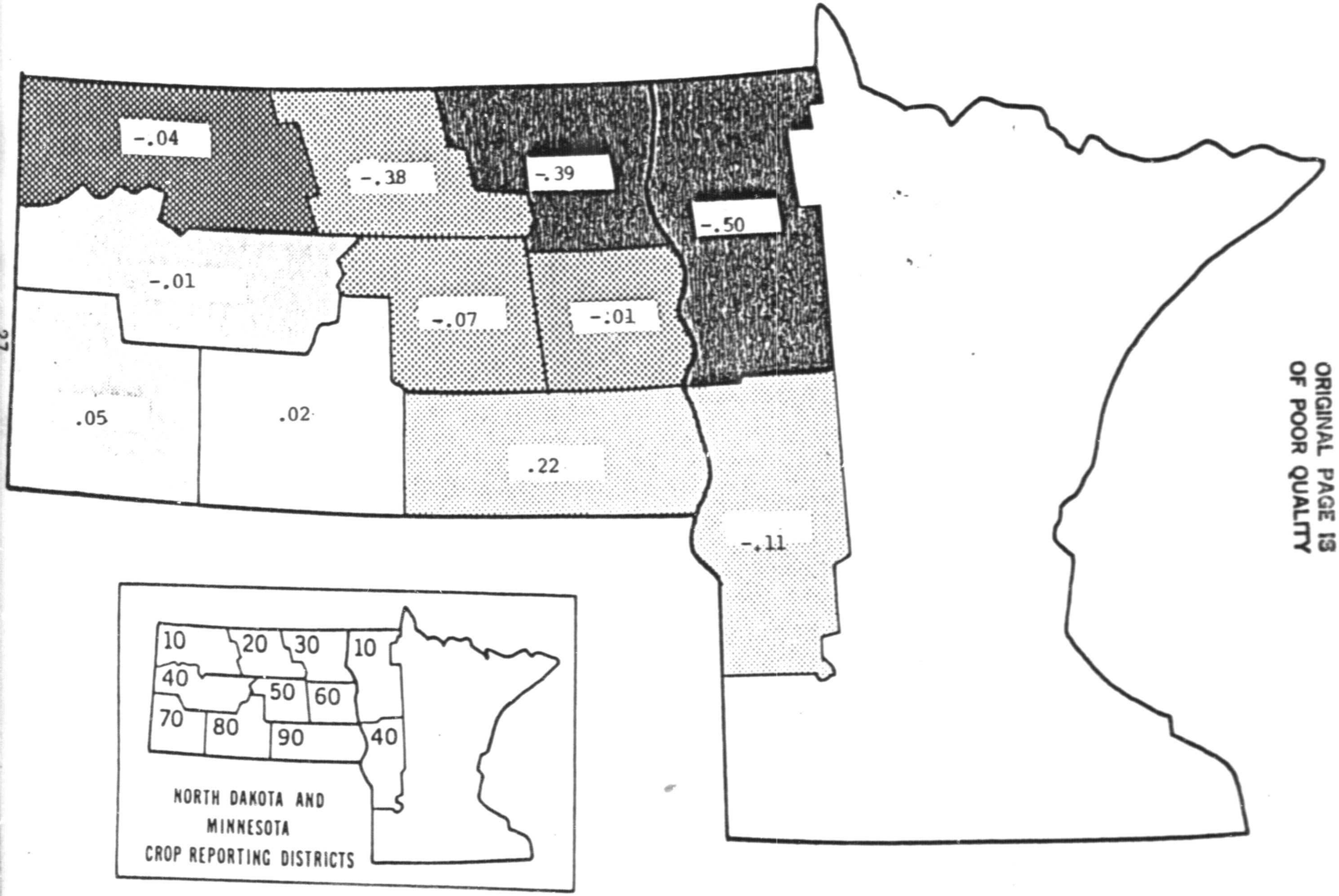
TABLE 7
CURRENT INDICATION OF
MODELED YIELD RELIABILITY

AGREEMENT BETWEEN BASE PERIOD PREDICTED
AND TEST YEAR ACTUAL ACCURACY

WILLIAMS TYPE MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	SPEARMAN CORRELATION COEF.
N.DAKOTA	10	-0.04
	20	-0.38
	30	0.39
	40	-0.01
	50	-0.07
	60	-0.01
	70	0.05
	80	0.02
	90	0.22
STATE MODEL		0.10
MINNESOTA	10	-0.50
	40	-0.11
STATE MODEL		-0.73

Figure 11. Spearman correlation coefficient between the estimate of the standard error of a predicted value from the base period model and the absolute value of the difference between the predicted and actual spring wheat yield in the test years (1970-79). Darker shades indicate CRDs with higher production.



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APPENDIX I
BOOTSTRAP TEST RESULTS FOR SPRING WHEAT YIELDS IN NORTH DAKOTA AND MINNESOTA USING A WILLIAMS TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	YIELD (Q/H) PRED.	D	RD	S.E. PRED.
N.DAKOTA	10	1970	16.2	15.5	-0.7	-4.3	2.29
		1971	20.0	17.8	-2.2	-11.0	2.26
		1972	19.9	21.2	1.3	6.5	2.30
		1973	20.1	16.5	-3.6	-17.9	2.25
		1974	14.8	15.6	0.8	5.4	2.26
		1975	16.7	16.2	-0.5	-3.0	2.27
		1976	17.6	17.3	-0.3	-1.7	2.24
		1977	16.5	15.9	-0.6	-3.6	2.25
		1978	21.9	19.7	-2.2	-10.0	2.22
		1979	14.5	15.3	0.8	5.5	2.21
	20	1970	14.9	14.5	-0.4	-2.7	2.27
		1971	20.7	17.5	-3.2	-15.5	2.25
		1972	19.2	19.2	0.0	0.0	2.28
		1973	19.8	16.6	-3.2	-16.2	2.24
		1974	12.9	15.9	3.0	23.3	2.25
		1975	16.4	15.0	-1.4	-8.5	2.26
		1976	16.4	16.4	0.0	0.0	2.23
		1977	14.8	15.7	0.9	6.1	2.25
		1978	19.7	17.9	-1.8	-9.1	2.20
		1979	16.6	14.5	-2.1	-12.7	2.20
	30	1970	18.9	18.0	-0.9	-4.8	2.27
		1971	24.1	22.1	-2.0	-8.3	2.24
		1972	21.0	22.2	1.2	5.7	2.29
		1973	20.4	20.6	0.2	1.0	2.22
		1974	15.3	18.6	3.3	21.6	2.29
		1975	20.9	18.7	-2.2	-10.5	2.25
		1976	19.9	19.8	-0.1	-0.5	2.23
		1977	20.3	20.7	0.4	2.0	2.30
		1978	22.3	22.1	-0.2	-0.9	2.30
		1979	23.8	20.0	-3.8	-16.0	2.30
	40	1970	14.2	15.5	1.3	9.2	2.28
		1971	18.6	16.5	-2.1	-11.3	2.24
		1972	20.2	20.4	0.2	1.0	2.29
		1973	17.7	15.7	-2.0	-11.3	2.24
		1974	11.6	14.4	2.8	24.1	2.25
		1975	16.5	15.8	-0.7	-4.2	2.26
		1976	17.3	15.6	-1.7	-9.8	2.23
		1977	15.4	15.4	0.0	0.0	2.24
		1978	20.1	19.2	-0.9	-4.5	2.21
		1979	15.2	15.1	-0.1	-0.7	2.19

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APPENDIX I
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A WILLIAMS TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
N.DAKOTA	50	1970	15.9	13.7	-2.2	-13.8	2.27
		1971	22.5	17.0	-5.5	-24.4	2.25
		1972	18.2	17.8	-0.4	-2.2	2.27
		1973	15.0	14.4	-0.6	-4.0	2.25
		1974	12.0	15.9	3.9	32.5	2.26
		1975	17.1	15.9	-1.2	-7.0	2.26
		1976	14.7	14.0	-0.7	-4.8	2.24
		1977	14.4	15.2	0.8	5.5	2.25
		1978	19.2	18.1	-1.1	-5.7	2.20
		1979	17.9	15.8	-2.1	-11.7	2.20
	60	1970	18.0	17.6	-0.4	-2.2	2.29
		1971	24.5	21.2	-3.3	-13.5	2.23
		1972	20.6	21.6	1.0	4.9	2.27
		1973	20.2	19.3	-0.9	-4.5	2.22
		1974	15.7	17.4	1.7	10.8	2.32
		1975	19.4	18.6	-0.8	-4.1	2.26
		1976	19.3	18.3	-1.0	-5.2	2.24
		1977	20.6	20.0	-0.6	-2.9	2.30
		1978	22.8	21.1	-1.7	-7.5	2.30
		1979	22.6	19.5	-3.1	-13.7	2.30
	70	1970	13.8	15.4	1.6	11.6	2.28
		1971	18.6	17.5	-1.1	-5.9	2.26
		1972	18.7	21.1	2.4	12.8	2.31
		1973	19.1	16.1	-3.0	-15.7	2.25
		1974	15.2	14.2	-1.0	-6.6	2.27
		1975	15.4	16.0	0.6	3.9	2.27
		1976	16.8	14.9	-1.9	-11.3	2.24
		1977	14.1	15.2	1.1	7.8	2.25
		1978	17.8	19.8	2.0	11.2	2.23
		1979	14.1	14.9	0.8	5.7	2.21
	80	1970	11.1	13.4	2.3	20.7	2.28
		1971	17.8	16.3	-1.5	-8.4	2.27
		1972	16.0	18.4	2.4	15.0	2.29
		1973	13.2	13.9	0.7	5.3	2.26
		1974	8.7	12.8	4.1	47.1	2.27
		1975	14.2	15.3	1.1	7.7	2.27
		1976	11.1	13.1	2.0	18.0	2.25
		1977	11.0	14.1	3.1	28.2	2.25
		1978	15.6	18.6	3.0	19.2	2.23
		1979	12.2	14.0	1.8	14.8	2.21

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APPENDIX I
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A WILLIAMS TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	YIELD (Q/H) PRED.	D	RD	S.E. PRED.
N.DAKOTA	90-	1970	14.3	13.7	-0.6	-4.2	2.27
		1971	21.5	17.3	-4.2	-19.5	2.25
		1972	17.3	19.0	1.7	9.8	2.27
		1973	15.9	13.9	-2.0	-12.6	2.24
		1974	12.9	15.7	2.8	21.7	2.27
		1975	15.3	16.8	1.5	9.8	2.29
		1976	11.9	12.6	0.7	5.9	2.24
		1977	17.1	16.1	-1.0	-5.8	2.24
		1978	17.3	19.3	2.0	11.6	2.22
		1979	17.3	16.5	-0.8	-4.6	2.19
STATE MODEL		1970	15.8	16.3	0.5	3.2	2.11
		1971	21.4	19.0	-2.4	-11.2	2.03
		1972	19.4	20.9	1.5	7.7	2.09
		1973	18.5	16.4	-2.1	-11.4	1.99
		1974	13.7	16.9	3.2	23.4	2.06
		1975	17.4	16.7	-0.7	-4.0	2.02
		1976	16.6	16.1	-0.5	-3.0	1.95
		1977	16.7	17.3	0.6	3.6	2.09
		1978	20.1	20.2	0.1	0.5	1.97
		1979	17.7	16.6	-1.1	-6.2	1.89
CRDS AGGR.		1970	15.8	15.6	-0.2	-1.3	
		1971	21.4	18.6	-2.8	-13.1	
		1972	19.4	20.4	1.0	5.2	
		1973	18.5	16.9	-1.6	-8.6	
		1974	13.7	16.1	2.4	17.5	
		1975	17.4	16.7	-0.7	-4.0	
		1976	16.6	16.3	-0.3	-1.8	
		1977	16.7	17.0	0.3	1.8	
		1978	20.1	19.7	-0.4	-2.0	
		1979	17.7	16.5	-1.2	-6.8	

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APPENDIX I
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A WILLIAMS TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
MINNESOTA	10	1970	18.5	18.7	0.2	1.1	2.29
		1971	26.9	22.4	-4.5	-16.7	2.25
		1972	24.2	23.3	-0.9	-3.7	2.29
		1973	26.0	22.1	-3.9	-15.0	2.22
		1974	18.6	18.7	0.1	0.5	2.32
		1975	22.7	20.6	-2.1	-9.3	2.27
		1976	24.6	21.1	-3.5	-14.2	2.25
		1977	23.6	21.4	-2.2	-9.3	2.32
		1978	26.6	22.9	-3.7	-13.9	2.31
		1979	24.9	21.2	-3.7	-14.9	2.31
	40	1970	18.4	17.9	-0.5	-2.7	2.27
		1971	23.3	20.2	-3.1	-13.3	2.27
		1972	17.3	18.6	1.3	7.5	2.42
		1973	26.7	20.2	-6.5	-24.3	2.23
		1974	19.4	18.4	-1.0	-5.2	2.31
		1975	18.2	18.7	0.5	2.7	2.28
		1976	14.9	16.9	2.0	13.4	2.29
		1977	28.6	20.1	-8.5	-29.7	2.31
		1978	17.3	19.8	2.5	14.5	2.32
		1979	21.6	19.6	-2.0	-9.3	2.30
STATE MODEL		1970	18.6	19.1	0.5	2.7	2.25
		1971	25.6	23.7	-1.9	-7.4	2.18
		1972	22.2	23.7	1.5	6.8	2.12
		1973	26.2	24.7	-1.5	-5.7	2.11
		1974	19.5	21.2	1.7	8.7	2.15
		1975	20.9	23.0	2.1	10.0	2.06
		1976	21.8	23.5	1.7	7.8	2.03
		1977	26.8	24.8	-2.0	-7.5	2.04
		1978	22.7	25.6	2.9	12.8	2.00
		1979	23.6	25.9	2.3	9.7	1.97
CRDS AGGR.		1970	18.5	18.4	-0.1	-0.5	
		1971	25.9	21.8	-4.1	-15.8	
		1972	22.3	22.0	-0.3	-1.3	
		1973	26.3	21.5	-4.8	-18.3	
		1974	18.9	18.6	-0.3	-1.6	
		1975	20.9	19.9	-1.0	-4.8	
		1976	20.9	19.5	-1.4	-6.7	
		1977	25.5	20.9	-4.6	-18.0	
		1978	23.3	21.8	-1.5	-6.4	
		1979	23.8	20.7	-3.1	-13.0	

APPENDIX 1
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A WILLIAMS TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	YIELD (Q/H) PRED.	D	RD	S.E. PRED.
REGION CRDS	AGGR.	1970	16.1	15.9	-0.2	-1.2	
		1971	22.0	19.1	-2.9	-13.2	
		1972	19.9	20.6	0.7	3.5	
		1973	19.9	17.7	2.2	-11.1	
		1974	14.7	16.5	1.8	12.2	
		1975	18.1	17.3	-0.8	-4.4	
		1976	17.5	17.0	-0.5	-2.9	
		1977	18.7	17.9	-0.8	-4.3	
		1978	20.7	20.1	-0.6	-2.9	
		1979	18.9	17.3	-1.6	-8.5	
STATES	AGGR.	1970	16.2	16.6	0.4	2.5	
		1971	22.0	19.7	-2.3	-10.5	
		1972	19.9	21.4	1.5	7.5	
		1973	19.9	17.9	-2.0	-10.1	
		1974	14.9	17.8	2.9	19.5	
		1975	18.2	18.1	-0.1	-0.5	
		1976	17.9	18.0	0.1	0.6	
		1977	19.3	19.3	0.0	0.0	
		1978	20.7	21.4	0.7	3.4	
		1979	18.9	18.6	-0.3	-1.6	

APPENDIX 2

RANGE OF VALUES FOR ESTIMATED COEFFICIENTS

SPRING WHEAT
WILLIAMS-TYPE MODEL

	Red River Valley	ND excluding Red River Valley	MN State	ND State
TREND 1	.825 - .906	.749 - .784		.806 - .834
TREND 2			.625 - .678	
TX	-2.84 - (-1.53)	5.668 - 6.956		
TXSQ	.012 - .022	-.070 - (-.057)		
CAPR			-.017 - (-.012)	
DEFSEAS	-.011 - (-.009	.115 - .158		-.019 - (-.015)
DEFSEASQ	-.00005 - (-.00004)			
PET5	.014 - 036	-.016 - (-.014)		.051 - .058
PET6	-.075 - (-.066	.041 - .045	-.076 - (-.069)	-.062 - (-.056)
PET7	-.141 - (-.118)	-.097 - (-.076)	-.164 - (-.138)	-.107 - (-.080)

APPENDIX 4

Brief Description of Growing Conditions for Spring Wheat in Bootstrap Test Years

Year	North Dakota	Minnesota
1970	Yield down 21%-production down 25%. Lowest yield since 1967, production since 1966. Wet early spring-planting delayed. Central and West areas dry out in July-moisture stress and slow growth. Nitrogen rate/acre up 3½%.	Yield down 8%-lowest yield and production since 1966. Cold, wet spring-planting delayed. Cold and moisture high through June-hot July hurts crop. Leaf rust loss 1.9 bu/acre (all wheat). Nitrogen rate/acre up 12%. Dominant variety is Chris. Era released as new variety.
1971	Yield up 34½%-production up 87%. Record yield and production-highest harvested area since 1953. Early planting. Moisture and temperature adequate through July. Early harvest after fine growing conditions. Nitrogen rate/acre up 23%.	Yield up 38%-harvested area up 87%. Record yield, harvested area and production. Early planting. Moisture good through July; cold July. Moisture short by mid August. Excellent harvest conditions. Nitrogen rate/acre down 35%.
1972	Yield down 9½%-production down 26%. Wet early spring-planting delayed. Dry June-mid July, especially Eastern two-thirds of state. Harvest on normal schedule. Nitrogen rate/acre up 2%.	Yield down 13%. Wet spring-planting delayed. Moisture short in North by mid July. Heavy rains/flood in Central during July. Cold wet August delays harvest. Nitrogen rate/acre up 243%.
1973	Yield down 4½%-production up 11½%. Dry spring-early planting. Much rain in June-early July but South remains dry. Harvest early. Nitrogen rate/acre up 24%.	Yield up 18%-record yield, harvested area and production. Harvested area up 236% from 1970. Cool, dry spring-early planting. Moisture very good through June. July drier. Harvest normal. Nitrogen rate/acre down 7%. Era accounts for 41% and Chris 12% of area.

APPENDIX 4

Brief Description of Growing Conditions for Spring Wheat in Bootstrap Test Years

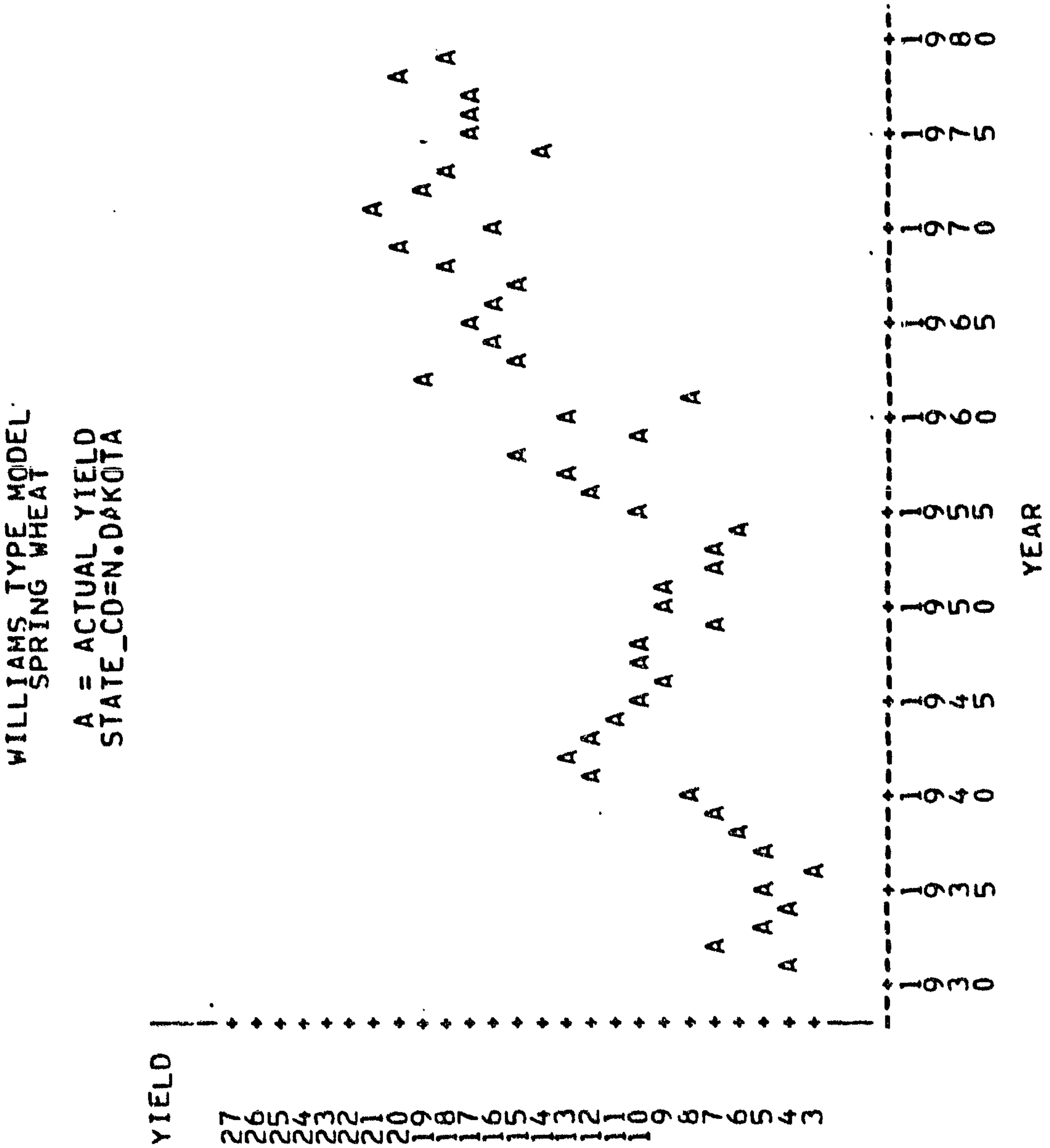
Year	North Dakota	Minnesota
1974	Yield down 22%-lowest since 1961. Production down 13%-lowest since 1970. Largest harvested area since 1951. Excess spring moisture--late planting. Late June-July very dry (1/3 normal precipitation) and hot. Harvest late. Nitrogen rate/acre down 8%. Dominant variety is Waldon (52%). Olef introduced with 4.2% of area.	Yield down 26%-lowest since 1970. Record harvested area and production. Harvested area up 328% from 1970. Cool wet spring-planting delayed in North. Hail and heavy rains in Central. Hot, dry July. Nitrogen rate/acre down 3%. Era accounts for 65% and Chris 6% of area. Price paid for wheat up 226%.
1975	Yield up 27½%-production up 26%. Late, wet spring-planting delayed. Heavy June rains-flooding in South Red River Valley. Hot, dry July. Nitrogen rate/acre up 19%. Olef accounts for 18% of planted area.	Yield up 7%. Record harvested area and production. Cold, rainy spring-planting delayed. Hot, dry July and August. Nitrogen rate/acre up 4%.
1976	Yield down 5%. Record harvested rea. Moisture favorable at planting. Hot, dry through August. Early harvest. Nitrogen rate/acre up 29%.	Yield up 5%-harvested area up 41% from 1975 and 470% from 1970. Record production and harvested area. Planting 2-3 weeks early-warmer, drier than normal. Very dry in South and Central during summer, but adequate rain in Red River Valley. Nitrogen rate/acre up 14%.
1977	Yield up 1%-production down 20%. Low spring moisture. Drought in South and Central. Hot temperature and dry winds in late July-September. Early harvest-heavy rains cause sprouting damage. Nitrogen rate/acre up 2%.	Yield up 23%-record yield and production. Early planting and sprouting. Moisture, temperature adequate through summer. Harvest normal to slightly late. Nitrogen rate/acre up 2%.

APPENDIX 4

Brief Description of Growing Conditions for Spring Wheat in Bootstrap Test Years

Year	North Dakota	Minnesota
1978	Yield up 20%-highest yield since 1971. Production up 24%. Very good growing conditions. Frequent rains early in season. Hot, dry mid July-September. Harvest early. Nitrogen rate/acre up 1½%. Olaf accounts for 35% and Waldron 28% of area.	Yield down 16%-production down 31%. Lowest harvested area since 1973. Good early season weather. Heavy rain, wind in early summer. Harvest slowed by wet weather-much lodging occurs. Nitrogen rate/acre up 7%.
1979	Yield down 12%-production down 11½%. Cold wet spring-planting delayed. Hot dry mid-June. Cool August with heavy rains and lodging in the East, hail damage in East and Central. Premature frost in Northwest (mid-August). Nitrogen rate/acre up 24%.	Yield up 4½%. Lowest production since 1975. Spring planting and development 2 weeks late. Good growing conditions throughout season. Normal precipitation in Red River area. Nitrogen rate/acre up 7%.

APPENDIX 5


WILLIAMS TYPE MODEL
SPRING WHEAT
A = ACTUAL YIELD
STATE_CD=N.DAKOTA
YIELD
YEAR
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980

APPENDIX 5

ORIGINAL PAGE IS
OF POOR QUALITY