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

Yield Model Development

DECEMBER 1981

EVALUATION OF THE CEAS MODEL FOR BARLEY YIELDS IN NORTH DAKOTA AND MINNESOTA

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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 1.

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Evaluation of the CEAS Model for Barley Yields in North Dakota and Minnesota

by

T. L. Barnett

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 1, as identified in the Yield Model Development Project Implementation Plan dated March 1981 (YM - J1 - C0618, JSC - 16857).

AgRISTARS

Yield Model Development

Project

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EVALUATION OF THE CEAS MODEL FOR BARLEY YIELDS IN NORTH DAKOTA AND MINNESOTA.
By Tom L. Barnett; N.A.S.A., Yield Model Development Center, Columbia, Missouri;
December, 1981.

ABSTRACT

The CEAS yield model is based upon multiple regression analysis at the CRD and state levels. For the historical time series, yield is regressed on a set of variables derived from monthly mean temperature and monthly precipitation. Technological trend is represented by piecewise linear and/or quadriatic functions of year. Indicators of yield reliability obtained from a ten-year bootstrap test (1970-79) demonstrated that biases are small and performance as indicated by the root mean square errors are acceptable for intended application. However, model response for individual years, particularly unusual years, is not very reliable and shows some large errors. The model is objective, adequate, timely, simple and not costly. It considers scientific knowledge on a broad scale but not in detail, and does not provide a good current measure of modeled yield reliability.

Key words: Model evaluation, yield modeling, linear regression.

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Summary

The CEAS yield model is based upon multiple regression analysis at the CRD and state levels. For the historical time series, yield is regressed on a set of variables derived from monthly mean temperature and monthly precipitation. Technological trend is represented by piecewise linear and/or quadratic functions of year. Model performance is evaluated on the basis of eight criteria - reliability, objectivity, consistency with scientific knowledge, adequacy, timeliness, cost, simplicity, and accurate current measures of modeled yield reliability. Ten-year bootstrap tests (1970-1979) were run for each crop reporting district in the major barley producing regions of North Dakota and Minnesota. These indicated that biases are generally small and performance as indicated by the root mean square errors is generally acceptable for the intended AgRISTARS large area applications. However, model response for individual years, particularly unusual years, is not very reliable and shows some large errors. The model is objective, adequate, timely, simple and not costly. It considers scientific knowledge on a broad scale but not in detail, and does not provide a good current measure of modeled yield reliability.

DESCRIPTION OF THE MODEL

The model designated "CEAS Barley Model" was developed at the Center for Environmental Assessment Services (CEAS) by R.P. Motha (R.P. Motha, "Barley Models for North Dakota and Minnesota", NOAA-CEAS, Columbia-Missouri, May, 1980).

Basic inputs to the model are historical USDA yields and monthly mean temperature and total precipitation at the Crop Reporting District (CRD) level. A wide variety of possible variables, such as cumulative precipitation from the previous September, monthly temperature and precipitation departures from normal, evapotranspiration (potential, actual and "climatically appropriate"), Z-index, aridity index, R-index, and moisture ratio are formed from the basic inputs.

Trends, accounting for general improvements in technology over the years, are defined by Motha as linear from 1931 to 1962, and linear and/or quadratic from 1961 on. Specifically the trend variables are:

TREND 1 = (YEAR-1930) for YEAR $\leq$ 1962
32 for YEAR > 1962

TREND 2 = 0.1 for YEAR $\leq$ 1962*
(YEAR-1961) for YEAR > 1962

TREND 2SQ = TREND 2 ** 2

The general form of the CEAS yield model is:

$$Y_i = \alpha + \beta * \text{TREND } 1_i + \beta' * \text{TREND } 2_i + \beta'' * \text{TREND } 2SQ_i + \sum_{K-i}^{n} \lambda * W_{iK}$$

where:

Y_i = estimate and yield for i-th year

α = intercept (constant term)

β β' = linear trend coefficients

β'' = quadratic trend coefficient

λ = slope coefficient associated with the k-th weather term

W_{iK} = k-th weather term for the i-th year

---

*Model was developed using these trends. Runs using TREND2 = 1.0 for year 1962 as one might commonly use, gave us no significant differences in predicted yields.

In developing the models for each CRD (MN CRD's 10 and 40, ND CRD's 10 through 90) and state (MN and ND) Motha ran stepwise multiple regressions which examined the possible variables and selected the statistically most significant set of several trend and weather terms on the basis of years 1931-1978. A certain amount of judgment was used to eliminate terms obviously in conflict with scientific knowledge (e.g., when a coefficient was strongly negative where it should be positive) or to include important terms even if they were not statistically significant. The result was a set of yield models at CRD and state level. Appendix 2 shows the terms included in each model and the range of the coefficients over the ten different but overlapping sets of model base period years.

There are some general patterns but wide diversity in detail, reflecting both real CRD-to-CRD variations and vagaries of the regression process on noisy data.

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 by Motha, it was felt that meaningful evaluation was difficult enough when the full-season weather was available.

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, objectivitiy, 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 CEAS model.

Bootstrap Technique Used to Generate Indicators of Yield Reliability

Indicators of yield reliability 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 relability 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. To accomplish this, the "bootstrap" technique is used. For each test year, the 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 are inserted into the equation and predicted yield is generated. Then, the last test year is added to the base period and the process is repeated. Continuing in this way, ten (1970-79) predictions of yield are obtained, each independent of the data used to fit the model.

The $\hat{Y}$ and d values for the ten year test period are obtained from models derived at the crop reporting district (CRD) level and state level. The latter are based on a weighted average of CRD weather to the state level. A second set of $\hat{Y}$ values are obtained at the state level using a weighted average of predicted yields from the CRD models. At the region level two sets of Y values are obtained, one by aggregating CRD model yields and the other by aggregating the state model yields. In each case the weighting factors are based on harvested area for the prediction year.

For both Minnesota and North Dakota, data for 1932-1969 are used to fit prediction models for 1970, data from 1932-1970 are used to fit models for 1971, etc. through 1979. This testing procedure closely simulates the way the models would be applied in practice.

The average and percent production and yield over the ten year test period are presented in Table 1 for each geographical region. Figure 1 presents percent production in each CRD. The bootstrap test results--Y, $\hat{Y}$, and d--are given in Appendix 1 for each geographical region.

Review of Indicators of Yield Reliability

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

Indicators Based on 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 percent probable that the absolute value of d for a future year will be less than one RMSE and 95 percent 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. An unbiased model, i.e. bias close to zero, is preferred.

Indicators Based on 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 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 performance 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 $\hat{Y}$ and 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. This represents a measure of how well deviations from average in the set of predicted yields correlate to deviations from average in the set of actual yields. 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).

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 subsequenty determined deviation between modeled and 'true' yield."

For regression models, this suggets 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, based on the model development base period and current (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, $s_{\hat{y}}$, is used for the first value, and the absolute value of the difference between the predicted and actual yield in the test year, $|d|$ is used as the second variable.

Since $s_{\hat{y}}$ incorporates current-year weather as compared to long-term average, if the relation of yield to weather specified in the model is valid the magnitude of $s_{\hat{y}}$ should fluctuate in phase with $|d|$, i.e., it should be positively correlated.

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

MODEL EVALUATION

Plots of actual and predicted yields for MN and ND state level models are presented in Figure 2 and 3. Results of the ten-year bootstrap tests on which these evaluations were based are presented in Appendix 1.

Indicators of Yield Reliability based on d Show Moderate Bias, Standard Deviations Ranging From 1.2 to 4.7 Q/Ha, and RMSE Ranging From 2.0 to 5.0 Q/Ha.

The indicators of yield reliability based on deviations d $(= \hat{Y} - Y)$ at CRD, state, and region levels are given in Table 2 and Figure 4.

CRD level biases for ND range from +1.6 to -1.8 Q/Ha, showing no obvious pattern. The biases for both MN CRD's are near -2 Q/Ha. Since the MN state model and aggregation to state level from CRD's both show about -2 Q/Ha this may indicate a general bias on this order for the CEAS MN model.

Root Mean Square Errors (RMSE) for ND CRD's range from 2.4 to 5.0 Q/Ha and for MN from 2.6 to 4.9 Q/Ha. State level RMSE values were somewhat smaller, 3.4 Q/Ha for ND and 2.9 Q/Ha for MN.

Values of standard deviation ranged from 2.2 to 4.7 Q/Ha for ND CRD's and from 1.2 to 4.4 Q/Ha for MN CRD's. State and regional values ranged from 1.6 to 2.7 Q/Ha.

Examination of plots of observed and predicted yields at state level in Figures 2 and 3 indicates that in both ND and MN the CEAS model predictions seem to be biased by a consistent -2 Q/Ha in the years 1975-1979. This may indicate a weakness in the CEAS model and is discussed in the conclusions section.

Indicators of Yield Reliability Based on rd show that a Large Number of Cases Have 50 Percent or More of Test Years with rd Greater Than 10 Percent

The CRD, state, and region values for the indicators of yield reliability based on absolute values of relative differences, | rd |, are given in Table 3 and Figures 5, 6, and 7.

Seven of the nine ND CRD's and both MN CRD's show 50% or more of the test years with rd greater than 10%. State and regional results show two of six cases with 50% or more of the test years with | rd | greater than 10%. These results would seem to indicate either a large natural variability in barley yields or a low level of model skills. Both indications are supported by the plots in Figures 2 and 3. If the model capabilities could be significantly improved in the years 1975-1979 the indicators of yield reliability would also be much improved.

For ND 1974 was the year with the largest relative difference in eight of nine CRD's. All nine represented an inability of the model to respond to a very low actual yield. For MN 1976 and 1977 were the worst years, representing underestimations by the model of high actual yields.

Indicators of Yield Reliability Based on Y and $\hat{Y}$ Show Moderately Good Correspondence Between the Direction of Change in Predicted Yield Compared to Actual Yield.

The predicted and actual yields at state level are plotted in Figures 2 and 3. The predicted yields, actual yields, and differences for CRD level are listed in Appendix 1. The CRD, state, and region level values for indicators of yield reliability based on actual and predicted yields are given in Table 4 and Figures 8, 9, and 10.

Out of the nine ND and two MN CRD's, six show a change of direction of predicted yields from the previous year corresponding to the actual change of direction more than 50 percent of the time. When the base period is the average of the previous three years the score is nine of eleven CRD's correct more than 50 percent of the time. For state and regional models the response direction from the previous year is correct more than 50 percent of the time in five of six cases, and the response direction from the three year average is correct in all six cases. These results indicate that the CEAS model does reasonably well in responding to changes in actual yield, particularly changes from a three-year base period.

Results for the correlation coefficient, r, between predicted and actual yields, representing correlation between fluctuations of predicted and actual yields from averages over the test period are not very satisfactory. Of the eleven CRD's only four show r greater than .55, the one-tailed value required for statistical significance. Values of r as low as 0.05 and 0.17 are found, and six of eleven are less than .30. The score for state and regional models is four of six greater than .55. Clearly the directional response capabilities of the model leave much to be desired. This is especially true for those specific cases of large actual fluctuations (see Figures 1 and 2).

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 given new 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.

One indicator of yield reliability, the mean square error (MSE), is the sum of squared d values ($d = \hat{Y} - Y$) for the independent test years divided by the number of test years (Table 5). 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 squared prediction equation using the base period years. Then instead of predicting the yield of 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 base period 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 an individual test year.

Another indicator of yield reliability is the correlation coefficient, r, between the observed and predicted yields for the independent test years (Table 6). 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 expressed as a proportion, $R(0 \leq R \leq 1)$. It can be interpreted as the correlation between observed and predicted yield. Values of R for each geographic area are given in Table 6, along with the Pearson correlation coefficient values from Table 4.

Average correlation coefficients over the base period (model development years) range from .88 to .97, indicating the model is doing a very good job of fitting the development data. The correlation coefficients over the independent test years range from lows of .05 to .17 to highs of .79 and .95. The average of r over the independent test years is around .43, less than half the r for the model development years. Clearly the CEAS model does not respond nearly as well in a predictive mode as it does in a fitting mode. Essentially, the values of R for model development years provide no indication of the predictive abilities of the model.

Model is Reasonably Objective

The nature of the CEAS model requires that it be redeveloped (i.e., coefficient values re-derived) for each test year, based on available years prior to it. Once the proper terms have been selected and fixed, development and application of the model is quite objective. A great deal of subjectivity, however, is required for initially selecting the terms, in specifying trend, particularly break points, and in choice of development years.

Model Considers Known Scientific Relationships on a Broad Scale

Selection of model terms is by stepwise regression. This guarantees only the set of terms "best" by some statistical criterion. Physical significance is not ensured. It seems unlikely that the wide variety of "significant" terms represented in Appendix 2 for different CRD models is, entirely meaningful in a physical sense. The selection criteria used by the model author are not well described.

Large-area crop yields are known to be related to weather over the growing season, to preseason stored soil moisture, and to a variety of other weather and agronomic factors. The details of the mathematical relationships that describe these physical relationships are far from established. Even the proper set of variables is open to question because there are only a few readily available observables and the variables formed from these tend to be highly interrelated. Large-area relationships are further confused by geographical variations in the observables that may or may not be important for any given situation.

In light of these problems, the authors of the CEAS models choose to rely on a practical approach of statistical regression of observed yields to monthly weather data, trend represented as a function of historical years, and a policy of refitting for each predictive year based on all available prior years.

Thus, the CEAS model is susceptable to criticism in regard to agreement with scientific knowledge in many respects. A few of the more important are noted below. The CEAS model handles technology and cropping practice trends by representing them as piecewise linear and/or quadratic functions of time. This glosses over the known qualitative relationships to variety improvement, fertilizer use, etc., but represents a practical way of treating the situation where it is unclear which effects are most important and where information is limited. Rationale for choosing breakpoints between trend segments or for specifying linear or quadratic segments seems to be primarily on a practical rather than a scientific basis. The CEAS model takes no explicit account of pests, disease, or other episodic events.

Model is Adequate Only for the Region In Which It Was Developed

By its nature, a given CEAS model can be applied with any degree of reliability only in the region for which it was developed. The CEAS models are not extendable even to apparently similar regions. On the other hand, the CEAS approach can be readily applied to any region where a reasonably lengthy record (say 15-20 years) of yield and weather observations exist.

Model Is Timely Enough For Intended Applications

A yield model for a new year can be built as soon as reliable yield and weather variable figures from the past year are available, in the U.S. generally a few months, after harvest, in foreign countries a longer period of time. Yield predictions during an application year can be made shortly after the end of each month for which weather data is available.

Model is Not Costly

Data to develop and run the CEAS barley model are readily available at low cost. The multiple regressions needed to compute the agronomic and meteorological variables and develop models can be run on any modest size computer. Routines are available in most computer libraries.

Model is Simple

The development and application of the CEAS model are straightforward. The only points where judgment is required are in selection of significant terms, specification of trend, and estimation of soil moisture budget capacity.

Model Has Poor Current Measure of Modeled Yield Reliability

The CRD, state, and region values of the correlation coefficient between the estimate of the standard error of the predicted yield values and the absolute differences between predicted and actual yield are presented in Table 7 and Figure 11. The results are very poor. In 11 of 13 cases the correlation is negative, and the largest positive value is 0.06. Clearly the model does not provide a good estimate as to how close the predicted yields will be to actual yields in any prediction year.

CONCLUSIONS

The CEAS yield model for barley represents a straightforward multiple regression fit of piecewise linear and/or quadratic trend and the most significant weather-related terms available for prior years. Fits are made at CRD and state levels. The data bases consist of USDA observed yields and monthly values of mean temperature and total precipitation. Indicators of yield reliability obtained from a ten year bootstrap test (1970-1979) are used to evaluate the model.

Over the set of test years the reliability of the model on average is indicated to be acceptable for many applications. Root mean square errors are about 3 Q/Ha. The CEAS model does not consistently predict high or low actual yields very accurately, and for any given year the actual error may be appreciably larger than the RMSE value. The model does not give a good current measure of yield reliability. However, it is objective, adequate for intended purposes, timely, simple, not costly, and makes a practical attempt at incorporating some general scientific knowledge.

Many general areas of needed improvement could be cited. The most obvious specific improvement would be to correct the consistent bias of the CEAS model in ND and MN in 1975-1979. This would considerably improve RMSE and other indicators of reliability. A fit made with the TREND2SQ term removed, leaving linear trend segments 1931-1961 and 1962-1979, gave predicted yields coinciding almost exactly with actual yields in 1975-1979 but much poorer correspondance in 1970-1974. Across the ten year test period the RMSE for this fit was slightly worse than that for the original CEAS model. Clearly, the fix is not such a simple adjustment.

One final note on the CEAS models should be added. During the several years of testing conducted for the Large Area Crop Inventory Experiment (LACIE) and subsequent years prior to AgRISTARS no yield model was found to outperform the CEAS models.

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

BARLEY
NORTH DAKOTA AND MINNESOTA

STATE	CRD	PRODUCTION (1,000) QUINTALS	PRODUCTION (1,000) BUSHELS	PERCENT OF STATE	PERCENT OF REGION	YIELD QNTL/HA	YIELD BU/ACRE
N.DAKOTA	10	1,081	4,964	5.7	3.9	19.4	36.1
	20	1,964	9,023	10.3	7.2	18.9	35.2
	30	6,559	30,126	34.3	24.0	21.9	40.8
	40	473	2,171	2.5	1.7	19.4	36.1
	50	1,374	6,309	7.2	5.0	18.8	34.9
	60	4,700	21,588	24.6	17.2	23.3	43.2
	70	647	2,972	3.4	2.4	18.9	35.1
	80	423	1,943	2.2	1.5	16.0	29.7
	90	1,885	8,659	9.9	6.9	20.0	37.2
STATE		19,106	87,754		69.8	21.0	39.1
MINNESOTA	10	5,801	26,646	70.1	21.2	24.9	46.2
	20	43	196	0.5	0.2	18.5	34.4
	30	5	21	0.1	0.0	19.7	36.5
	40	2,203	10,119	26.6	8.0	22.3	41.5
	50	77	353	0.9	0.3	20.8	38.8
	60	20	92	0.2	0.1	20.5	38.2
	70	51	235	0.6	0.2	20.9	38.9
	80	17	80	0.2	0.1	23.7	44.0
	90	55	252	0.7	0.2	24.7	46.0
STATE		8,272	37,994		30.2	24.0	44.6
REGION		27,378	125,748			21.9	40.6

Figure 1: Production of barley by CRD (1970-1979 average) as a percent of the regional total. Darker shades indicate CRD's with higher production.

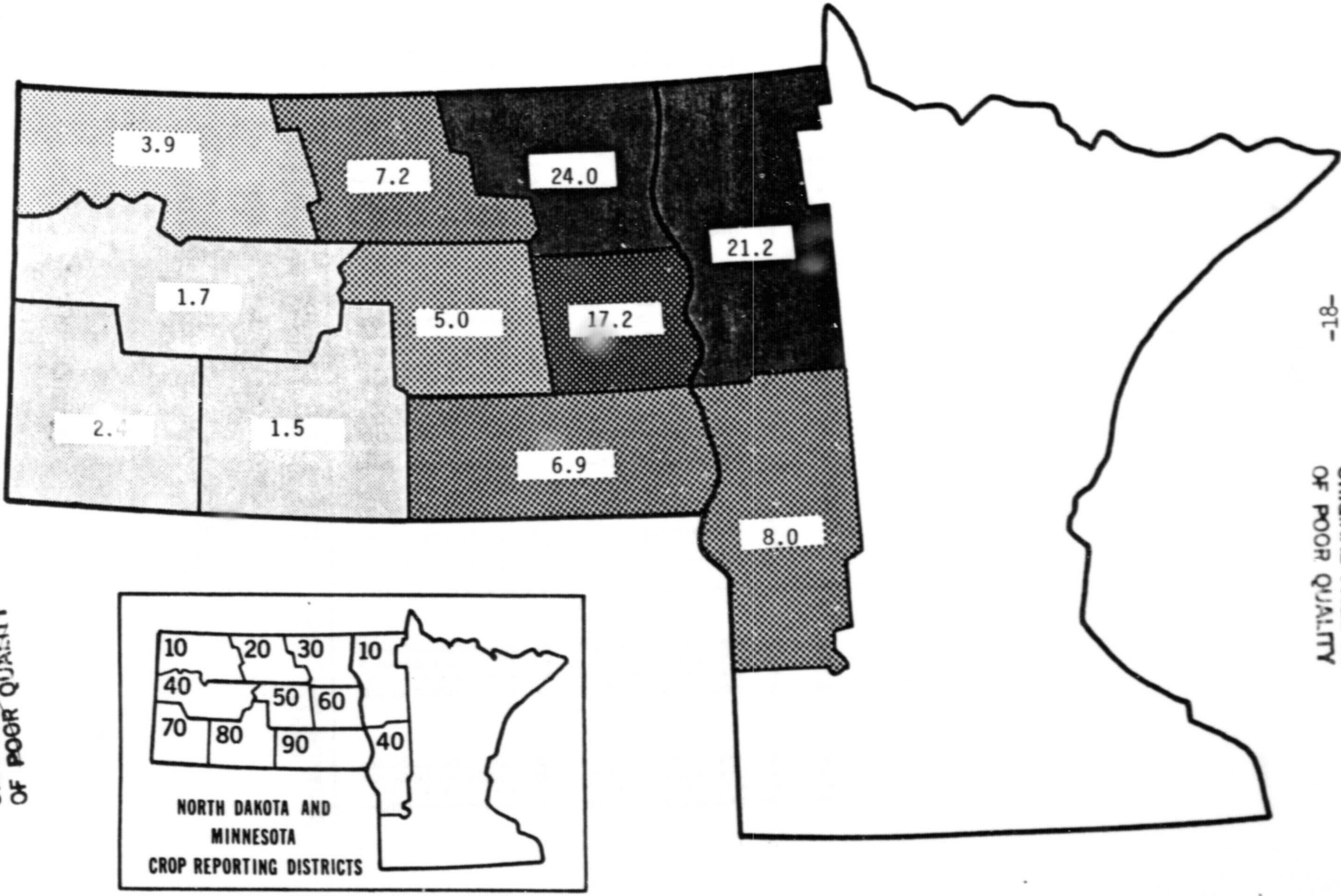

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Figure 2
Actual and Predicted
Yields for North Dakota

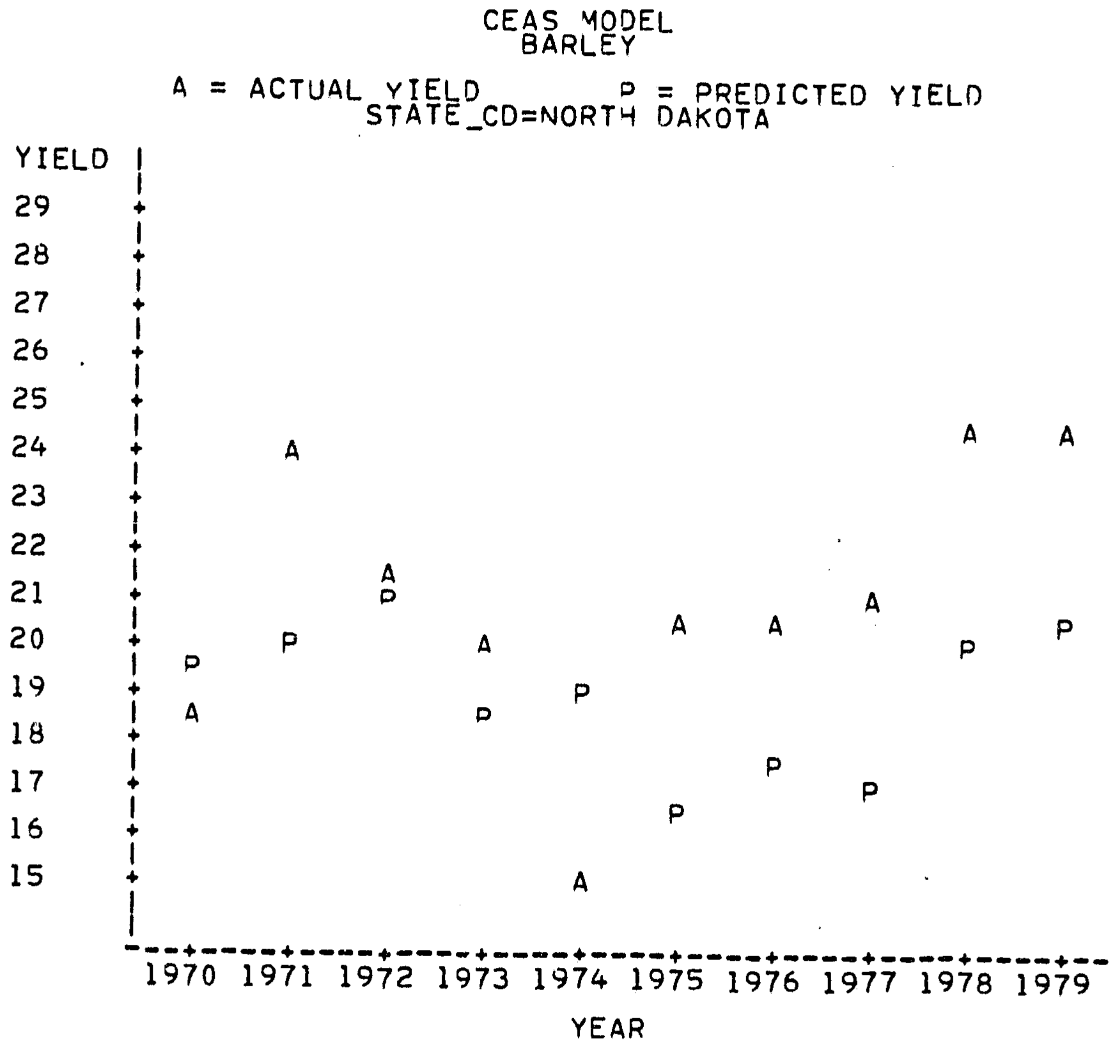

Figure 3
Actual and Predicted
Yields for Minnesota

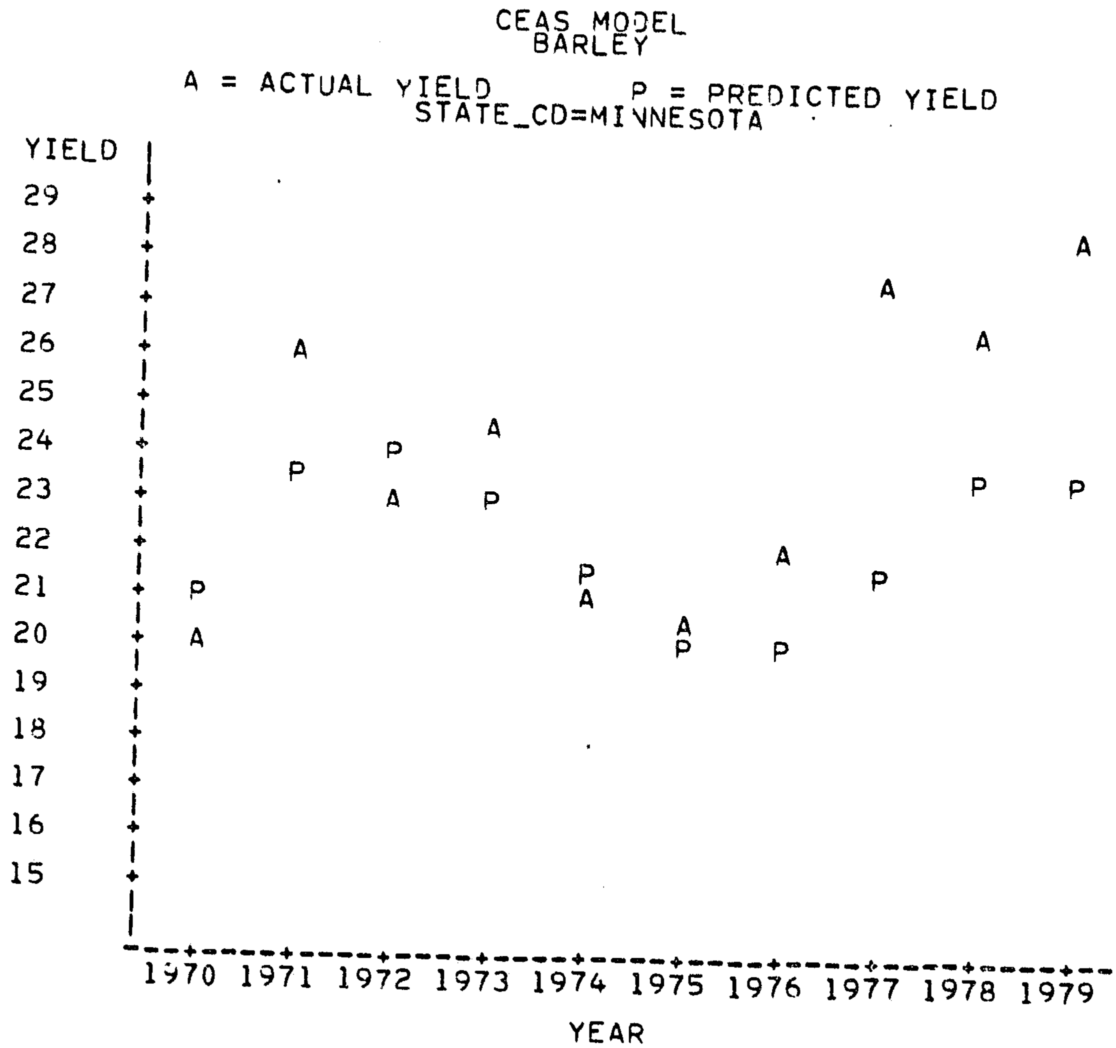

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TABLE 2
INDICATORS OF YIELD RELIABILITY
BASED ON D = PREDICTED - ACTUAL YIELD

CEAS MODEL - BARLEY
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	8.95	2.99	15.4	6.36	2.52	12.0	2.59	1.61	8.3
	20	11.53	3.39	17.9	9.84	3.14	15.5	1.69	1.30	6.9
	30	5.78	2.40	11.0	4.88	2.21	9.7	0.90	0.95	4.3
	40	25.05	5.01	25.8	21.78	4.67	26.5	3.28	-1.81	-9.3
	50	16.87	4.11	21.8	14.62	3.82	22.1	2.25	-1.50	-8.0
	60	10.65	3.26	14.0	10.08	3.18	13.2	0.56	0.75	3.2
	70	15.17	3.90	20.6	14.78	3.84	21.0	0.40	-0.63	-3.3
	80	13.23	3.64	22.7	13.06	3.61	23.2	0.17	-0.41	-2.6
	90	12.94	3.60	18.0	11.38	3.37	18.0	1.56	-1.25	-6.2
STATE MODEL		11.22	3.35	15.9	7.38	2.72	14.3	3.84	-1.96	-9.3
CRDS AGGR.		5.93	2.44	11.6	5.77	2.40	11.2	0.16	0.40	1.9
MINNESOTA	10	6.49	2.55	10.2	1.47	1.21	5.4	5.02	-2.24	-9.0
	40	23.94	4.89	21.9	19.58	4.42	21.9	4.37	-2.09	-9.4
STATE MODEL		8.35	2.89	12.1	4.93	2.22	10.0	3.42	-1.85	-7.7
CRDS AGGR.		7.00	2.65	11.0	2.63	1.62	7.4	4.37	-2.09	-8.7
REGION										
CRDS AGGR.		4.38	2.09	9.6	4.30	2.07	9.6	0.08	-0.28	-1.3
STATES AGGR.		9.75	3.12	14.3	5.95	2.44	12.3	3.80	-1.95	-8.9

Figure 4: Root Mean Square Error (RMSE) for barley in quintals per hectare based on test years 1970-1979. Darker shades indicate CRD's with higher production.

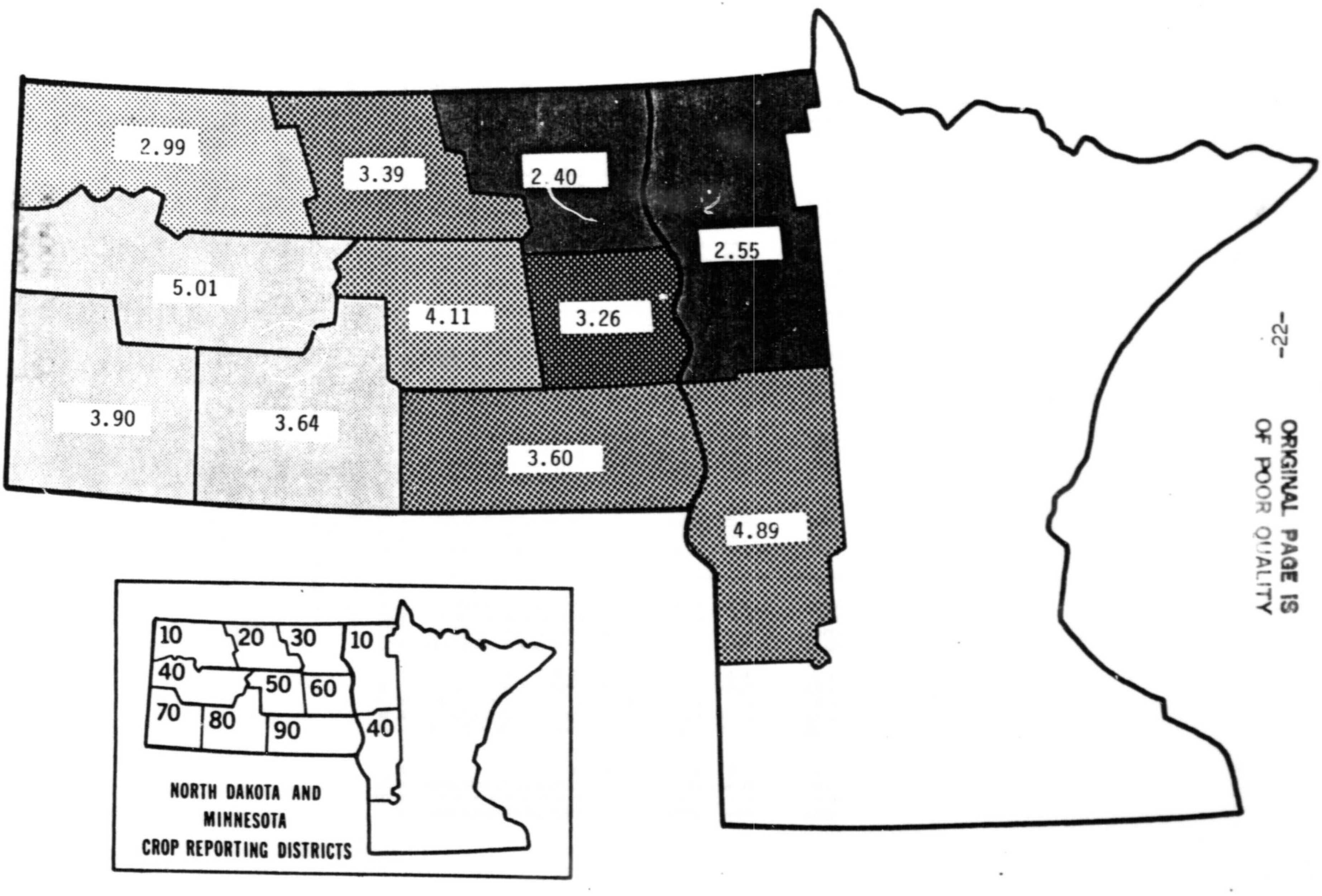

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TABLE 3
INDICATORS OF YIELD RELIABILITY
BASED ON RD = 100 * ((PREDICTED-ACTUAL YIELD)/ACTUAL YIELD)

CEAS MODEL - BARLEY
NORTH DAKATO AND MINNESOTA

STATE	CRD	PERCENT OF YEARS |RD|>10%	LARGEST |RD| RD (YEAR)	NEXT LARGEST	SMALLEST |RD|	RANGE |RD|
N.DAKOTA	10	40	44.9 (1974)	30.7	0.5	44.4
	20	70	68.9 (1974)	21.5	0.0	68.9
	30	30	38.5 (1974)	14.4	-1.2	37.3
	40	80	71.8 (1974)	-38.1	0.4	71.4
	50	70	41.5 (1974)	36.6	0.6	40.9
	60	60	29.7 (1970)	25.0	-1.7	28.1
	70	60	46.4 (1974)	-28.5	2.4	44.0
	80	90	58.4 (1974)	-26.6	-4.7	53.7
	90	60	36.8 (1974)	-27.9	1.1	35.8
STATE MODEL		70	26.5 (1974)	-19.1	-1.4	25.1
CRDS AGGR.		30	39.1 (1974)	13.7	-1.0	38.1
MINNESOTA	10	50	-14.2 (1976)	-12.9	-0.5	13.7
	40	50	-38.6 (1977)	36.1	0.5	38.2
STATE MODEL		30	-21.5 (1977)	-17.2	-2.0	19.6
CRDS AGGR.		30	-19.3 (1977)	-16.0	0.4	18.8
REGION						
CRDS AGGR.		20	24.7 (1974)	-12.7	2.4	22.3
STATES AGGR.		70	-19.2 (1977)	18.0	-0.5	18.8

Figure 5: Percent of test years (1970-1979) the absolute value of the relative difference is greater than ten percent for barley. Darker shades indicate CRD's with higher production.

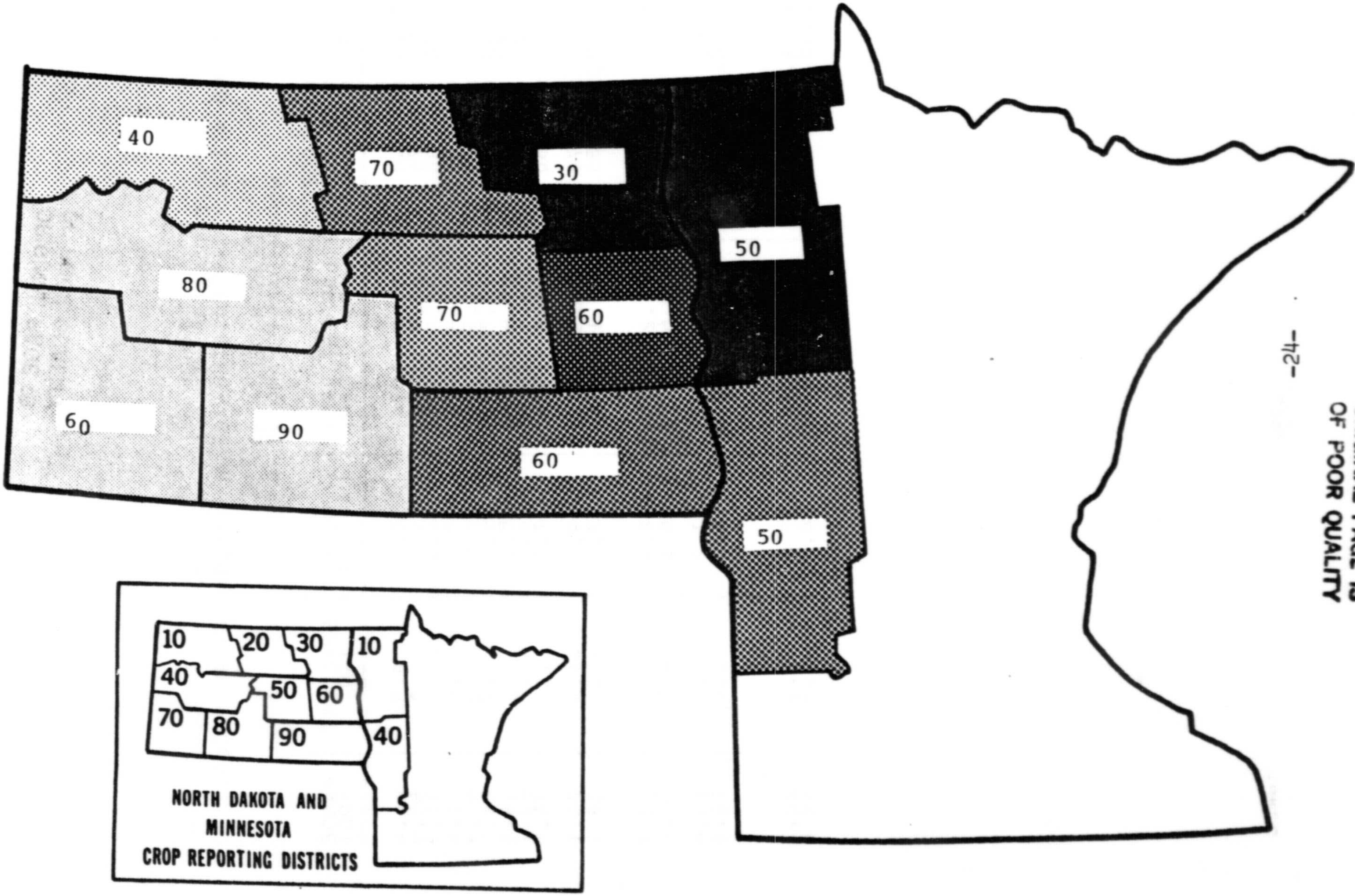

Figure 6: Largest absolute value of the relative difference for barley during the test years 1970-1979. Darker shades indicate CRD's with higher production.

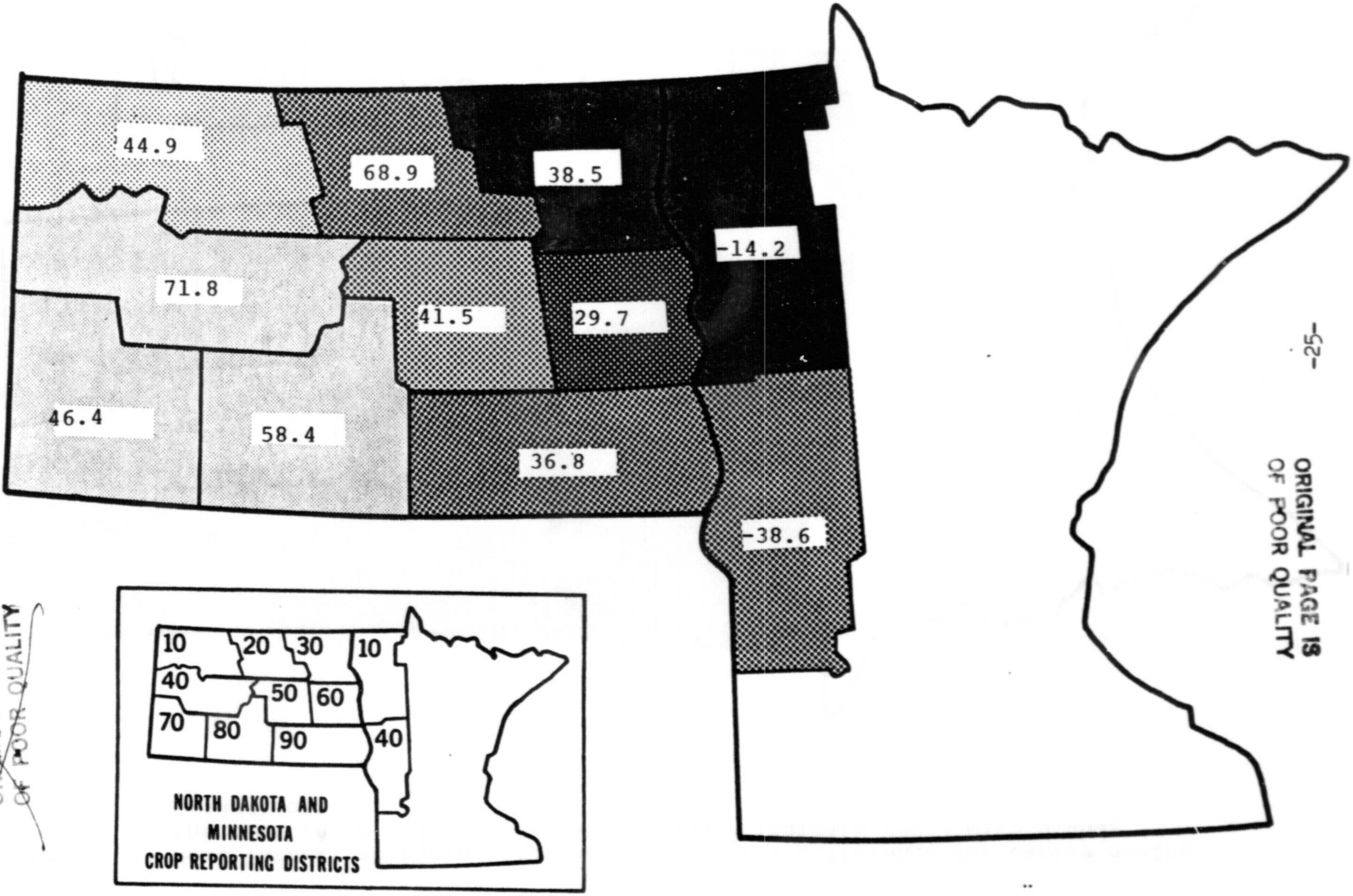

Figure 7: Next largest absolute value of the relative difference for barley during the test years 1970-1979. Darker shades indicate CRD's with higher productions.

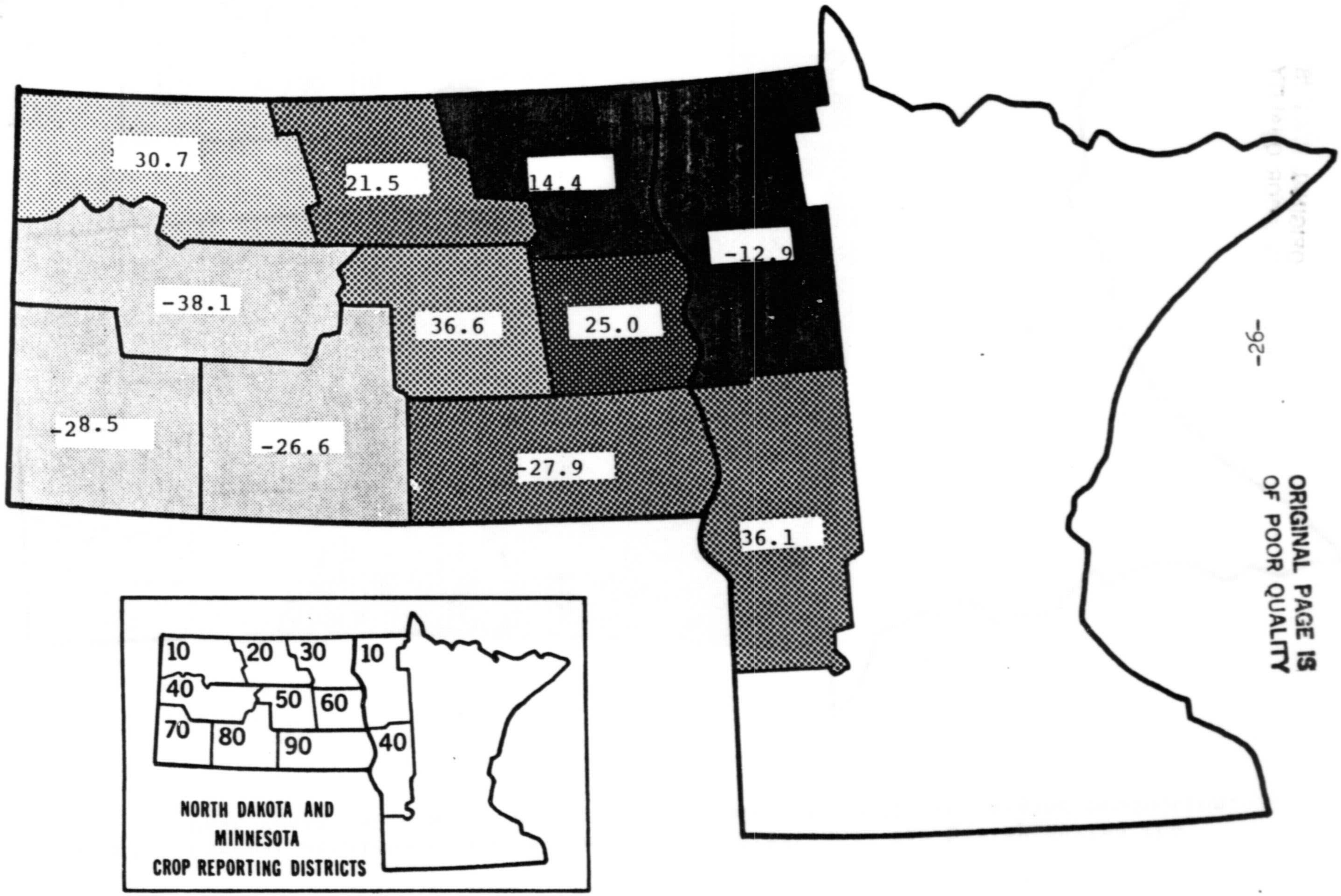

TABLE 4
INDICATORS OF YIELD RELIABILITY
BASED ON ACTUAL AND PREDICTED YIELDS

CEAS MODEL - BARLEY
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	67	43	0.57
	20	33	86	0.05
	30	78	71	0.79
	40	56	57	0.17
	50	56	57	0.29
	60	56	71	0.57
	70	44	43	0.23
	80	44	57	0.27
	90	44	71	0.42
STATE MODEL		33	57	0.35
CRDS AGGR.		67	71	0.57
MINNESOTA	10	78	100	0.95
	40	33	71	0.18
STATE MODEL		56	86	0.69
CRDS AGGR.		67	86	0.86
REGION				
CRDS AGGR.		78	71	0.73
STATES AGGR.		67	71	0.48

Figure 8: Percent of test years (1970-1979) the direction of change in predicted yield from the previous year agrees with direction of change in actual barley yield. Darker shades indicate CRD's with higher production.

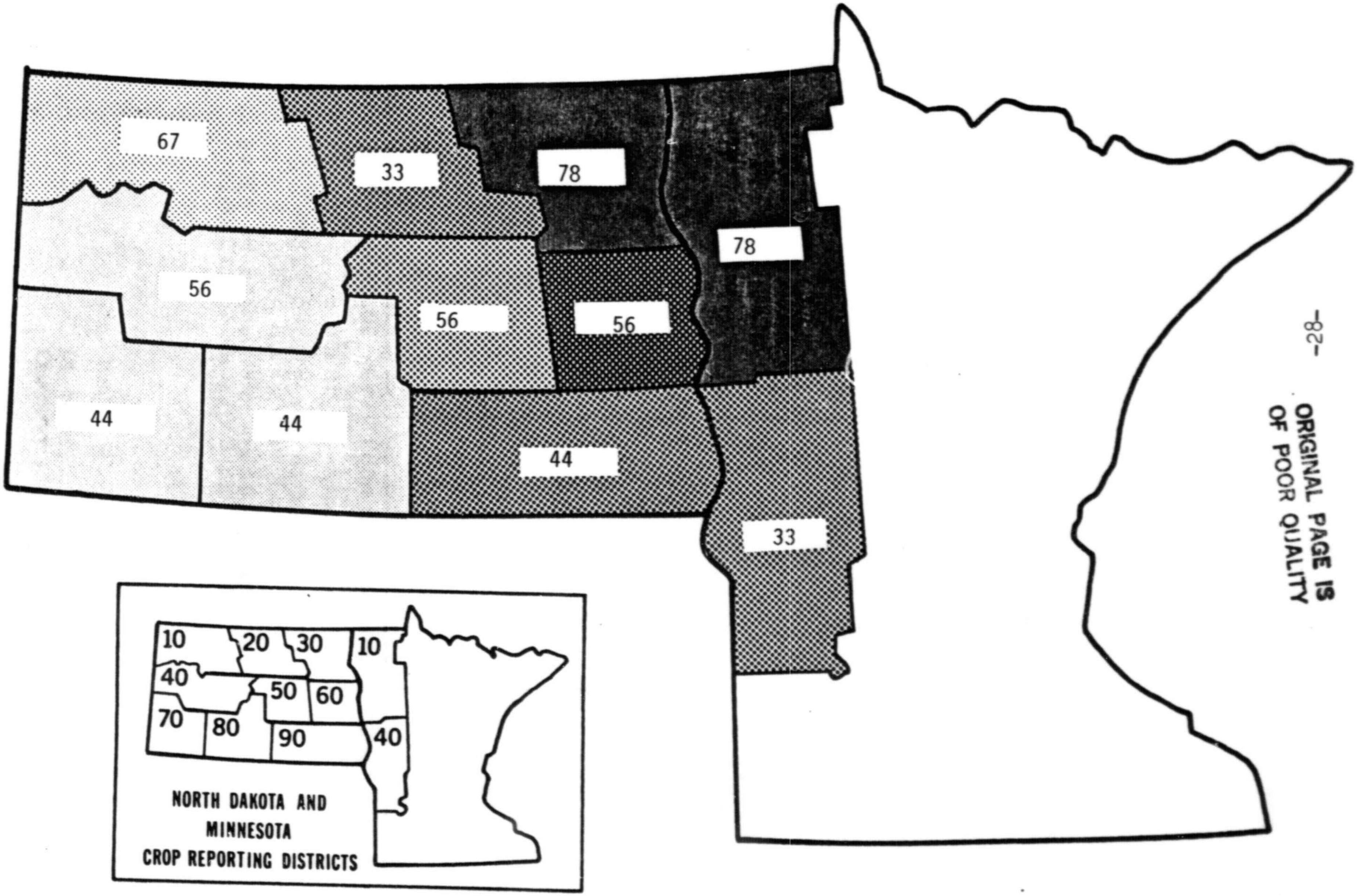

Figure 9: Percent of test years (1970-1979) the directions of change of predicted yield from the previous three year average agrees with the direction of change in actual barley yield. Darker shades indicate CRD's with higher production.

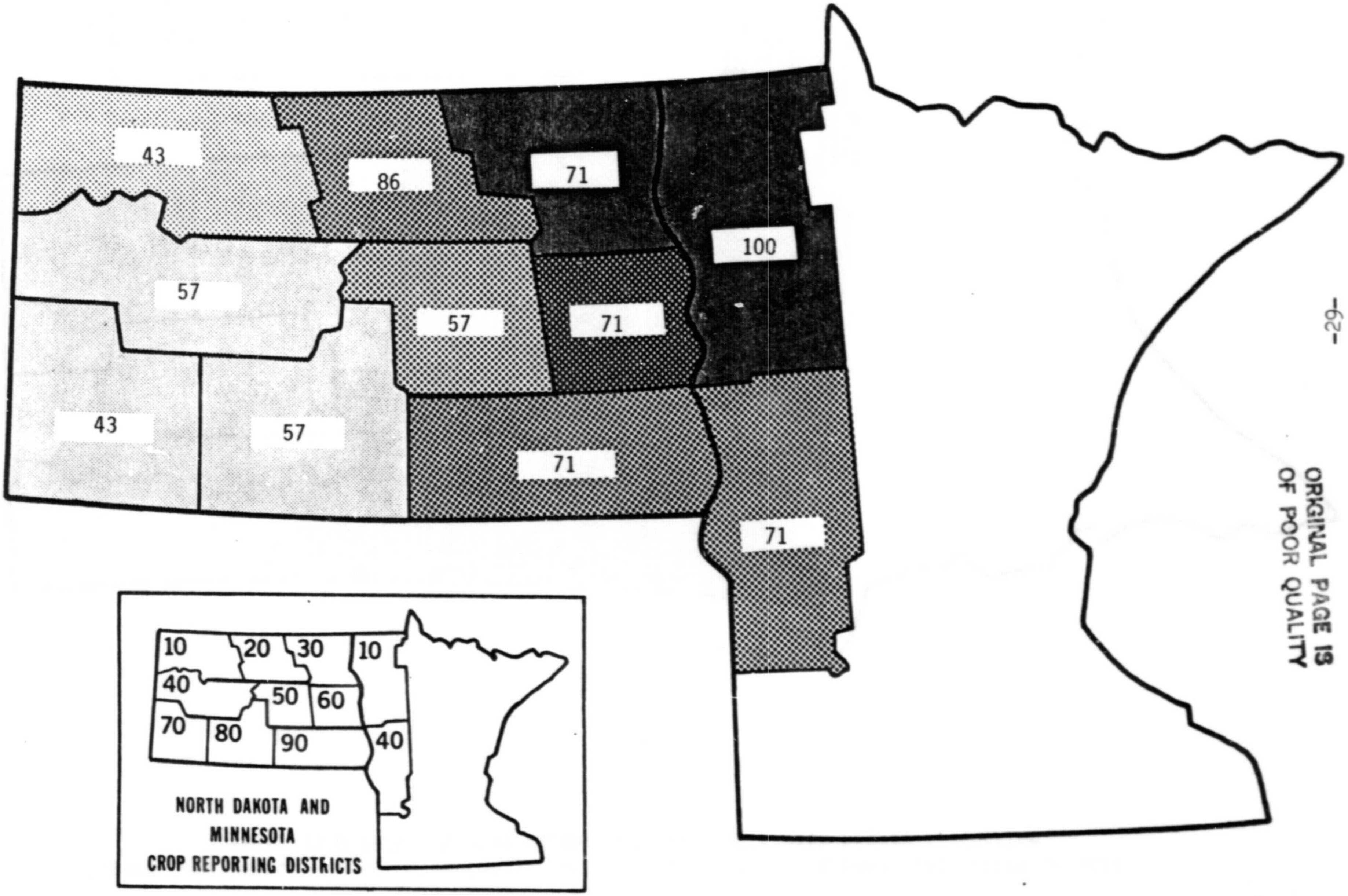

Figure 10: Pearson Correlation Coefficient between actual and predicted yields in test years 1970-1979. Darker shades indicate CRD's with higher production.

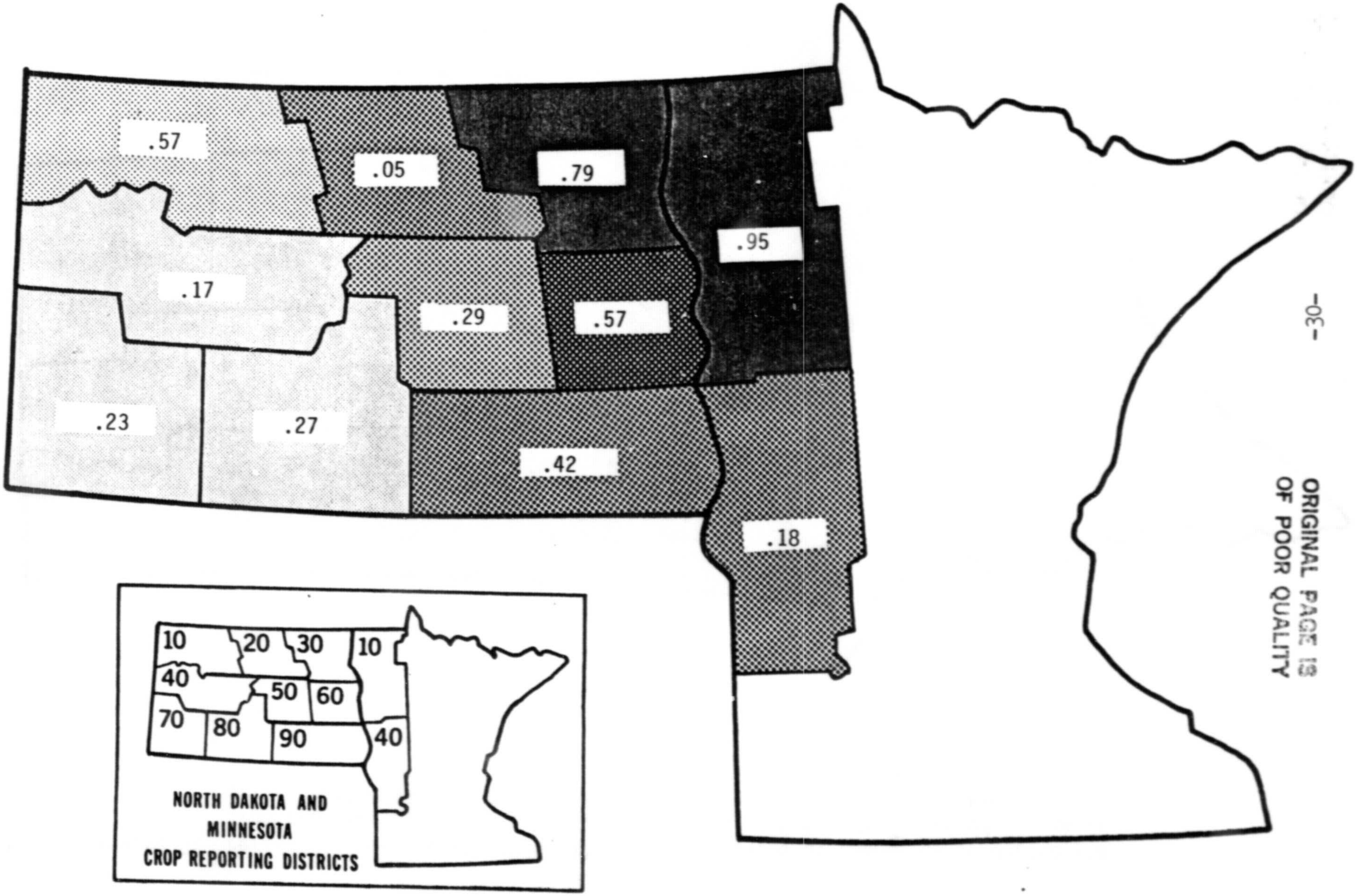

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TABLE 5
RESIDUAL MEAN SQUARE AS AN
INDICATOR OF THE FIT OF THE MODEL
BASED ON THE MODEL DEVELOPMENT BASE PERIOD

CEAS MODEL - BARLEY
NORTH DAKOTA AND MINNESOTA

STATE	CRD	BASE PERIOD RESIDUAL MEAN SQUARE LOW	HIGH	AVERAGE	INDEPENDENT TEST MSE
N.DAKOTA	10	5.33	6.29	5.78	8.95
	20	5.12	6.37	5.76	11.53
	30	2.63	3.21	2.90	5.78
	40	3.63	5.63	4.81	25.05
	50	4.73	5.99	5.20	16.87
	60	2.02	3.07	2.71	10.65
	70	4.58	5.69	5.20	15.17
	80	3.54	4.24	3.94	13.23
	90	2.40	2.76	2.58	12.94
STATE MODEL		1.99	2.77	2.25	11.22
MINNESOTA	10	1.58	1.89	1.68	6.49
	40	5.21	7.03	5.74	23.94
STATE MODEL		3.26	3.79	3.56	8.35

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

CEAS MODEL - BARLEY
NORTH DAKOTA AND MINNESOTA

TEST STATE	CRD	BASE PERIOD CORRELATION COEF. LOW	HIGH	AVERAGE	INDEPENDENT CORR. COEF.
N.DAKOTA	10	0.91	0.93	0.92	0.57
	20	0.87	0.90	0.88	0.05
	30	0.93	0.95	0.94	0.79
	40	0.92	0.94	0.93	0.17
	50	0.91	0.93	0.92	0.29
	60	0.94	0.96	0.95	0.57
	70	0.92	0.93	0.93	0.23
	80	0.93	0.94	0.93	0.27
	90	0.96	0.97	0.97	0.42
STATE MODEL		0.95	0.96	0.96	0.35
MINNESOTA	10	0.97	0.97	0.97	0.95
	40	0.91	0.93	0.92	0.18
STATE MODEL		0.91	0.94	0.93	0.69

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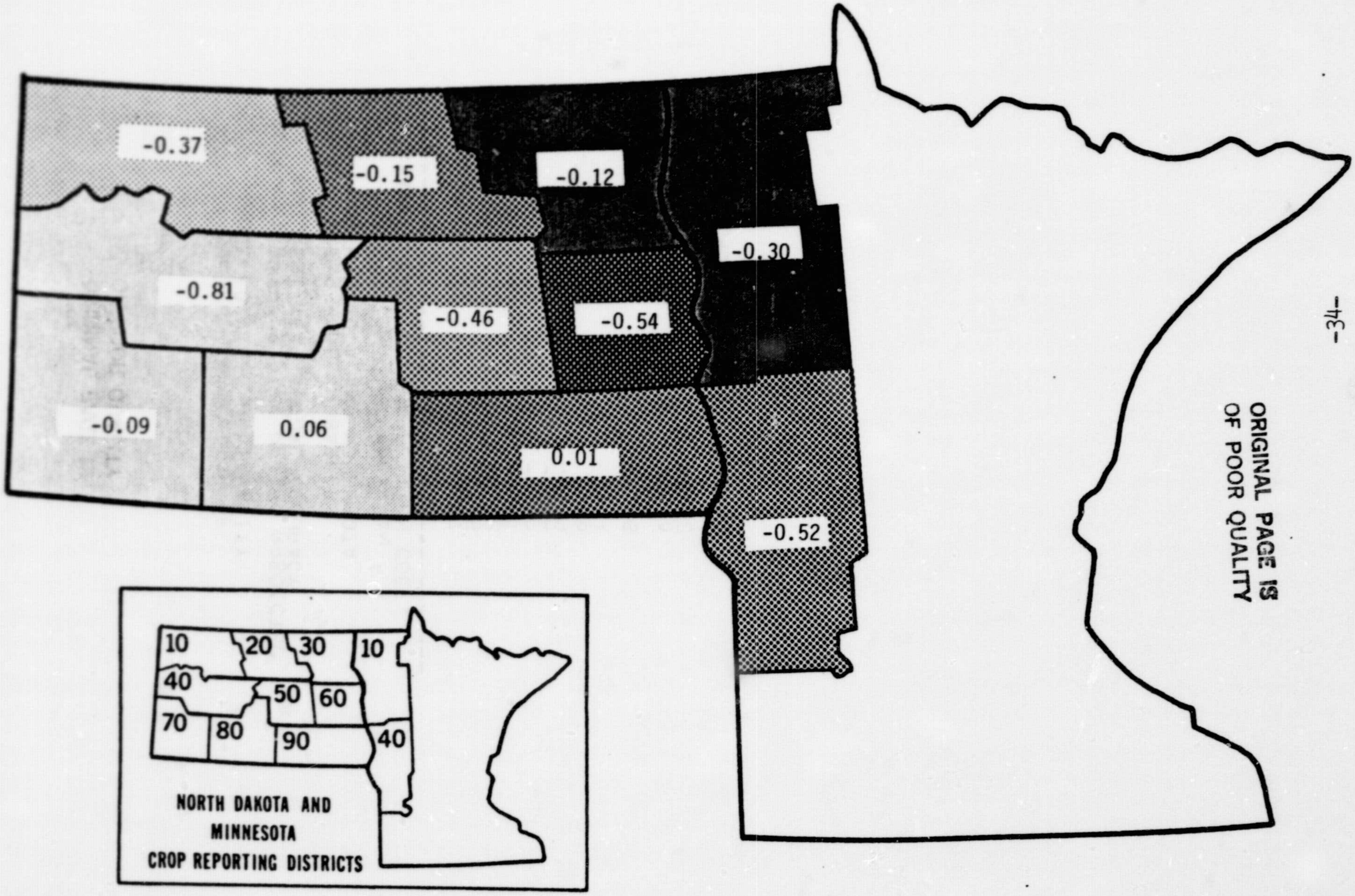
TABLE 7
CURRENT INDICATION OF
MODELED YIELD RELIABILITY

AGREEMENT BETWEEN BASE PERIOD PREDICTED
AND TEST YEAR ACTUAL ACCURACY

CEAS MODEL - BARLEY
NORTH DAKOTA AND MINNESOTA

STATE	CRD	SPEARMAN CORRELATION COEF.
N.DAKOTA	10	-0.37
	20	-0.15
	30	-0.12
	40	-0.81
	50	-0.46
	60	-0.54
	70	-0.09
	80	0.06
	90	0.01
STATE MODEL		-0.35
MINNESOTA	10	-0.30
	40	-0.52
STATE MODEL		-0.55

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 barley yield in the test years 1970-1979. Darker shades indicate CRD's with higher production.



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APPENDIX 1
BOOTSTRAP TEST RESULTS
FOR BARLEY YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
N.DAKOTA	10	1970	20.1	23.5	3.4	16.9	2.86
		1971	20.9	22.1	1.2	5.7	2.81
		1972	21.0	23.1	2.1	10.0	2.73
		1973	22.5	21.2	-1.3	-5.8	2.73
		1974	13.8	20.0	6.2	44.9	2.69
		1975	16.6	21.7	5.1	30.7	2.84
		1976	19.0	19.1	0.1	0.5	2.90
		1977	18.6	17.7	-0.9	-4.8	2.79
		1978	25.0	23.5	-1.5	-6.0	2.73
		1979	16.9	18.6	1.7	10.1	2.71
	20	1970	18.6	22.6	4.0	21.5	2.78
		1971	21.4	21.5	0.1	0.5	2.80
		1972	20.6	20.6	0.0	0.0	2.70
		1973	20.4	22.5	2.1	10.3	2.63
		1974	12.2	20.6	8.4	68.9	2.61
		1975	17.7	19.6	1.9	10.7	2.88
		1976	19.8	17.7	-2.1	-10.6	2.87
		1977	16.4	18.4	2.0	12.2	2.90
		1978	22.5	19.0	-3.5	-15.6	2.81
		1979	19.7	19.8	0.1	0.5	2.75
	30	1970	19.5	21.6	2.1	10.8	2.04
		1971	24.5	25.1	0.6	2.4	2.07
		1972	21.9	23.1	1.2	5.5	2.04
		1973	20.1	23.0	2.9	14.4	1.89
		1974	14.8	20.5	5.7	38.5	2.17
		1975	22.7	21.3	-1.4	-6.2	2.14
		1976	22.3	21.6	-0.7	-3.1	2.06
		1977	21.8	23.5	1.7	7.8	1.97
		1978	24.4	24.1	-0.3	-1.2	1.95
		1979	27.2	24.9	-2.3	-8.5	1.92
	40	1970	17.1	19.9	2.8	16.4	3.19
		1971	21.5	13.3	-8.2	-38.1	3.00
		1972	23.9	24.0	0.1	0.4	3.23
		1973	20.8	14.4	-6.4	-30.8	3.13
		1974	11.7	20.1	8.4	71.8	3.06
		1975	17.4	18.1	0.7	4.0	3.27
		1976	19.9	14.7	-5.2	-26.1	3.08
		1977	16.7	14.1	-2.6	-15.6	3.35
		1978	25.5	21.6	-3.9	-15.3	3.13
		1979	19.6	15.8	-3.8	-19.4	3.32

APPENDIX 1
BOOTSTRAP TEST RESULTS
FOR BARLEY YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
N.DAKOTA	50	1970	17.7	17.8	0.1	0.6	3.65
		1971	24.5	21.3	-3.2	-13.1	3.38
		1972	20.4	19.0	-1.4	-6.9	3.30
		1973	14.5	19.8	5.3	36.6	3.16
		1974	12.3	17.4	5.1	41.5	3.46
		1975	19.9	14.6	-5.3	-26.6	3.24
		1976	18.3	15.4	-2.9	-15.8	3.07
		1977	16.7	11.2	-5.5	-32.9	3.13
		1978	22.9	17.1	-5.8	-25.3	3.09
		1979	20.9	19.5	-1.4	-6.7	3.15
	60	1970	17.5	22.7	5.2	29.7	1.81
		1971	26.5	25.2	-1.3	-4.9	1.99
		1972	22.6	25.0	2.4	10.6	1.85
		1973	21.3	25.0	3.7	17.4	1.81
		1974	18.4	23.0	4.6	25.0	1.94
		1975	21.5	20.9	-0.6	-2.8	2.11
		1976	22.8	24.7	1.9	8.3	2.02
		1977	24.1	23.7	-0.4	-1.7	2.02
		1978	28.6	25.3	-3.3	-11.5	1.90
		1979	29.3	24.6	-4.7	-16.0	2.07
	70	1970	16.4	16.8	0.4	2.4	3.79
		1971	21.6	15.5	-6.1	-28.2	3.27
		1972	21.4	25.1	3.7	17.3	3.47
		1973	22.1	18.0	-4.1	-18.6	3.19
		1974	15.3	22.4	7.1	46.4	3.12
		1975	16.9	16.2	-0.7	-4.1	3.38
		1976	19.6	17.0	-2.6	-13.3	3.22
		1977	17.2	12.3	-4.9	-28.5	4.13
		1978	20.8	22.2	1.4	6.7	3.25
		1979	17.7	17.2	-0.5	-2.8	3.05
	80	1970	13.0	16.4	3.4	26.2	3.43
		1971	21.4	15.7	-5.7	-26.6	2.94
		1972	18.9	22.1	3.2	16.9	3.00
		1973	16.3	14.4	-1.9	-11.7	2.87
		1974	10.1	16.0	5.9	58.4	2.72
		1975	17.8	14.6	-3.2	-18.0	3.08
		1976	14.2	16.0	1.8	12.7	2.92
		1977	12.7	12.1	-0.6	-4.7	2.83
		1978	19.0	16.3	-2.7	-14.2	2.65
		1979	16.5	12.2	-4.3	-26.1	2.65

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APPENDIX 1
BOOTSTRAP TEST RESULTS
FOR BARLEY YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
N.DAKOTA	90	1970	18.5	17.5	-1.0	-5.4	2.82
		1971	24.8	20.9	-3.9	-15.7	2.47
		1972	21.3	23.1	1.8	8.5	2.54
		1973	18.7	18.9	0.2	1.1	2.40
		1974	17.1	23.4	6.3	36.8	2.82
		1975	17.8	15.5	-2.3	-12.9	2.45
		1976	13.8	13.4	-0.4	-2.9	2.57
		1977	23.1	19.1	-4.0	-17.3	2.60
		1978	22.3	19.5	-2.8	-12.6	2.35
		1979	22.9	16.5	-6.4	-27.9	2.37
STATE MODEL		1970	18.3	19.7	1.4	7.7	2.43
		1971	24.2	19.9	-4.3	-17.8	2.19
		1972	21.5	21.2	-0.3	-1.4	2.30
		1973	19.9	18.5	-1.4	-7.0	2.12
		1974	15.1	19.1	4.0	26.5	2.36
		1975	20.4	16.5	-3.9	-19.1	2.19
		1976	20.4	17.6	-2.8	-13.7	2.16
		1977	21.0	17.2	-3.8	-18.1	2.04
		1978	24.7	20.2	-4.5	-18.2	2.07
		1979	24.7	20.7	-4.0	-16.2	2.10
CRDS AGGR.		1970	18.3	20.8	2.5	13.7	
		1971	24.2	23.0	-1.2	-5.0	
		1972	21.5	22.9	1.4	6.5	
		1973	19.9	21.5	1.6	8.0	
		1974	15.1	21.0	5.9	39.1	
		1975	20.4	19.4	-1.0	-4.9	
		1976	20.4	20.1	-0.3	-1.5	
		1977	21.0	20.8	-0.2	-1.0	
		1978	24.7	22.6	-2.1	-8.5	
		1979	24.7	22.1	-2.6	-10.5	

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APPENDIX 1
BOOTSTRAP TEST RESULTS
FOR BARLEY YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
MINNESOTA	10	1970	18.4	18.3	-0.1	-0.5	2.42
		1971	26.9	23.8	-3.1	-11.5	1.99
		1972	24.8	24.2	-0.6	-2.4	1.88
		1973	24.2	22.7	-1.5	-6.2	1.82
		1974	20.9	18.8	-2.1	-10.0	1.89
		1975	21.5	19.6	-1.9	-8.8	1.75
		1976	26.7	22.9	-3.8	-14.2	1.84
		1977	27.4	24.1	-3.3	-12.0	1.76
		1978	28.4	26.2	-2.2	-7.7	1.85
		1979	29.4	25.6	-3.8	-12.9	1.84
	40	1970	22.9	20.7	-2.2	-9.6	4.14
		1971	25.2	25.8	0.6	2.4	3.71
		1972	19.3	21.3	2.0	10.4	3.51
		1973	26.3	20.0	-6.3	-24.0	3.28
		1974	21.2	21.3	0.1	0.5	3.49
		1975	18.6	18.0	-0.6	-3.2	3.30
		1976	13.3	18.1	4.8	36.1	3.23
		1977	27.7	17.0	-10.7	-38.6	3.13
		1978	22.2	20.7	-1.5	-6.8	3.51
		1979	26.4	19.3	-7.1	-26.9	3.43
STATE MODEL		1970	19.9	20.8	0.9	4.5	3.53
		1971	26.1	23.5	-2.6	-10.0	3.03
		1972	23.1	23.8	0.7	3.0	2.83
		1973	24.7	22.8	-1.9	-7.7	2.72
		1974	21.0	21.5	0.5	2.4	2.79
		1975	20.4	20.0	-0.4	-2.0	2.57
		1976	22.1	20.2	-1.9	-8.6	2.53
		1977	27.4	21.5	-5.9	-21.5	2.41
		1978	26.6	23.6	-3.0	-11.3	2.52
		1979	28.5	23.6	-4.9	-17.2	2.54
CRDS AGGR.		1970	19.9	19.1	-0.8	-4.0	
		1971	26.3	24.5	-1.8	-6.8	
		1972	23.3	23.4	0.1	0.4	
		1973	24.8	21.9	-2.9	-11.7	
		1974	21.0	19.7	-1.3	-6.2	
		1975	20.5	19.1	-1.4	-6.8	
		1976	22.2	21.3	-0.9	-4.1	
		1977	27.5	22.2	-5.3	-19.3	
		1978	26.8	24.8	-2.0	-7.5	
		1979	28.7	24.1	-4.6	-16.0	

APPENDIX 1
BOOTSTRAP TEST RESULTS
FOR BARLEY YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
REGION CRDS	AGGR.	1970	18.6	20.4	1.8	9.7	
		1971	24.8	23.4	-1.4	-5.6	
		1972	21.9	23.0	1.1	5.0	
		1973	21.1	21.6	0.5	2.4	
		1974	16.6	20.7	4.1	24.7	
		1975	20.5	19.3	-1.2	-5.9	
		1976	20.9	20.4	-0.5	-2.4	
		1977	22.9	21.2	-1.7	-7.4	
		1978	25.4	23.2	-2.2	-8.7	
		1979	26.0	22.7	-3.3	-12.7	
STATES	AGGR.	1970	18.7	20.0	1.3	7.0	
		1971	24.7	20.9	-3.8	-15.4	
		1972	21.9	21.8	-0.1	-0.5	
		1973	21.1	19.5	-1.6	-7.6	
		1974	16.7	19.7	3.0	18.0	
		1975	20.4	17.5	-2.9	-14.2	
		1976	20.9	18.3	-2.6	-12.4	
		1977	22.9	18.5	-4.4	-19.2	
		1978	25.3	21.2	-4.1	-16.2	
		1979	25.9	21.6	-4.3	-16.6	

APPENDIX 2: Terms and Range of Values of Coefficients

CEAS	NORTH DAKOTA									STATE	MINNESOTA		
BARLEY	10	20	30	40	50	60	70	80	90	ND	10	40	MN
Trend 1	0.2398 0.2755	0.22 0.25	0.152 0.169	0.127 0.158	0.167 0.198	0.202 0.278	0.180 0.2193	0.041 0.051	0.159 0.143	0.129 0.152	0.128 0.155	0.175 0.200	0.086 0.103
Trend 2	0.31 0.74	0.32 0.74	0.57 0.88	1.07 2.36	1.03 1.94	0.489 0.931	1.00 1.60	0.99 1.54	1.90 1.78	1.08 2.09	0.86 1.95	1.46 2.31	1.186 1.973
Trend 2SQ				-0.223 -0.035	-0.128 -0.031		-0.108 -0.016	-0.101 -0.017	-0.118 -0.039	-0.162 -0.037	-0.15 -0.02	-0.177 -0.073	-0.131 -0.041
CMAY				0.033 0.045					0.0119 0.0194	0.0098 0.0179			
TD4						0.367 0.428	0.866 0.913	0.361 0.456	0.256 0.318		0.295 0.408	0.242 0.369	0.185 0.287
TD5				0.194 0.339					0.244 0.352				
TD6						-0.45 -0.30		-0.65 -0.49	-0.58 -0.51		-0.37 -0.33	-0.767 -0.675	-0.563 -0.518
TD7			-0.765 -0.607		-0.79 -0.50	-0.79 -0.62			-0.85 -0.53	-0.71 -0.51	-1.44 -1.32	-0.964 -0.850	-0.813 -0.726
TD8									-0.67 -0.41				
RD5SQ								0.00108 0.00118	-0.00070 -0.00053		-0.00035 -0.00023		
RD6SQ										-0.00038 -0.00014			
RD7SQ					0.000499 0.000415		0.00050 0.00094					-0.000561 -0.000475	-0.00039 -0.00034
RD8SQ							-0.0018 -0.0015						
AET4						24.4 27.0	23.8 32.2		23.137 25.892				
AET5			5.102 5.890					5.56 6.35					

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AET6	12.25 12.87	7.76 8.34			9.57 11.26		6.92 8.96		
AET8			-1.84 -0.27			6.18 6.76			
DEF6			0.021 0.033	0.038 0.045					
DEF7	0.40 0.53	0.0421 0.0494	0.018 0.02	0.027 0.036					
MR6								3.17 4.29	
MR7									-1.86 -1.22

TREND 1, TREND2, TREND2SQ as defined in text;

CMAY = cumulative precipitation September through May

TD4,5,6,7,8 = temperature departure from normal for April, May, June, July, August, respectively

RD5SQ, RD6SQ, RD7SQ, RD8SQ = squares of precipitation departures from normal for May, July, August respectively

AET4,5,6,8 = actual evapotranspiration estimated from monthly temperatures nad precipitation for April, May, June and August respectively

DEF6,7 = deficits (precipitation - potential evapotranspiration) for June, July

MR6,7 = moisture ratios (precipitation/potential evapotranspiration) for June, July

Pairs of numbers represent minimum and maximum values of coefficients over 10 year test period.