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COMPARISON OF THE CEAS AND WILLIAMS-TYPE BARLEY YIELD MODELS FOR NORTH DAKOTA AND MINNESOTA

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16. Abstract

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Comparison of CEAS and Williams-Type Barley Models for North Dakota and Minnesota

by

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Yield Model Development
Project

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ABSTRACT

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

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by Sharon LeDuc

Review of Models

The CEAS (Motha, 1980) and the Williams-Type (Williams 1975) barley models are multiple regression models which use monthly mean temperature and monthly total precipitation data as the basis for developing predictor variables. The temperature and precipitation are the average for all stations within a crop reporting district. Information on the models is available in two papers: "Evaluation of CEAS Barley Model in North Dakota and Minnesota" and "Evaluation of Williams Type Barley Model in North Dakota and Minnesota" (Barnett, 1981). The Williams-Type model was designed to parallel the models by Williams (1975) but still be comparable to the CEAS models. Trend is handled identically in the two models as a linear and quadratic function of year. The distinguishing differences are the inclusion of soil texture and topographical variables in the Williams type model and the subsequent pooling of cross sectional data (the separate crop reporting districts) in selecting predictor variables and estimating the coefficients.

Comparison Methodology

Eight Model Characteristics to be Compared

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 cost, simplicity, and accurate current measures of modeled yield reliability.

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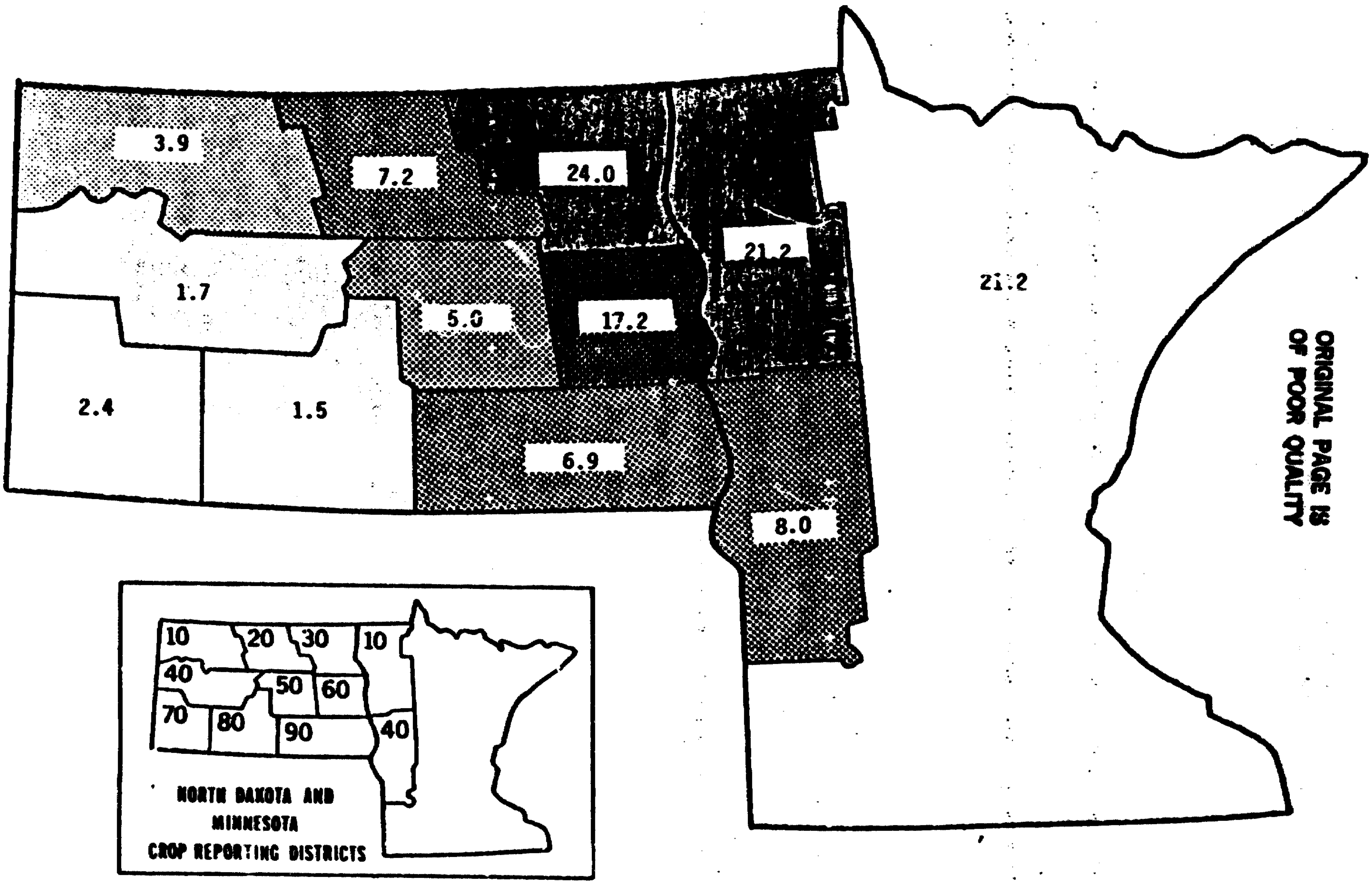
TABLE 1
AVERAGE PRODUCTION AND YIELD
FOR TEST YEARS 1970-74

BARLEY
NORTH DAKOTA AND MINNESOTA

STATE	CRD	PRODUCTION (1.000) QUINTALS	BUSHELS	PERCENT OF STATE	REGION	YIELD QNTL/HA	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	30.125	34.3	24.0	21.9	40.9
	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		69.5	21.0	39.1
MINNESOTA	10	5.801	26.645	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	35.5
	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		27.373	125.748			21.9	40.6

Figure 1. Production of barley by CRD (1970–79 average) as a percent of the regional total. Darker shades indicate CRDs with higher production.



The models will be compared using these characteristics; each is discussed individually without regard to the other characteristics. The present discussion makes no presumption as to the relative importance of the characteristics.

Quantitative Model Comparisons Are Based on the Same Data

Direct quantitative comparisons between models will be made for two of the previously mentioned criteria: (1) yield indication reliability and (2) accurate current measures of modeled yield reliability. The quantities involved are derived from the observed yields and the model predicted yields and standard errors of prediction obtained from independent bootstrap tests for each of ten years (1970-1979). The same base period is used for all models in computing model related values for a particular year. The average production and yield over the ten year test period are listed in Table 1 for each geographic area. Also shown is the percent production each crop reporting district (CRD) contributes to its state and the three state region and the percent production each state contributes to the region. The percentage of regional production for each CRD is shown graphically in Figure 1. Darker shades indicate higher productivity. Separate models are derived for each CRD, state, and the region. Model related values (predictions and standard errors of prediction) at the state level are also obtained by using a weighted average of that state's CRD model values. Model related values for the region are also obtained using a weighted average of the values from the CRD models and from the state models. The weighting factor used is harvested acreage. Results obtained by aggregating from the CRD models are identified in tables as "CRD AGGR." Results obtained by aggregating from the state models are identified as "STATES AGGR."

In addition to the CEAS and Williams-type model, the "strawman" model is included in Tables 2-10, 12-14 and in Appendix 1. This model type is described by Sebaugh (1981) and will not be discussed here.

Models Are Ranked According to Performance

Models are ranked for each of the following indicators of yield reliability (order does not imply relative importance):

(1) the bias,

(2) the root mean square error (RMSE),

(3) the standard deviation (SD),

(4) the percent of years the absolute value of the relative difference exceeds ten percent,

(5) the largest absolute value of the relative difference,

(6) the next largest absolute value of the relative difference,

(7) the percent of years in which the direction of change from the previous year in the $\hat{Y}$'s agrees with the Y's.

(8) the percent of years in which the direction of change from the average of the previous three years in the Y's agrees with the Y's, and

(9) the Pearson correlation coefficient between the actual and predicted yields during the independent test years.

Models are also ranked according to the value of the Spearman correlation coefficient which indicates the utility of the model's current measure of modeled yield reliability. For most of the indicators (1-6), the model with the smallest numeric value exhibits the best performance in terms of yield reliability and is given a rank of 1. For the remaining quantities, the model with the largest value exhibits the most desirable performance. If models are tied for the same level of performance, they are all assigned the lowest rank for which they are tied. For example, if two models are tied for best performance, they are both assigned a rank of 1, the lower of ranks 1 and 2.

It should be remembered that the models are ranked only in relation to each other and not to an absolute standard. Therefore, saying that a particular model performs better, is superior to, or more desirable than another model does not necessarily imply that the model is the best of all possible models. It is the best of only those with which it is currently being compared.

Models are Compared Using Statistical Tests Based on $d = \hat{Y} - Y$

It is desirable to run a statistical test comparing the reliability of competing models. A formal statistical test considers the variability of model performance over time and allows the user to specify an upper limit on the probability of incorrectly declaring one model better than another. This probability is known as α, the level of significance, or the Type I error.

However, because of the manner in which models are chosen for testing and how they are evaluated, it is challenging to construct a meaningful statistical test. Only yield models which have been presented in the literature or developed by known experts are considered. Therefore, a priori, great differences between the reliability of the models are not expected. A powerful statistical procedure is needed which is able to detect small, although important, differences in reliability. Also, the test should be able to function well with relatively small samples of data for each model, say ten years.

The test should also perform well when only two models are being compared. Often only two models of a particular type, for example, two monthly weather data models or two daily weather data models, are competitive and available for testing. When models of different types are to be compared, it is unlikely that all possible model comparisons will be made. It is more likely that the best models of each type will be compared.

It would appear that an F test could be useful in comparing the mean square errors of two models. However, if the mean square errors are based on ten years of test data and $\alpha = .05$, then one model's mean square error must be four times larger than anothers before the models can be declared different. This is an unreasonable requirement since models which are in the evaluation process will almost always be more competitive than this.

A test may be constructed by considering that one model is considered more reliable than another model if its predicted yields, Y's, are closer to the actual yields, Y's. No difference in the reliability of two models for a particular year means that the absolute value of the difference between their predicted yields and the actual yield is the same. The absolute value of the difference is used because it does not matter whether one model over-estimates and the other underestimates or whether they both over or under-estimate. The reliability of a model for that year is related to the amount of the discrepancy, not its direction. We may define $|d_1| = |\hat{Y}_1 - Y|$, $|d_2| = |\hat{Y}_2 - Y|$, and $D = |d_1| - |d_2|$. The models are equally reliable in a year for which D equals zero. If D is not equal to zero, one model is more reliable than the other for that year. In formal terms, we want to test the null hypothesis that there is no difference in the reliability of the models over all years. To do so the values of D from the ten test years may be used to compute a test statistic and a decision made whether or not to reject the null hypothesis. Since the results for the models are paired each year, paired-sample statistical tests are used.

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Two types of paired-sample statistical tests are used: a parametric test using the student t-test statistic and a nonparametric test using the Wilcoxon signed rank test statistic. One reason for applying both tests is that they require different assumptions. The parametric t-test assumes the D values are normally distributed while the nonparametric test does not. The d values may be considered to be approximately normally distributed. The | d | values would then be folded normals rather than normally distributed. Although both models are folded at | d | = 0, their means may be different and the distribution of D has a possibility of not being normally distributed. The t-test is robust with respect to the normality assumption; however, this possible violation of the assumption is one reason for also running the non-parametric test.

The other reason for running both tests concerns the conditions under which the null hypothesis is rejected by each test. Using the parametric test, the basis for rejecting the null hypothesis is the average size of the D values as compared to their variability. The t-test statistic is the average of the sample D's divided by the sample standard error of the D's. The hypothesis will be rejected and the model with the smaller | d | values declared more reliable if t is large (either positive or negative). However, it is possible that one model could have a smaller | d | value for each of the test years, in other words, be very consistent in outperforming the other model, and still the null hypothesis may not be rejected by the parametric test unless the average value of D is large enough. The parametric test implicitly requires that one model have more years with | d | values smaller by a sufficient amount before that model may be declared more reliable.

Using the nonparametric test, the null hypothesis will always be rejected if one model has smaller | d | values for each of the test years, regardless of the magnitude of the D values. Therefore, if the models are very competitive in terms of the | d | values each year, but one model consistently, although slightly, outperforms the other model, the nonparametric test will still declare the consistent model to be more reliable.

The hypothesis of equal model performance will only be rejected by the nonparametric test if one model has more years with smaller | d | values than the other model. The model with more smaller | d | values is considered the more reliable model in terms of consistency of performance. However, to reject the null hypothesis and declare one model clearly better than another, consistency of performance is a necessary, but not a sufficient, requirement. Consider the situation in which one model is more consistent than the other but the largest D values occur when the less consistent model performs better. In the few years the less consistent model performs better, it performs much better. A dilemma exists since one model is more consistent than the other but the biggest differences between the models occur when the consistent model performs worse. The null hypothesis will not be rejected and the consistent model will not be declared better if this situation occurs. The null hypothesis will be rejected only if one model is more consistent and the biggest differences between the models occur when the consistent model performs better.

MODEL COMPARISON

Indicators of Yield Reliability Based on $d = \hat{Y} - Y$ Show Williams-type Preferred for CRD Models, but CEAS Models Better for Aggregated Estimates

The model values and comparative ranks for the bias, the root mean square error (RMSE), and the standard deviation (SD) are given in Tables 2, 3, and 4. Most (all but 4) individual CRD estimates from the Williams type model are less biased than the estimates from the CEAS models. The CEAS state model estimates and regional estimates aggregated from the CRD estimates are less biased than those from the Williams type model (Table 2).

The results shown in Table 3 indicate smaller RMSE for eight CRD's with the Williams-type model, Figure 2; for the CRD's aggregated to state or regional values the CEAS model had smaller RMSE. The Williams type model generally has smaller standard deviations than the CEAS models (Table 4). The CEAS aggregated CRDs had smaller standard deviations for Minnesota and the region. One reason is that the CEAS CRD models are better in ND 30 and MN 10, both high production areas.

Indicators of Yield Reliability Based on $rd = (d/Y^*$ 100 Show Williams Type Slightly Better for CRD estimates

The model values and comparative ranks for the indicators of yield reliability based on the relative difference, rd, are given in Tables 5, 6, and 7. These indicators are valuable for demonstrating the worst performance of a model. Therefore, the better performing model will have the smaller value for percentage years when the absolute value of the relative

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TABLE 2
MODEL COMPARISON BASED ON THE
BIAS (QUINTALS/HECTARE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	BIAS	RANK	BIAS	RANK	BIAS	RANK
N.DAKOTA	10	2.02	(3)	-1.06	(1)	1.61	(2)
	20	1.68	(3)	-0.45	(1)	1.30	(2)
	30	0.47	(1)	-1.15	(3)	0.95	(2)
	40	1.02	(1)	-1.40	(2)	-1.81	(3)
	50	1.96	(3)	-1.28	(1)	-1.50	(2)
	60	0.74	(1)	-3.31	(3)	0.75	(2)
	70	2.16	(3)	-0.58	(1)	-0.63	(2)
	80	1.76	(3)	1.07	(2)	-0.41	(1)
	90	2.31	(2)	-2.95	(3)	-1.25	(1)
STATE MODEL		1.16	(1)	-2.31	(3)	-1.96	(2)
CRDS AGGR.		1.12	(2)	-1.75	(3)	0.40	(1)
MINNESOTA	10	0.19	(1)	-3.06	(3)	-2.24	(2)
	40	2.86	(3)	-0.87	(1)	-2.09	(2)
STATE MODEL		1.00	(1)	-1.90	(3)	-1.85	(2)
CRDS AGGR.		1.03	(1)	-2.38	(3)	-2.09	(2)
REGION							
CRDS AGGR.		1.07	(2)	-1.95	(3)	-0.28	(1)
STATES AGGR.		1.12	(1)	-2.20	(3)	-1.95	(2)

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TABLE 3
MODEL COMPARISON BASED ON THE
ROOT MEAN SQUARE ERROR (QUINTALS/HECTARE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	RMSE	RANK	RMSE	RANK	RMSE	RANK
N.DAKOTA	10	4.19	(3)	2.95	(1)	2.99	(2)
	20	3.67	(3)	2.65	(1)	3.39	(2)
	30	3.15	(3)	3.02	(2)	2.40	(1)
	40	4.36	(2)	3.05	(1)	5.01	(3)
	50	4.34	(3)	2.73	(1)	4.11	(2)
	60	3.50	(2)	4.41	(3)	3.26	(1)
	70	3.62	(2)	2.32	(1)	3.90	(3)
	80	4.04	(3)	2.67	(1)	3.64	(2)
	90	4.33	(3)	3.46	(1)	3.60	(2)
STATE MODEL		3.12	(1)	3.30	(2)	3.35	(3)
CRDS AGGR.		3.10	(3)	2.80	(2)	2.44	(1)
MINNESOTA	10	2.84	(2)	4.21	(3)	2.55	(1)
	40	5.60	(3)	3.07	(1)	4.89	(2)
STATE MODEL		2.97	(3)	2.97	(2)	2.89	(1)
CRDS AGGR.		2.96	(2)	3.34	(3)	2.65	(1)
REGION							
CRDS AGGR.		2.94	(3)	2.85	(2)	2.09	(1)
STATES AGGR.		2.92	(1)	3.07	(2)	3.12	(3)

Figure 2. Number indicates the model with smallest root mean square error for barley yields based on test years 1970-1979. Darker shades indicate CRDs with higher production.

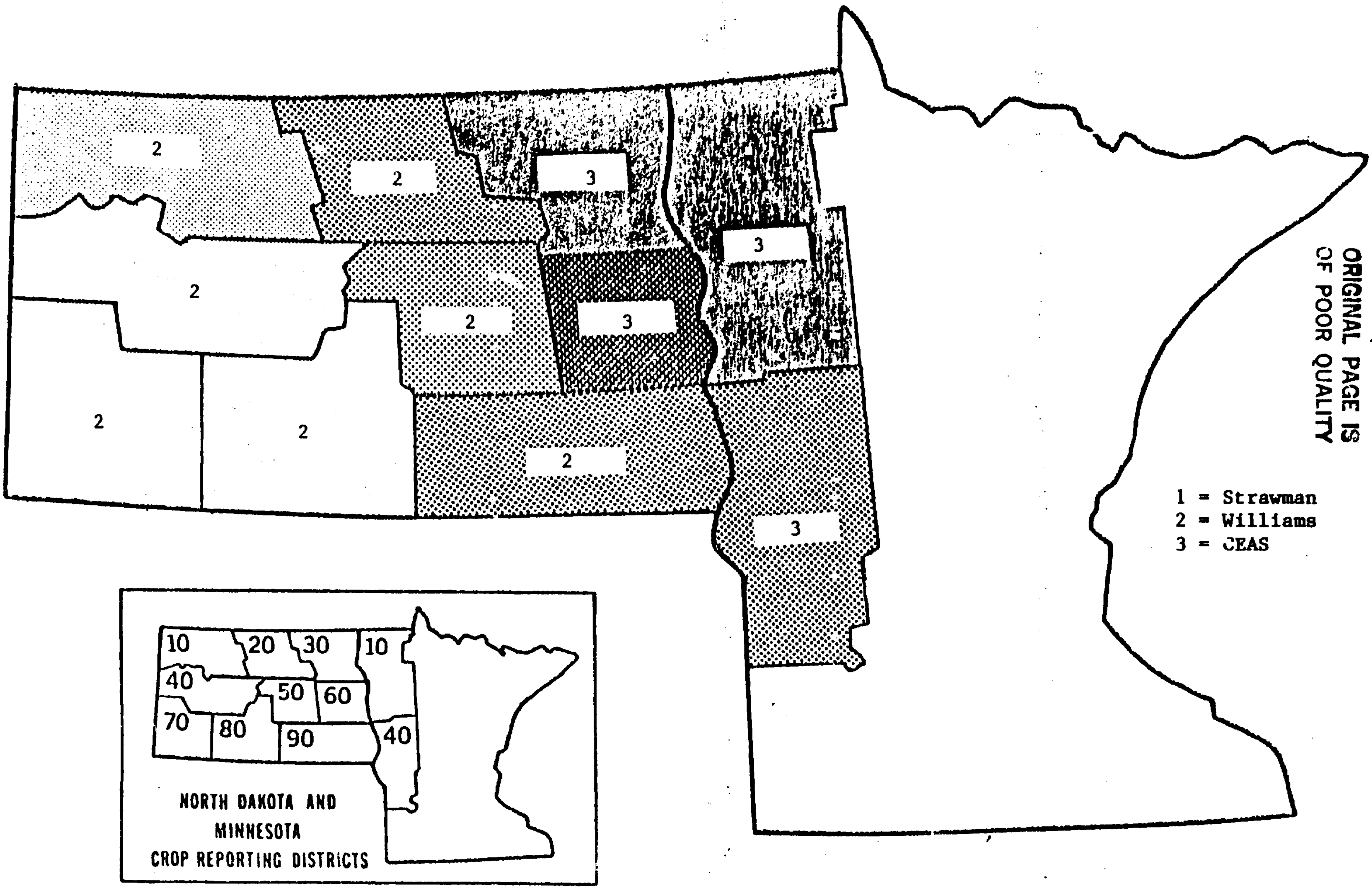

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TABLE 4
MODEL COMPARISON BASED ON THE
STANDARD DEVIATION (QUINTALS/HECTARE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	SD	RANK	SD	RANK	SD	RANK
N.DAKOTA	10	3.67	(3)	2.76	(2)	2.52	(1)
	20	3.26	(3)	2.62	(1)	3.14	(2)
	30	3.12	(3)	2.79	(2)	2.21	(1)
	40	4.24	(2)	2.71	(1)	4.67	(3)
	50	3.87	(3)	2.41	(1)	3.82	(2)
	60	3.42	(3)	2.92	(1)	3.18	(2)
	70	2.90	(2)	2.24	(1)	3.84	(3)
	80	3.64	(3)	2.44	(1)	3.61	(2)
	90	3.66	(3)	1.81	(1)	3.37	(2)
STATE MODEL		2.89	(3)	2.36	(1)	2.72	(2)
CRDS AGGR.		2.89	(3)	2.18	(1)	2.40	(2)
MINNESOTA	10	2.84	(2)	2.89	(3)	1.21	(1)
	40	4.81	(3)	2.94	(1)	4.42	(2)
STATE MODEL		2.80	(3)	2.28	(2)	2.22	(1)
CRDS AGGR.		2.77	(3)	2.34	(2)	1.62	(1)
REGION							
CRDS AGGR.		2.74	(3)	2.09	(2)	2.07	(1)
STATES AGGR.		2.70	(3)	2.14	(1)	2.44	(2)

difference exceeds ten percent. The largest and the next largest absolute value of the relative difference should also be as small as possible with the preferred model. In 6 of the 11 CRD's the Williams type model is within 10% of the relative difference more often than is the CEAS model (Figure 3). For this attribute the CRD estimates aggregated to state and regional estimates are better with the CEAS model, Table 5.

With regard to the largest absolute relative difference (Figure 4), the Williams-type model estimates are better in CRD 40 in Minnesota and in all of North Dakota (except CRD 90) than the estimates from the CEAS models. The aggregated CEAS CRD models are better than the aggregated Williams-type models only for Minnesota (Table 6). This is also true with the next largest absolute relative differences (Figure 5 and Table 7). Only 3 CRDs show CEAS being better. However, 2 are the higher production areas so the regional aggregation of CEAS CRD models is better. With the CEAS model the largest relative differences are all positive for North Dakota. The Williams-type appears better for CRD estimates with the aggregated CRD estimates revealing no clear preference.

Indicators of Yield Reliability Based on Direction of Change and Pearson Correlation Show the Williams-Type Models Preferable for CRD's but CEAS Models Better for State and Regional Estimates

Plots of the actual and predicted yield for both models as well as the strawman model are shown for the state level in Figures 6 and 7. The model values and the comparative ranks for the indicators of yield reliability based on Y and $\hat{Y}$ are given in Tables 8, 9, and 10. These indicators demonstrate the correspondence between actual and predicted yields. The better model will have the larger percentage of years in which the direction of change from the previous year and from the average of the previous three years in the Y's agrees with the corresponding change in the Y's. The correlation coefficient between the actual and predicted yields will also be higher.

In terms of correct direction of change from the previous year, as shown in Table 8 the Williams-type model ranks at least as good as the CEAS models for all areas except the Minnesota state model and the northeast crop reporting district (30) of North Dakota. However, for models aggregated to the state or regional level, and for the state models, CEAS ranks better. The better model for each CRD is shown in Figure 8.

When the direction of change from the average of the last three years is considered, the Williams-type model is again better than the CEAS models for most individual CRDs (Table 9). However, the state and aggregated CEAS models are as good as, and in the case of Minnesota better than, the Williams-type model. The better model for each CRD is indicated in Figure 9.

In all but three of the CRDs the Pearson correlation coefficient is higher for the Williams-type model (Figure 10 and Table 10). The CEAS model has a higher correlation coefficient for the Minnesota state model and for the Minnesota state estimate derived from aggregation of CRD estimates. The CEAS CRD models aggregated to the regional level also have a higher correlation coefficient than the Williams-type models.

Statistical Tests Based on $d=Y-\hat{Y}$

Preference for Aggregated CRD Estimate for North Dakota using CEAS Model

Results of the parametric and nonparametric paired-sample statistical tests are given in Tables 11, 12 and 13.

Figure 3. Number indicates the barley model (s) with smallest percent of test years (1970-1979) having absolute value of the relative difference greater than ten percent. Darker shades indicate CRDs with higher production.

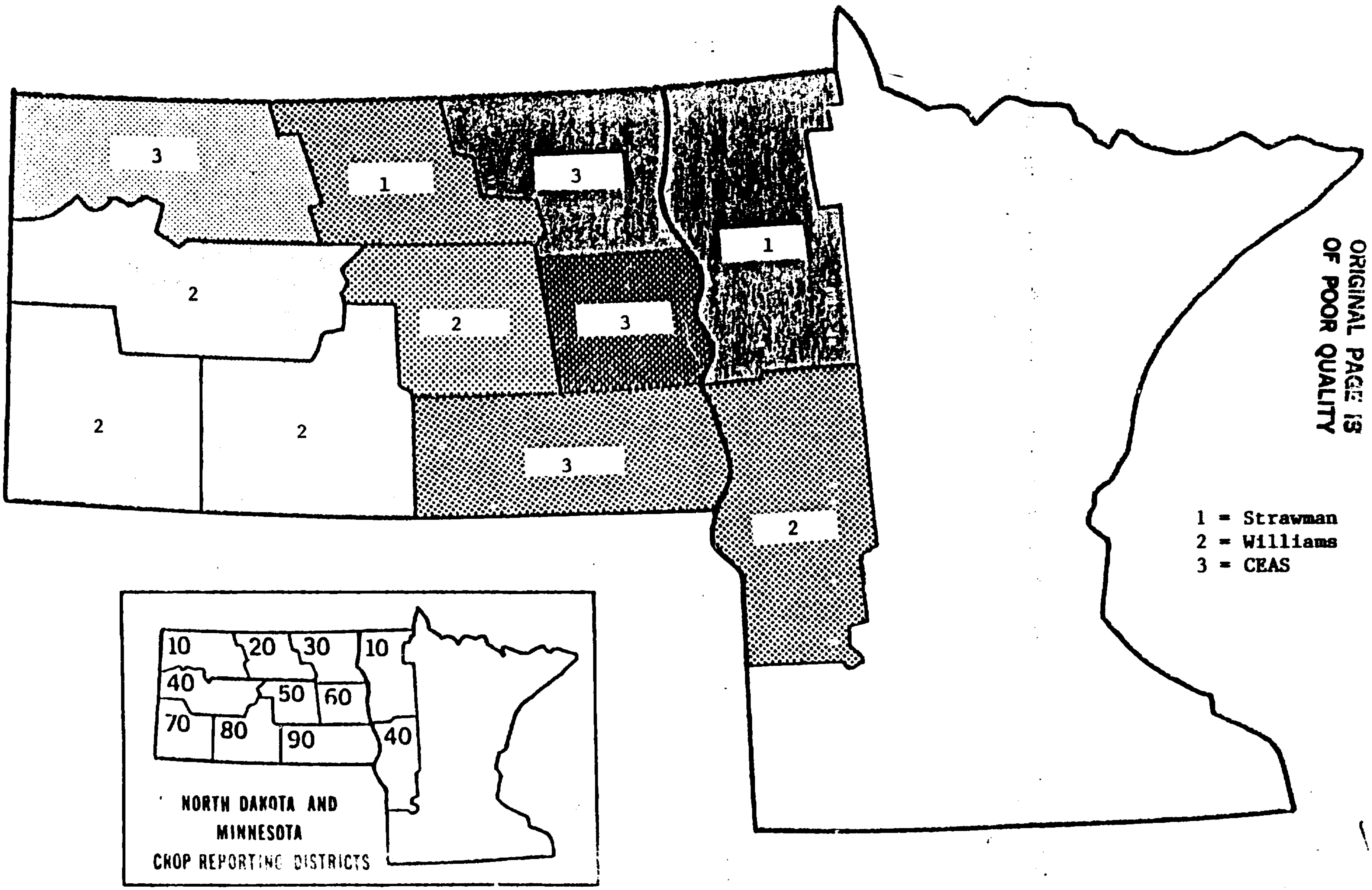

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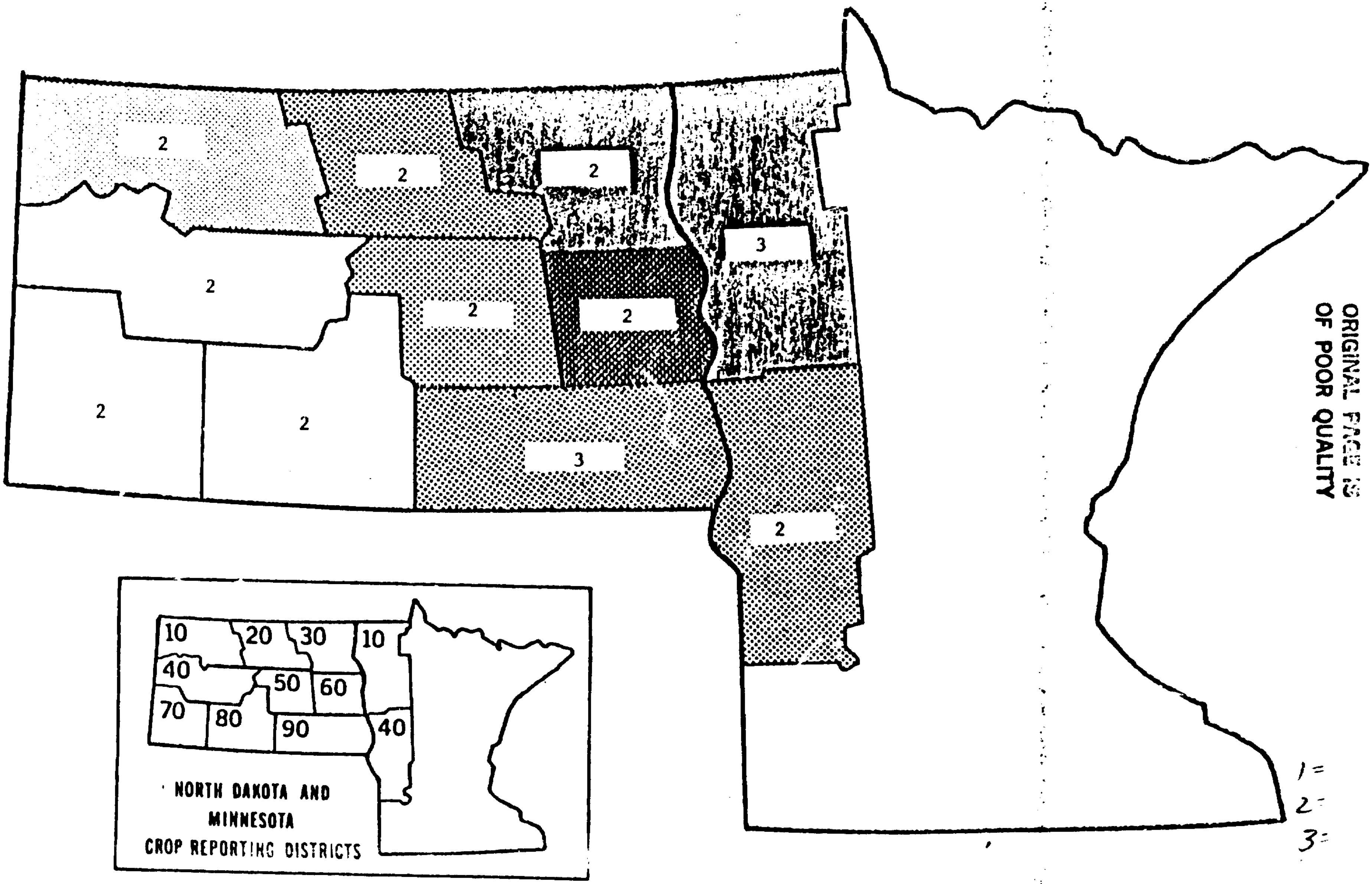
TABLE 5
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS |RELATIVE DIFFERENCE| > 10%
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		MODEL				
	STRAWMAN		WILLIAMS		CEAS	
STATE CRD	%	RANK	%	RANK	%	RANK
N.DAKOTA 10	60	(2)	60	(2)	40	(1)
20	30	(1)	50	(2)	70	(3)
30	40	(2)	50	(3)	30	(1)
40	70	(2)	60	(1)	80	(3)
50	70	(2)	60	(1)	70	(2)
60	70	(2)	80	(3)	60	(1)
70	70	(3)	20	(1)	60	(2)
80	60	(2)	50	(1)	90	(3)
90	60	(1)	80	(3)	60	(1)
STATE MODEL	40	(1)	80	(3)	70	(2)
CRDS AGGR.	50	(2)	70	(3)	30	(1)
MINNESOTA 10	40	(1)	60	(3)	50	(2)
40	60	(3)	30	(1)	50	(2)
STATE MODEL	50	(2)	50	(2)	30	(1)
CRDS AGGR.	50	(2)	50	(2)	30	(1)
REGION						
CRDS AGGR.	50	(2)	70	(3)	20	(1)
STATES AGGR.	50	(1)	70	(2)	70	(2)

Figure 4. Number indicates the barley model with smallest value of the largest absolute relative difference during the test years 1970-1979. Darker shades indicate CRDs with higher production.



1=
2=
3=

TABLE 6
MODEL COMPARISON BASED ON THE
LARGEST |RELATIVE DIFFERENCE|
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

	MODEL					
	STRAWMAN		WILLIAMS		CEAS	
STATE CRD	RD	RANK	RD	RANK	RD	RANK
N.DAKOTA 10	65.9	(3)	-28.4	(1)	44.9	(2)
20	77.9	(3)	48.4	(1)	68.9	(2)
30	54.7	(3)	31.1	(1)	38.5	(2)
40	86.3	(3)	37.6	(1)	71.8	(2)
50	73.2	(3)	40.7	(1)	41.5	(2)
60	32.6	(3)	-27.6	(1)	29.7	(2)
70	45.1	(2)	-24.9	(1)	46.4	(3)
80	84.2	(3)	38.6	(1)	58.4	(2)
90	65.2	(3)	-38.5	(2)	36.8	(1)
STATE MODEL	51.0	(3)	-21.4	(1)	26.5	(2)
CRDS AGGR.	51.0	(3)	19.2	(1)	39.1	(2)
MINNESOTA10	22.8	(2)	-27.7	(3)	-14.2	(1)
40	93.2	(3)	33.1	(1)	-38.6	(2)
STATE MODEL	26.0	(3)	-24.8	(2)	-21.5	(1)
CRDS AGGR.	25.4	(2)	-26.9	(3)	-19.3	(1)
REGION						
CRDS AGGR.	42.2	(3)	-17.9	(1)	24.7	(2)
STATES AGGR.	41.3	(3)	-22.7	(2)	-19.2	(1)

Figure 5. Number indicates the barley model with smallest value of the next largest absolute relative difference during the test years 1970–1979. Darker shades indicate CRDs with higher production.

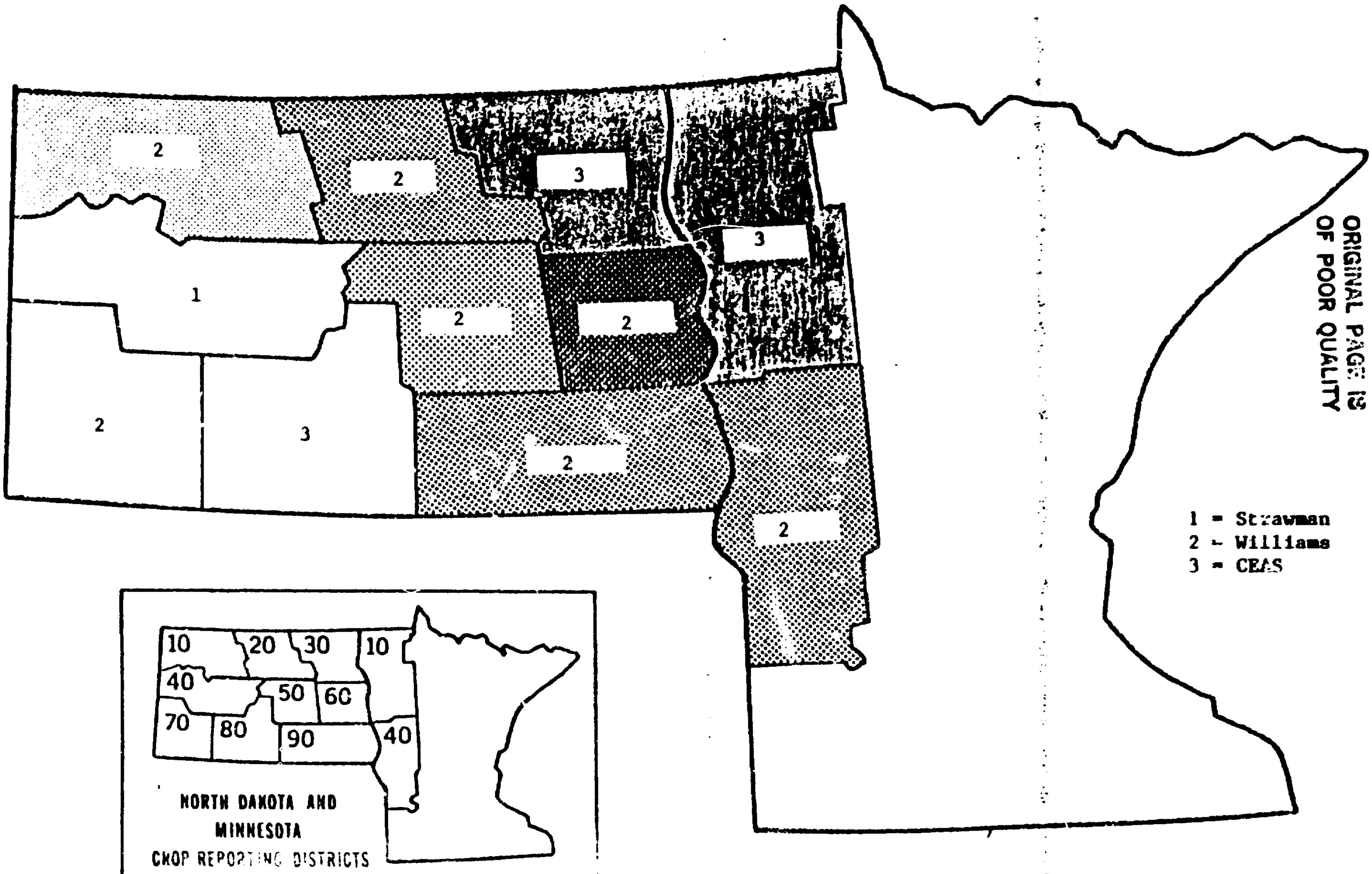


TABLE 7
MODEL COMPARISON BASED ON THE
NEXT LARGEST (RELATIVE DIFFERENCE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

STATE	CRD	MODEL STRAWMAN RD	RANK	MODEL WILLIAMS RD	RANK	MODEL CEAS RD	RANK
N.DAKOTA	10	34.9	(3)	26.8	(1)	30.7	(2)
	20	29.3	(3)	-18.3	(1)	21.5	(2)
	30	-15.1	(2)	-22.5	(3)	14.4	(1)
	40	26.3	(1)	-26.[illegible]	(2)	-38.1	(3)
	50	50.3	(3)	-20.8	(1)	36.6	(2)
	60	28.0	(3)	-2[illegible].1	(1)	25.0	(2)
	70	30.2	(3)	-17.9	(1)	-28.5	(2)
	80	41.7	(3)	36.2	(2)	-26.6	(1)
	90	35.1	(3)	-18.8	(1)	-27.9	(2)
STATE MODEL		-14.5	(1)	-20.1	(3)	-19.1	(2)
CRDS AGGR.		-14.5	(2)	-19.1	(3)	13.7	(1)
MINNESOTA	10	21.1	(2)	-26.2	(3)	-12.9	(1)
	40	41.9	(3)	-24.2	(1)	36.1	(2)
STATE MODEL		21.9	(3)	-13.0	(1)	-17.2	(2)
CRDS AGGR.		22.4	(3)	-14.6	(1)	-16.0	(2)
REGION							
CRDS AGGR.		-13.7	(2)	-17.7	(3)	-12.7	(1)
STATES AGGR.		13.7	(1)	-16.2	(2)	18.0	(3)

Figure 6 TREND AND MONTHLY WEATHER DATA MODELS

BARLEY

A = ACTUAL YIELD

S = PREDICTED YIELD FOR STRAW MAN 1 LINE MODEL

W = PREDICTED YIELD FOR WILLIAMS TYPE MODEL

C = PREDICTED YIELD FOR CEAS MODEL

STATE_CD=NORTH DAKOTA

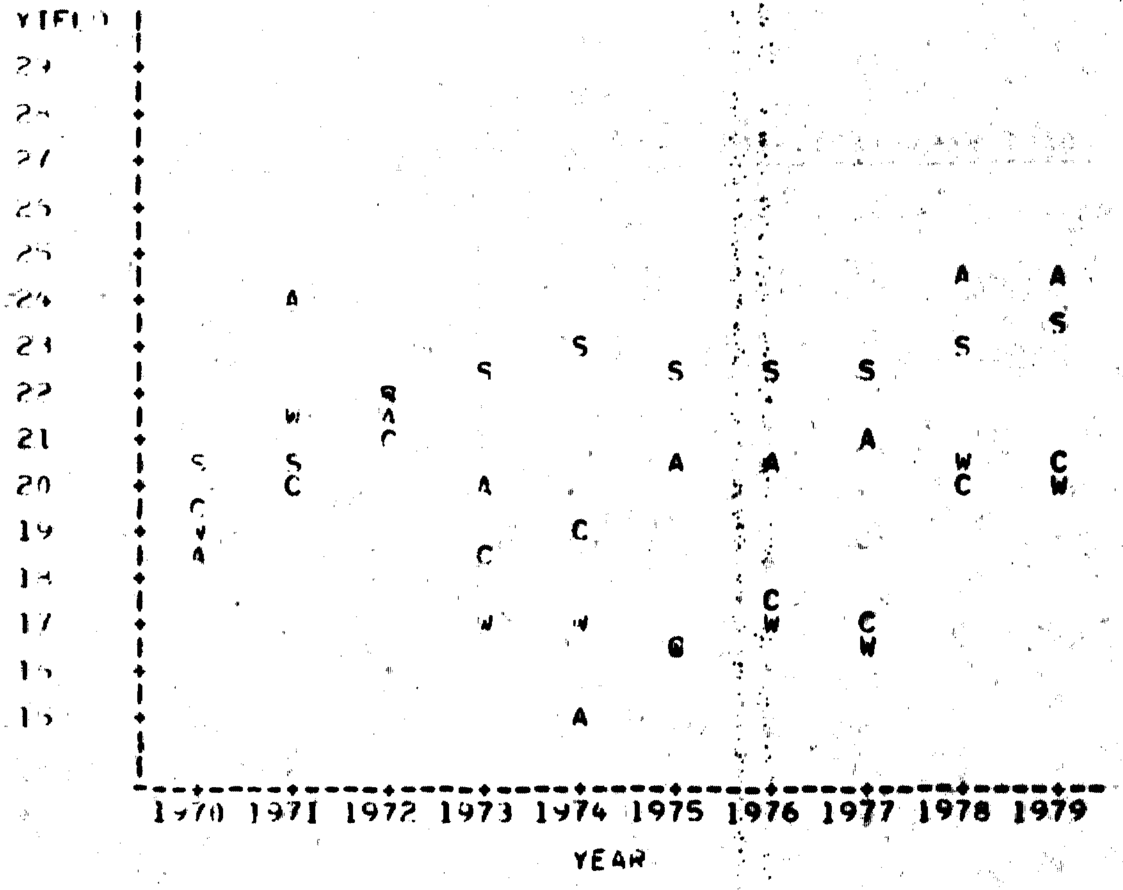


Figure 7 TREND AND MONTHLY WEATHER DATA MODELS
BARLEY

A = ACTUAL YIELD
S = PREDICTED YIELD FOR STRAW MAN 1 LINE MODEL
W = PREDICTED YIELD FOR WILLIAMS TYPE MODEL
C = PREDICTED YIELD FOR CEAS MODEL
STATE_CD=MINNESOTA

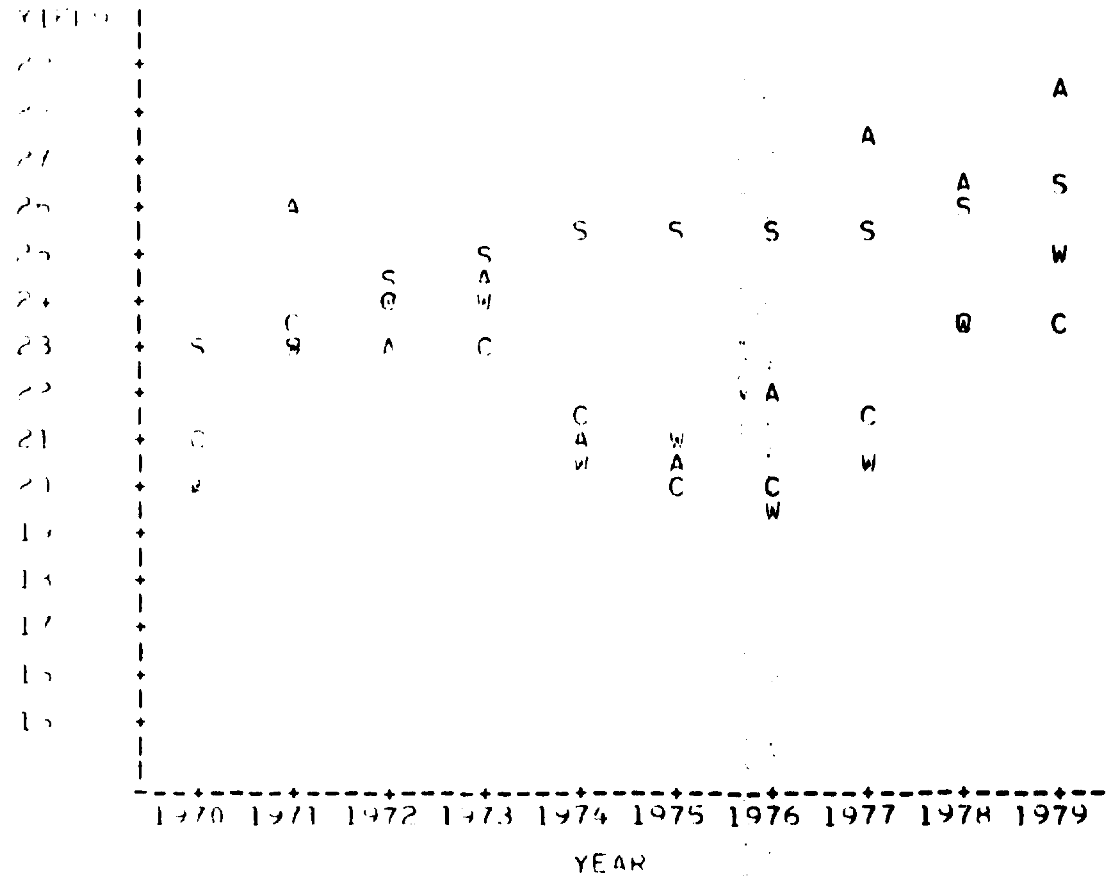


TABLE 8
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS THE DIRECTION OF CHANGE
FROM THE PREVIOUS YEAR IS CORRECT
DURING INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		MODEL				
		STRAWMAN		WILLIAMS		CEAS
STATE	CRD	%	RANK	%	RANK	%	RANK

STATE	CRD	STRAWMAN %	STRAWMAN RANK	WILLIAMS %	WILLIAMS RANK	CEAS %	CEAS RANK
N.DAKOTA	10	33	(3)	67	(1)	67	(1)
	20	11	(3)	67	(1)	33	(2)
	30	33	(3)	67	(2)	78	(1)
	40	22	(3)	78	(1)	56	(2)
	50	22	(3)	67	(1)	56	(2)
	60	33	(3)	56	(1)	56	(1)
	70	22	(3)	44	(1)	44	(1)
	80	22	(3)	67	(1)	44	(2)
	90	44	(1)	44	(1)	44	(1)
STATE MODEL		33	(1)	33	(1)	33	(1)
CRDS AGGR.		33	(3)	44	(2)	67	(1)
MINNESOTA	10	44	(3)	89	(1)	78	(2)
	40	33	(2)	89	(1)	33	(2)
STATE MODEL		33	(3)	44	(2)	56	(1)
CRDS AGGR.		44	(3)	67	(1)	67	(1)
REGION							
CRDS AGGR.		56	(2)	44	(3)	78	(1)
STATES AGGR.		56	(3)	67	(1)	67	(1)

Figure 8 Number indicates the barley model (s) with largest percent of test years (1970-1979) having agreement in direction of change from the previous year between predicted and actual yields. Darker shades indicate CRDs with higher production.

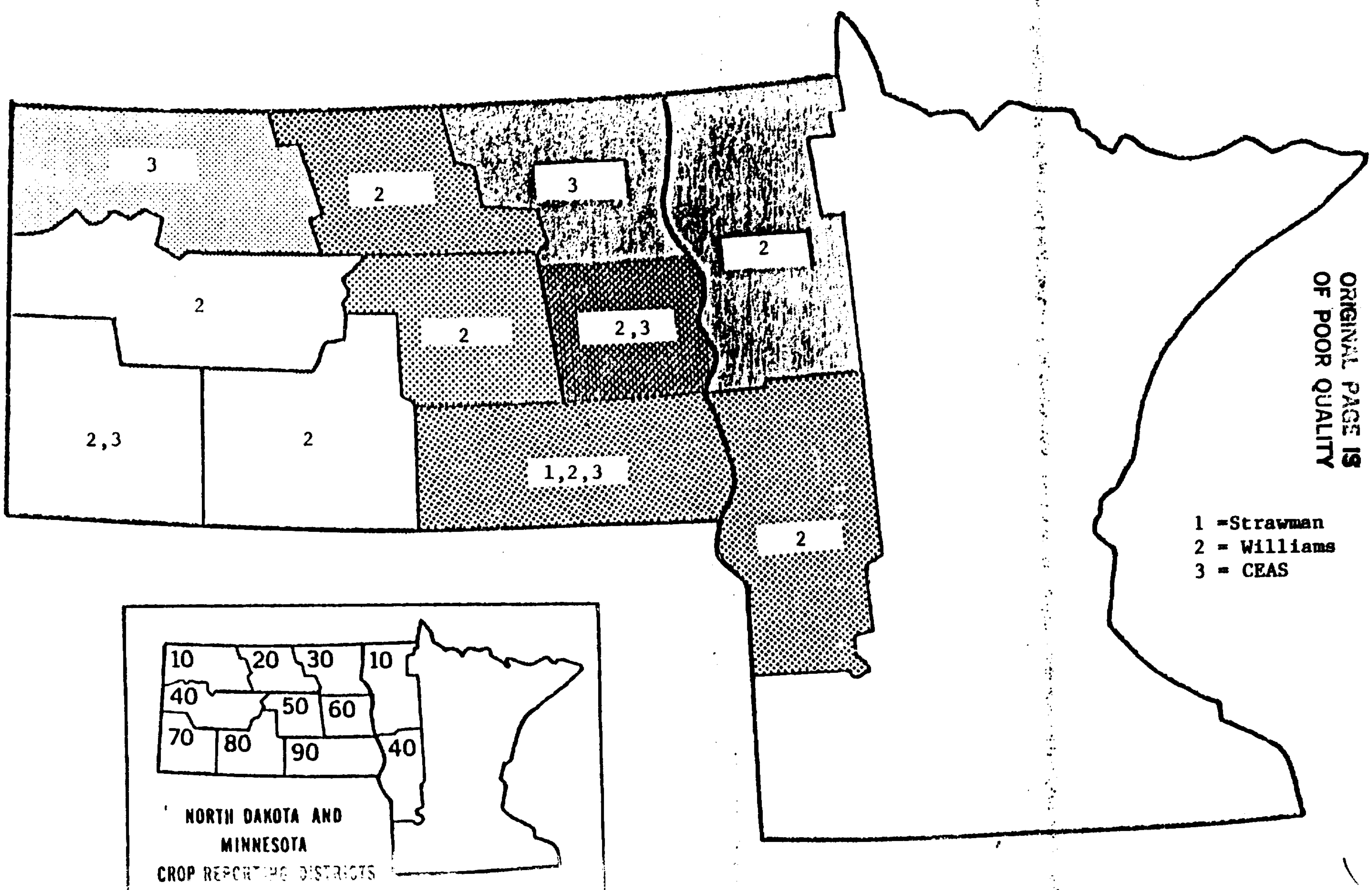


Figure 9 Number indicates the barley model (s) with largest percent of test years (1970-1979) having agreement in direction of change from the previous three year average between predicted and actual yields. Darker shades indicate CRDs with higher production.

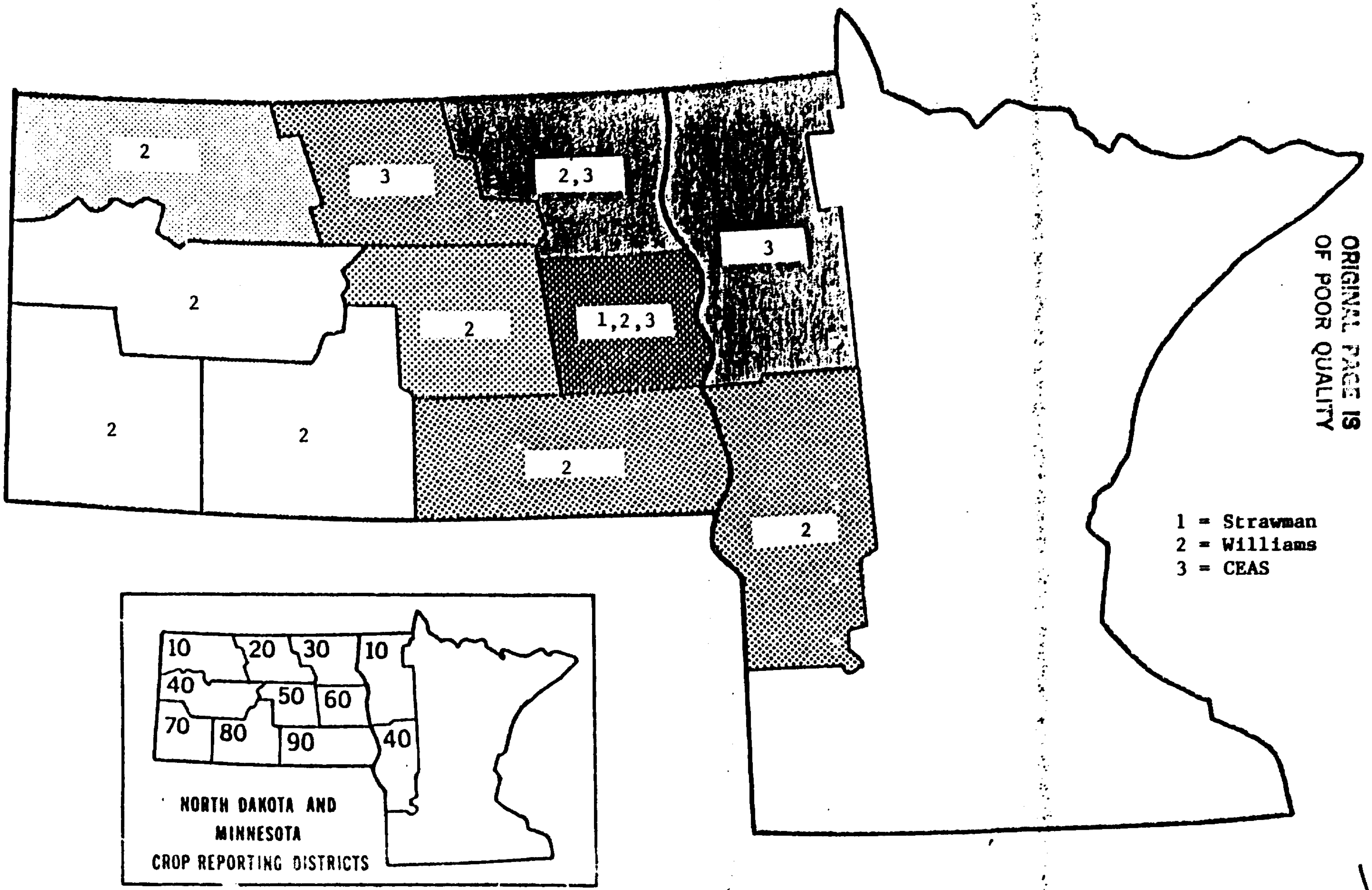


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TABLE 9
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS THE DIRECTION OF CHANGE
FROM A THREE YEAR BASE PERIOD IS CORRECT
DURING INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
"BARLEY"
NORTH DAKOTA AND MINNESOTA

STATE	CRD	MODEL STRAHMAN %	STRAHMAN RANK	WILLIAMS %	WILLIAMS RANK	CEAS %	CEAS RANK
N.DAKOTA	10	14	(3)	71	(1)	43	(2)
	20	43	(3)	57	(2)	86	(1)
	30	57	(3)	71	(1)	71	(1)
	40	0	(3)	86	(1)	57	(2)
	50	14	(3)	71	(1)	57	(2)
	60	71	(1)	71	(1)	71	(1)
	70	14	(3)	57	(1)	43	(2)
	80	29	(3)	71	(1)	57	(2)
	90	29	(3)	100	(1)	71	(2)
STATE MODEL		43	(3)	57	(1)	57	(1)
CRDS AGGR.		57	(3)	71	(1)	71	(1)
MINNESOTA	10	71	(2)	71	(2)	100	(1)
	40	29	(3)	86	(1)	71	(2)
STATE MODEL		57	(3)	86	(1)	86	(1)
CRDS AGGR.		43	(3)	71	(2)	86	(1)
REGION							
CRDS AGGR.		71	(1)	71	(1)	71	(1)
STATES AGGR.		71	(1)	57	(3)	71	(1)

The CEAS and Williams-type models are tested against each other with the paired t-test; the results are given in Table 11. There is a significant difference in three of the CRDs. The nonparametric test (Table 11 and Figure 12) shows a significant difference in four of the CRDs and in the regional level aggregated from CRDs. The Williams-type model is better in those cases where there is a significant difference; the exception is the northwest CRD (10) in Minnesota (Figure 12). The CRDs where the CEAS model is better has higher production than the CRDs where the Williams-type model is better. The CEAS model is also better for the aggregated regional estimate.

Results comparing each of the models with a linear trend model are included. The results shown in Table 12 are the basis for comparison of the Williams-type model and a "strawman" model (Sebaugh, 1980) for barley yield. The paired t-tests show no significant differences (Figure 13) and the nonparametric rank test (Figure 14) shows significant differences in two CRDs with the strawman or linear trend model being better in both cases.

In comparison of the CEAS model with the "strawman" model (Table 13 and Figure 15-16), only the CRD estimates aggregated to a state estimate for North Dakota show any significant difference between the strawman and CEAS model estimates using either the paired t-test or the nonparametric test. The CEAS model estimates were better in this case. CEAS models were also better than the Williams type estimate for this case.

In summary, the CEAS model estimates were significantly better than the Williams-type model estimates for the aggregated estimate for North Dakota. In CRDs having significant differences the CEAS model was better in one higher producing CRD but the Williams-type was better for three lower producing CRDs. CEAS was also better for the aggregation to the regional estimate.

Figure 10 Number indicates the barley model with the largest correlation coefficient between actual and predicted yields over the test years (1970-1979). Darker shades indicate CRDs with higher production.

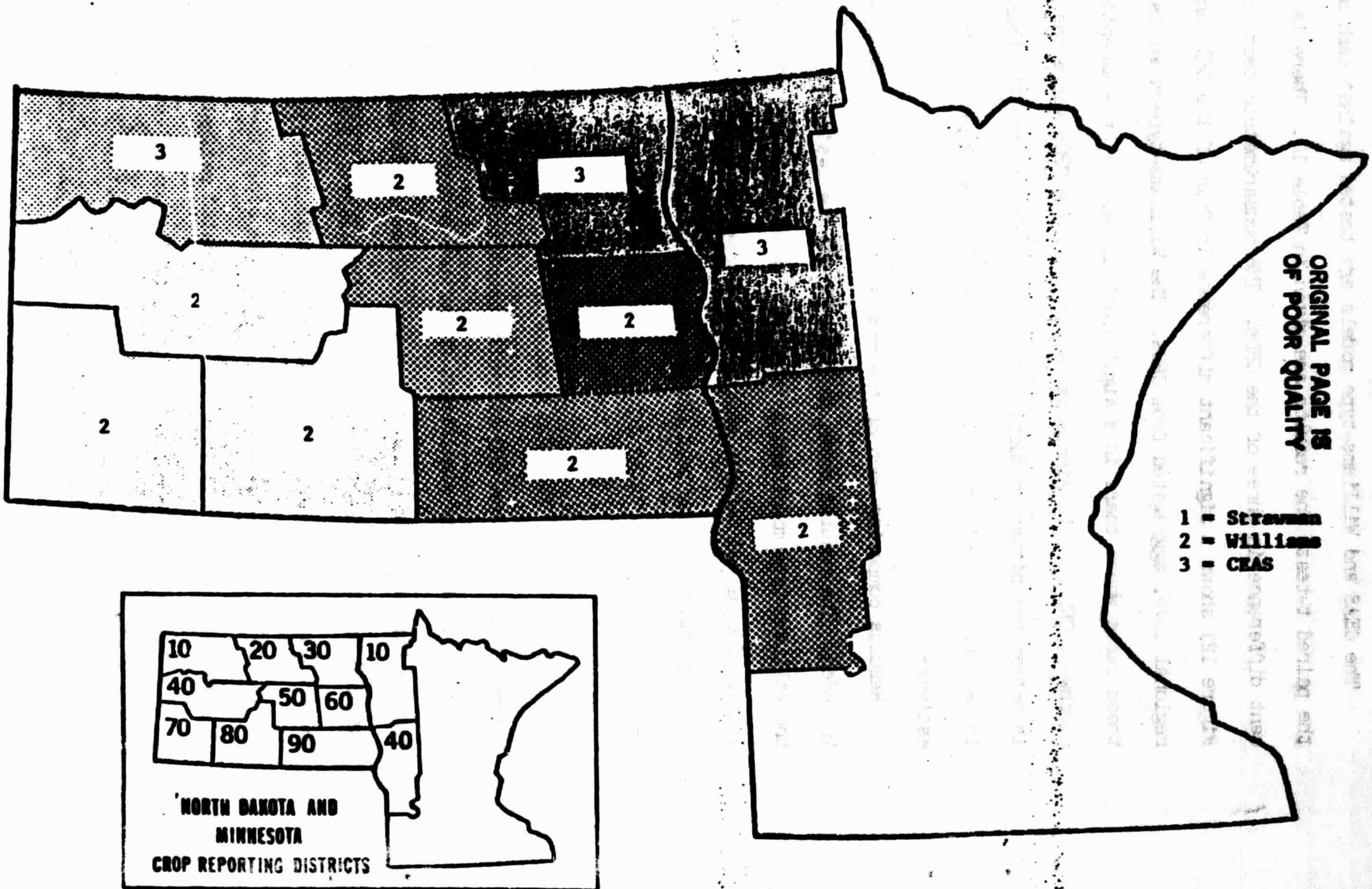

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TABLE 10
MODEL COMPARISON BASED ON THE
CORRELATION BETWEEN ACTUAL AND PREDICTED YIELDS
DURING INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

STATE	CRD	STRAUMAN R	STRAUMAN RANK	WILLIAMS R	WILLIAMS RANK	CEAS R	CEAS RANK
N.DAKOTA	10	-0.50	(3)	0.55	(2)	0.57	(1)
	20	-0.43	(3)	0.47	(1)	0.05	(2)
	30	0.23	(3)	0.51	(2)	0.79	(1)
	40	-0.26	(3)	0.59	(1)	0.17	(2)
	50	-0.46	(3)	0.73	(1)	0.29	(2)
	60	0.45	(3)	0.63	(1)	0.57	(2)
	70	-0.24	(3)	0.52	(1)	0.23	(2)
	80	-0.40	(3)	0.59	(1)	0.27	(2)
	90	-0.45	(3)	0.85	(1)	0.42	(2)
STATE MODEL		0.13	(3)	0.58	(1)	0.35	(2)
CRDS AGGR.		0.14	(3)	0.65	(1)	0.57	(2)
MINNESOTA	10	0.56	(2)	0.54	(3)	0.95	(1)
	40	-0.63	(3)	0.80	(1)	0.18	(2)
STATE MODEL		0.32	(3)	0.63	(2)	0.69	(1)
CRDS AGGR.		0.38	(3)	0.52	(2)	0.86	(1)
REGION							
CRDS AGGR.		0.29	(3)	0.58	(2)	0.73	(1)
STATES AGGR.		0.27	(3)	0.64	(1)	0.48	(2)

TABLE 11
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
WILLIAMS MODEL WITH CEAS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		PARAMETRIC T-TEST				NONPARAMETRIC RANK TEST			
		AVERAGE |D| MODEL		DIFFERENCE OF		% SMALLER |D| MODEL		DIFFERENCE OF	
STATE	CRD	WILIAM	CEAS	AVERAGES		WILIAM	CEAS	PERCENTAGE	
N.DAKOTA	10	2.5	2.3	0.1		50	50	0	
	20	2.1	2.4	0.3		50	50	0	
	30	2.5	1.9	0.6		30	70	40	
	40	2.4	4.2	1.8	**	80	20	60	***
	50	2.3	3.6	1.3		60	40	20	
	60	3.7	2.8	0.9		40	60	20	
	70	1.7	3.1	1.4		60	40	20	
	80	2.2	3.3	1.1		80	20	60	*
	90	2.9	2.9	0.0		50	40	10	
STATE MODEL		3.0	3.0	0.0		40	60	20	
CRDS AGGR.		2.6	1.9	0.7		30	70	40	
MINNESOTA	10	3.5	2.2	1.3	**	30	60	30	**
	40	2.3	3.6	1.3	*	70	30	40	*
STATE MODEL		2.2	2.3	0.0		40	60	20	
CRDS AGGR.		2.7	2.1	0.5		40	60	20	
REGION									
CRDS AGGR.		2.6	1.8	0.8		30	70	40	*
STATES AGGR.		2.7	2.8	0.1		60	40	20	

Figure 11 Comparison of model 2 and model 3 to predict barley yields based on the average of $|d| = |\hat{Y}-Y|$ for 1970–1979. Number indicates model with smaller average $|d|$. Blank denotes tie. Stars indicate the level of significance, none ($P \geq 0.10$), *($0.05 < P \leq 0.10$), **($0.01 < P \leq 0.05$), ***($P \leq 0.01$). Darker shades indicate CRDs with higher production.

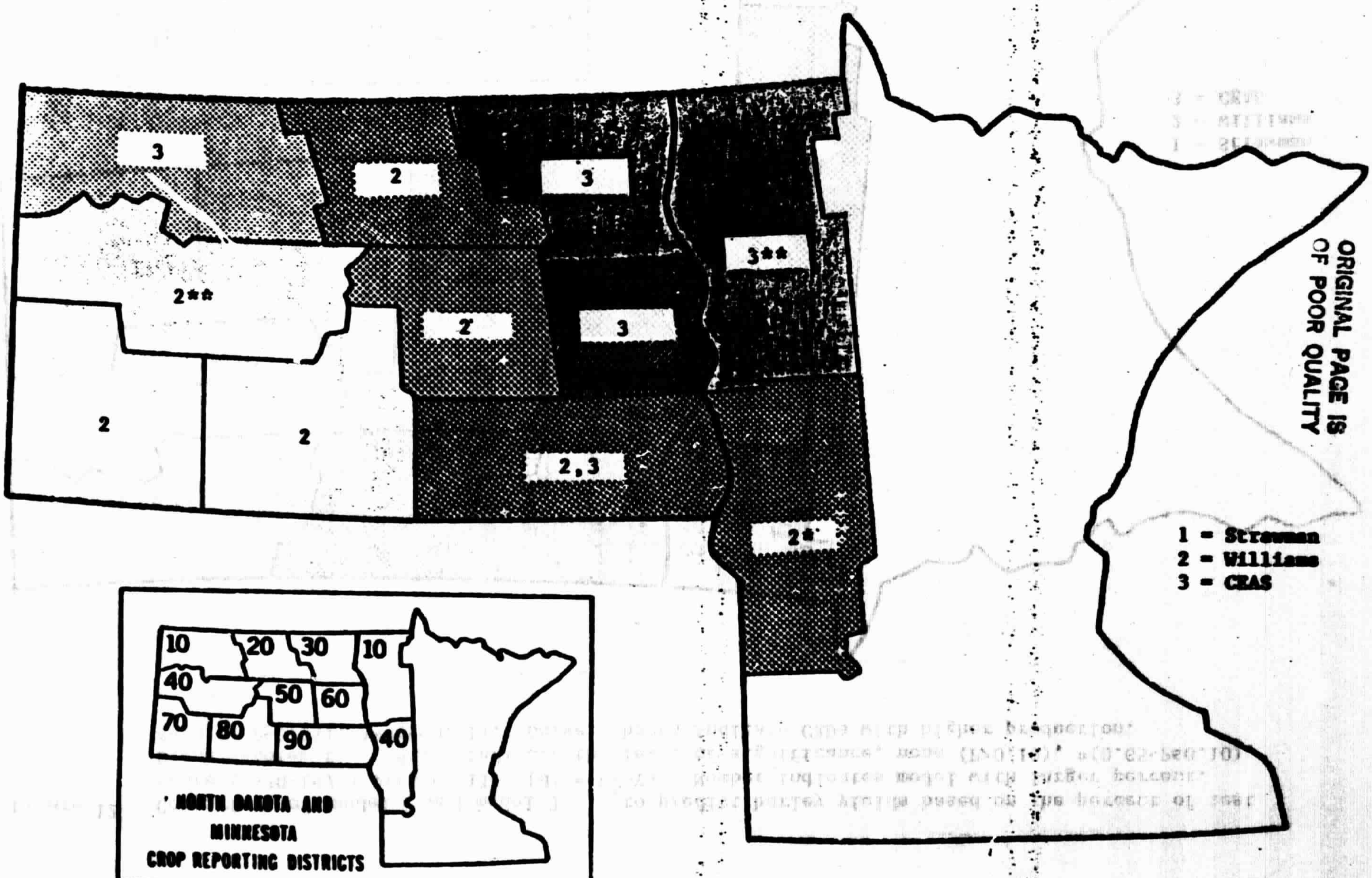

Figure 12 Comparison of model 2 and model 3 to predict barley yields based on the percent of test years (1970–1979) with smaller $|d| = |\hat{Y}-Y|$. Number indicates model with larger percent. Blank denotes tie. Stars indicate the level of significance, none ($P>0.10$), *($0.05<P\leq0.10$), **($0.01<P\leq0.05$), ***($P\leq0.01$). Darker shades indicate CRDs with higher production.

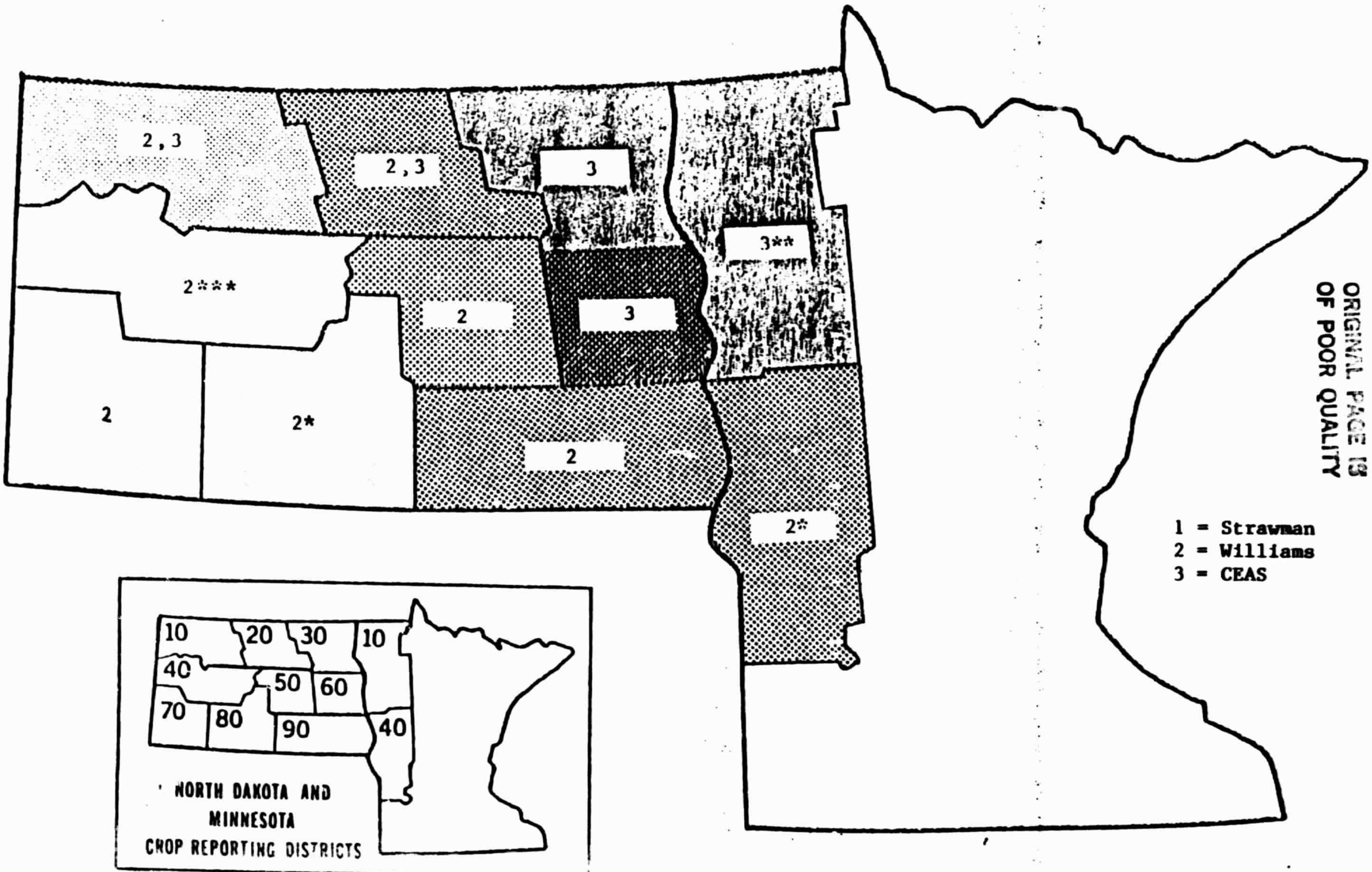

TABLE 12
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
STRAWMAN MODEL WITH WILLIAMS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		PARAMETRIC T-TEST			NONPARAMETRIC RANK TEST			
		AVERAGE |D| MODEL		DIFFERENCE OF	% SMALLER |D| MODEL		DIFFERENCE OF	
STATE	CRD	STRMAN	WILIAM	AVERAGES	STRMAN	WILIAM	PERCENTAGE	
N.DAKOTA	10	3.2	2.5	0.7	40	60	20	
	20	2.5	2.1	0.3	50	40	10	
	30	2.2	2.5	0.3	60	40	20	
	40	3.4	2.4	1.0	40	50	10	
	50	3.4	2.3	1.1	30	70	40	
	60	3.1	3.7	0.7	60	40	20	
	70	3.0	1.7	1.3	30	70	40	
	80	3.3	2.2	1.1	30	70	40	*
	90	3.4	2.9	0.4	60	40	20	
STATE MODEL		2.5	3.0	0.5	70	30	40	
CRDS AGGR.		2.4	2.6	0.1	70	30	40	
MINNESOTA	10	2.4	3.5	1.2	50	50	0	
	40	4.3	2.3	2.0	30	60	30	*
STATE MODEL		2.5	2.2	0.3	50	50	0	
CRDS AGGR.		2.5	2.7	0.2	40	50	10	
REGION								
CRDS AGGR.		2.3	2.6	0.2	60	40	20	
STATES AGGR.		2.4	2.7	0.3	50	50	0	

Figure 13 Comparison of model 1 and model 2 to predict barley yields based on the average of $|d| = |\hat{Y}-Y|$ for 1970-1979. Number indicates model with smaller average $|d|$. Blank denotes tie. Stars indicate the level of significance, none ($P>0.10$), *($0.05<P\leq0.10$), **($0.01<P\leq0.05$), ***($P\leq0.01$). Darker shades indicate CRDs with higher production.

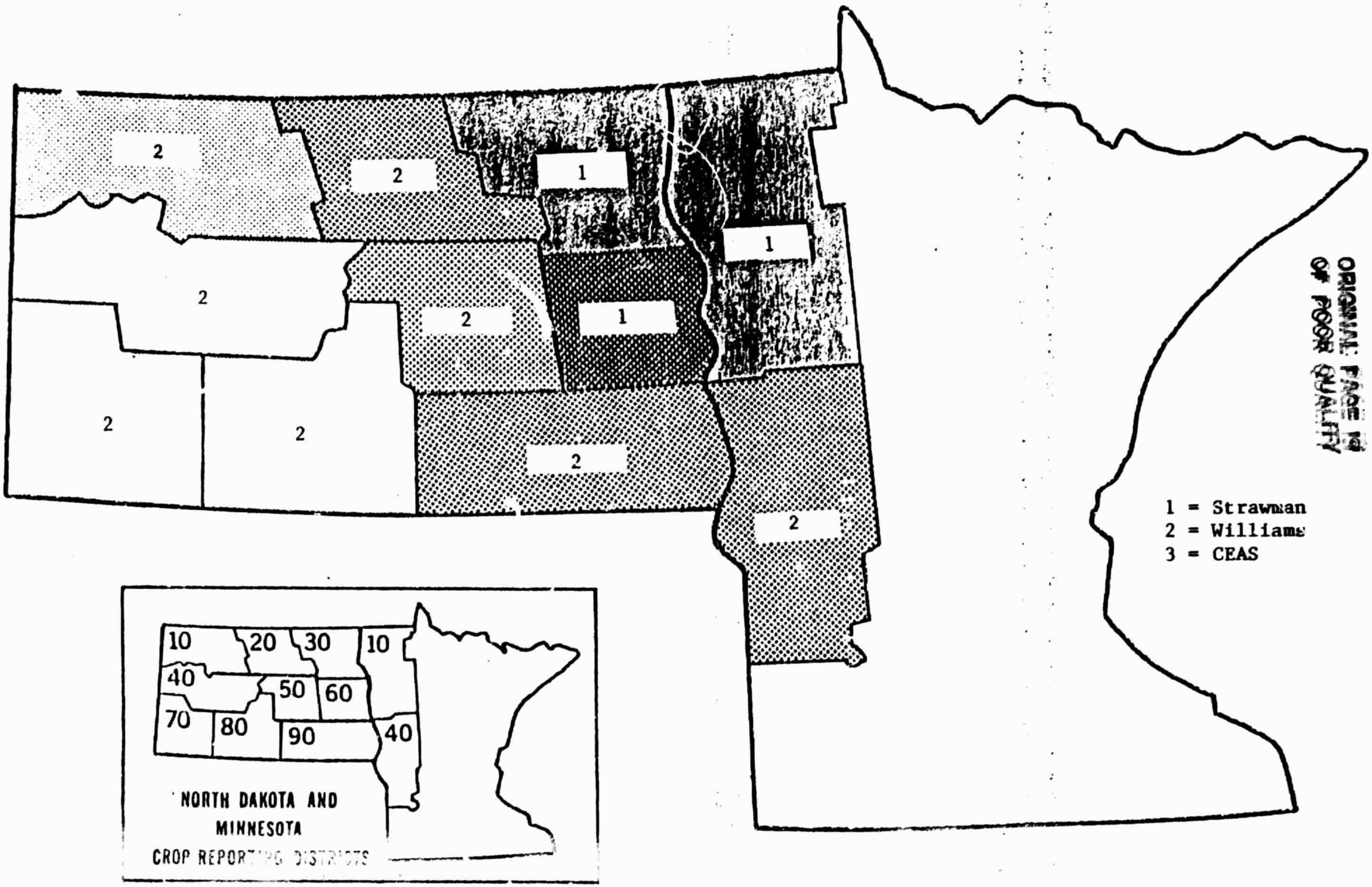

Figure 14 Comparison of model 1 and model 2 to predict barley yields based on the percent of test years (1970-1979) with smaller $|d| = |\hat{Y}-Y|$. Number indicates model with larger percent. Blank denotes tie. Stars indicate the level of significance, none ($P>0.10$), *($0.05<P\leq0.10$), **($0.01<P\leq0.05$), ***($P\leq0.01$). Darker shades indicate CRDs with higher production.

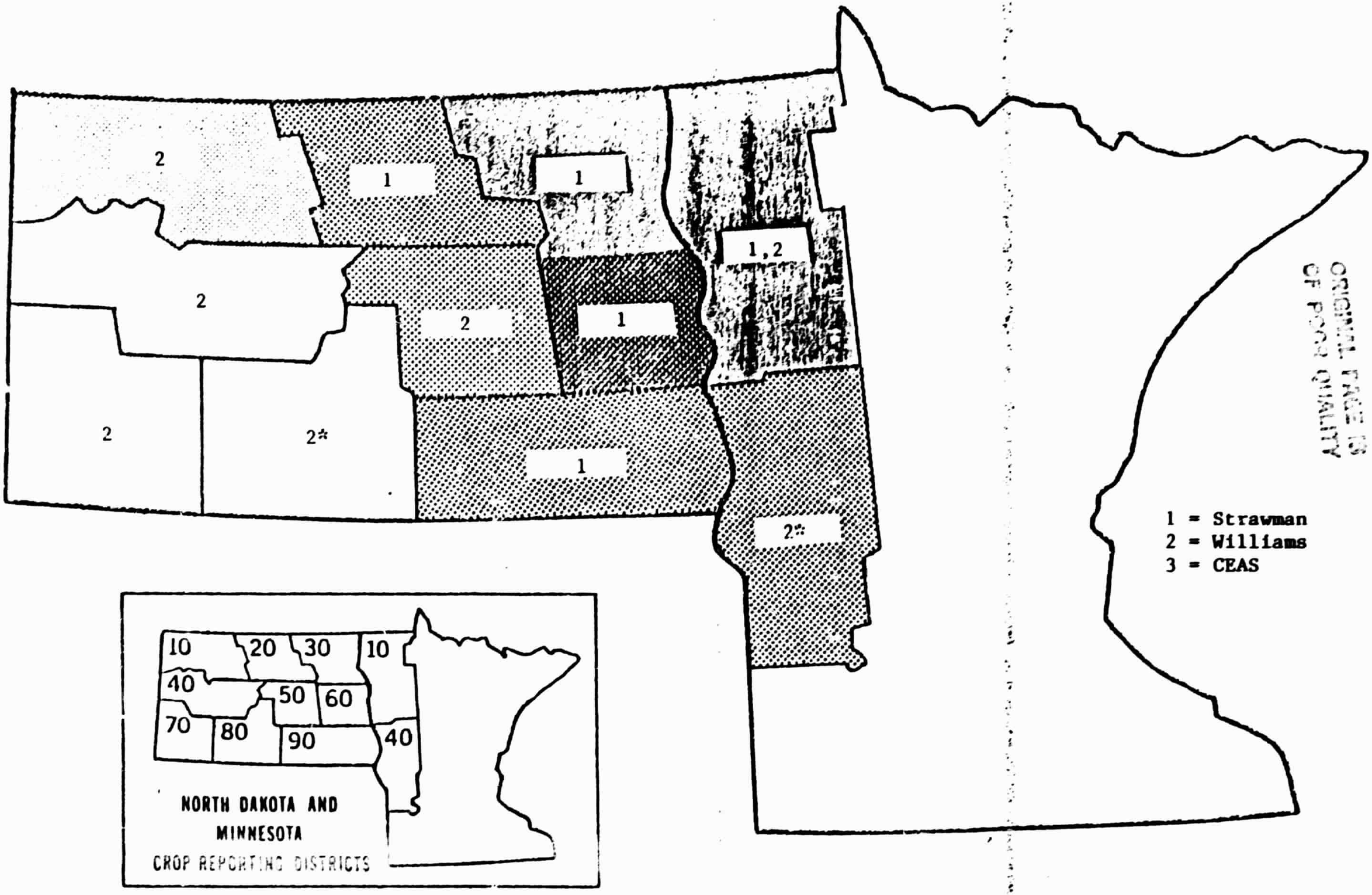

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TABLE 13
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
STRAWMAN MODEL WITH CEAS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

STATE	CRD	PARAMETRIC T-TEST: AVERAGE |D| MODEL STRMAN	PARAMETRIC T-TEST: AVERAGE |D| MODEL CEAS	PARAMETRIC T-TEST: DIFFERENCE OF AVERAGES	NONPARAMETRIC RANK TEST: % SMALLER |D| MODEL STRMAN	NONPARAMETRIC RANK TEST: % SMALLER |D| MODEL CEAS	NONPARAMETRIC RANK TEST: DIFFERENCE OF PERCENTAGE
N.DAKOTA	10	3.2	2.3	0.8	40	60	20
	20	2.5	2.4	0.1	40	60	20
	30	2.2	1.9	0.3	60	40	20
	40	3.4	4.2	0.8	50	50	0
	50	3.4	3.6	0.2	60	40	20
	60	3.1	2.8	0.2	60	40	20
	70	3.0	3.1	0.1	70	30	40
	80	3.3	3.3	0.0	50	40	10
	90	3.4	2.9	0.5	60	40	20
STATE MODEL		2.5	3.0	0.6	60	40	20
CRDS AGGR.		2.4	1.9	0.6	40	60	20 *
MINNESOTA	10	2.4	2.2	0.1	50	50	0
	40	4.3	3.6	0.7	50	50	0
STATE MODEL		2.5	2.3	0.3	40	60	20
CRDS AGGR.		2.5	2.1	0.4	40	60	20
REGION							
CRDS AGGR.		2.3	1.8	0.6	40	60	20
STATES AGGR.		2.4	2.8	0.4	60	40	20

Figure 15 Comparison of model 1 and model 3 to predict barley yields based on the average of $|d| = |\hat{Y}-Y|$ for 1970-1979. Number indicates model with smaller average $|d|$. Blank denotes tie. Stars indicate the level of significance, none ($P>0.10$), *($0.05<P\leq 0.10$), **($0.01<P\leq 0.05$), ***($P\leq 0.01$). Darker shades indicate CRDs with higher production.

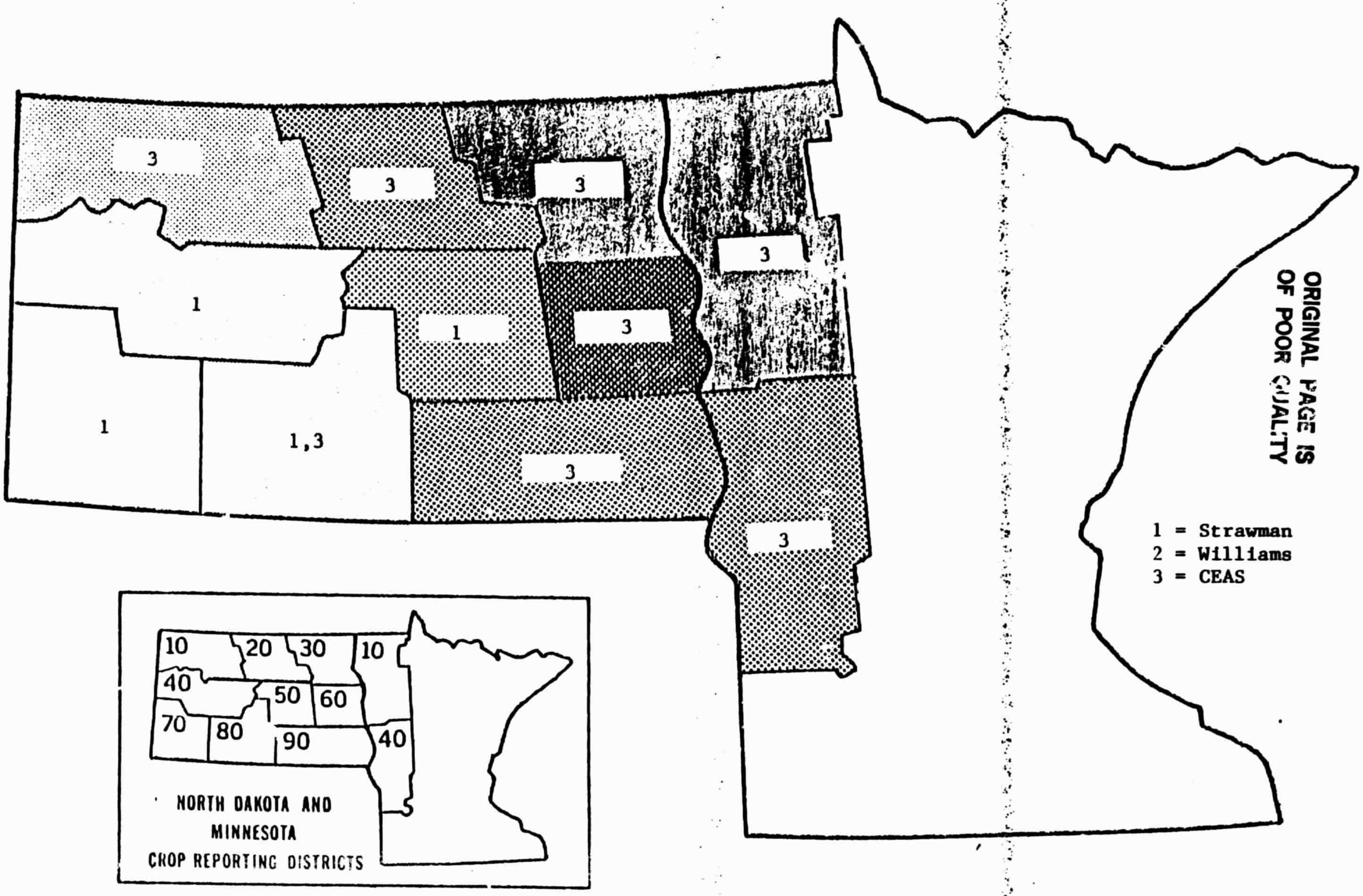
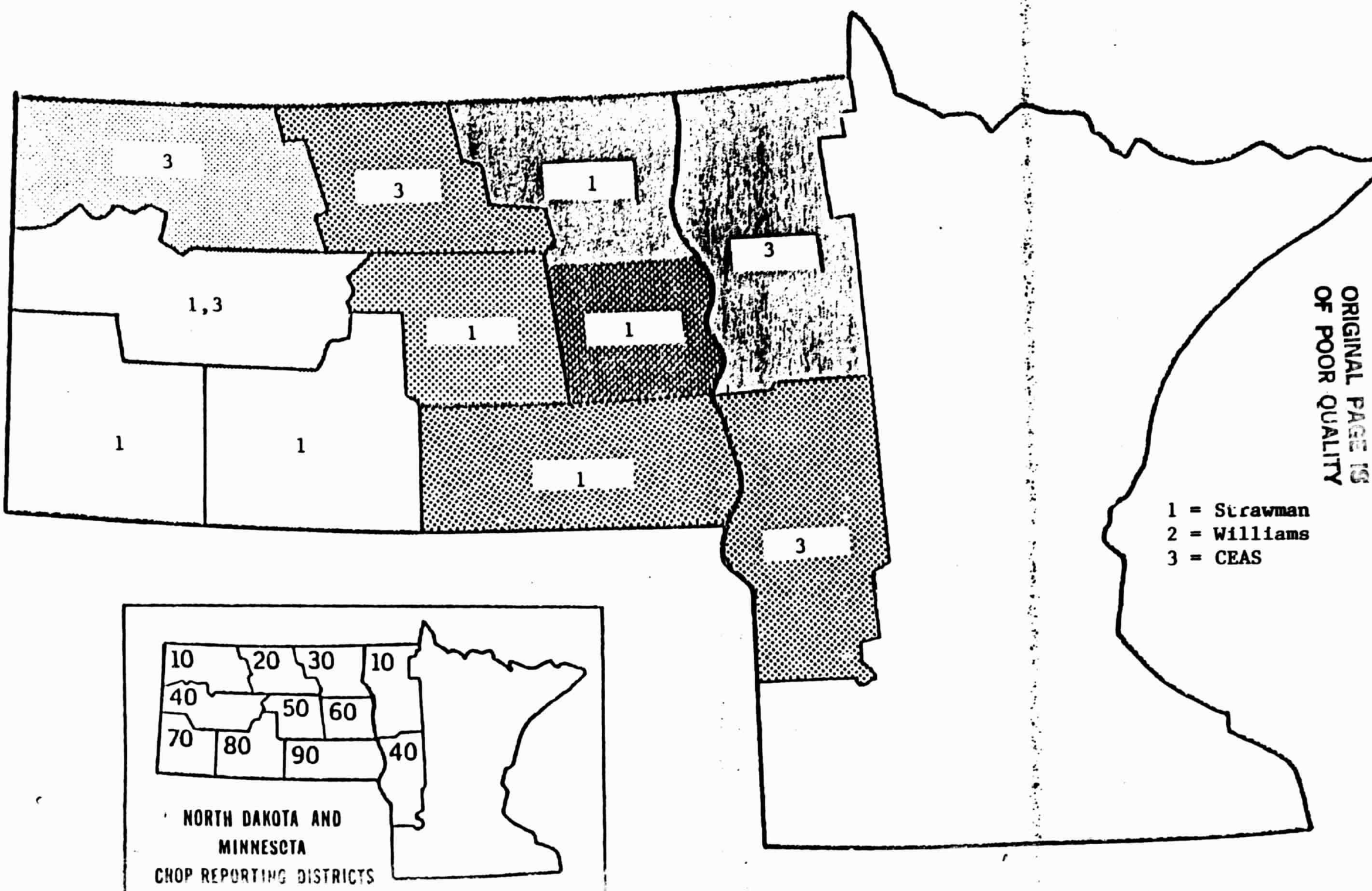


Figure 16 Comparison of model 1 and model 3 , to predict barley yields based on the percent of test years (1970-1979) with smaller |d| = Y-Y . Number indicates model with larger percent. Blank denotes tie. Stars indicate level of significance, none (P 0.10), *(0.05 P 0.10), **(0.01 P 0.05), ***(P 0.01). Darker shades indicate CRDs with higher production.



Models are Equally Objective

The models are entirely objective once the variables have been selected. The form of the trend variable in both models and the determination of the testure and topological variables for Williams-type models are subjectively determined prior to the operational use of the models. The selection of variables is somewhat more objective for the Williams-type model since there is no screening of variables other than fixed statistical criteria.

CEAS Models Attempt to Incorporate Known Physical Relationships if Statistically Significant

Both models consider basically the same set of meteorological variables. The Williams-type tries to eliminate the CRD difference through use of soil and topological considerations. Meteorological variables are included if and only if they are statistically significant for a specified level of significance. The CEAS models apply to individual areas; neighboring areas may incorporate different meteorological variables. The Will'ams-type models use the same variables for all areas and implicitly assume the response is the same. Both types of models consider the same variables for trend. The choice of trends was subjective. The determination of future or present trends is a potential problem. Models do not detect the influence of extreme climate conditions beyond the range of conditions contained in the developmental data. The impact of short term conditions (less than a month) that are not relflected in the monthly summay statistics and the impact of events of shorter time periods cannot be assessed.

Models are Adequate
For Some Purposes

Adequacy depends upon the requirements of the model. The models can provide estimates at the end of each month if coefficients for the variables for climate conditions prior to the end of that month are available. If these are not available, an assumption or forecast of conditions through the rest of the season is necessary. This capability has not been tested. The requirements for models of these types include a history of yield data and chronologically corresponding climate data. For Williams-type, information on soil type and texture is required. Both types require background information regarding the calendar of normal and anomalous crop development. The size of the area over which the yield is to be estimated must correspond to the area used to develop the model. The model might be adequate for a different area of another size, but that assumption needs to be confirmed or the model shown to be adequate before it is used. The models can not assess the impact of abrupt changes in technology.

Timeliness of Models

Estimates can be obtained with the models at the end of the month. How quickly these are available depends directly upon availability of the monthly temperature and precipitation data. If temperature and precipitation data are derived from the same source as the historic data, yield estimates would not be available from the models until one month after the end of the month of interest. Estimates of temperature and precipitation for these same areas, but derived from a subset of the stations used in the historic data base, may be used instead. Yield estimates using these data

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can be available about a week after the end of the month. Timing of the availability of yield estimates probably requires use of these substitute data for most applications. The effect of substituting these data in similar models has been examined (Sakamoto, et al).

Difference in Cost of Models is Negligible

Data requirements and sophistication of software required to implement the models operationally are insignificant. The Williams-type models do use observations from many CRDs simultaneously; this requires more storage in the computer than a model for a single CRD which might lead to higher costs. However, the same model is used for each CRD which might also result in a savings.

Models are Simple Regression Models

Both models are straightforward applications of ordinary least squares regression models. Specification of the algorithms to calculate some of the variables is the main complication. These are necessary but once incorporated into the software should not be any problem. Application would be difficult on most hand calculators.

Models Have Poor Current Measure of Modeled Yield Reliability

The Spearman correlation coefficient between the estimate of the standard error of a predicted yield from the base period model, S_y, and the absolute value of the difference between the predicted and actual yield, d, indicates whether the model provides an accurate current measure of modeled yield reliability. It is desirable to have the r value as close to +1 as

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possible, indicating that a narrow confidence interval (a function of s_y) about the predicted value is associated with smaller deviations of the predicted and actual yields. It would be reassuring if the years showing large deviations were the years when large deviations were expected.

Examination of Table 14 reveals that not only were the values of the correlation not close to +1, but also they were more often negative. The CEAS model was worse, but neither the CEAS model nor the Williams-type model was even close to being acceptable.

Conclusions

Models were quite comparable with respect to most of the criteria: adequacy, timeliness, cost, simplicity and accurate current measures of modeled yield reliability. CEAS models are somewhat better with regard to requiring scientific and physical interpretation of variables selected for models rather than relying exclusively on statistical significance. Objectivity is equal once models are developed. The reliability of the yield indication is somewhat better with the CEAS model in the higher production CRDs and in the aggregated estimates. Estimates for individual CRDs are better with the Williams-type model.

Recommendations

Since models were quite comparable the recommendation is difficult. Although it was believed that CEAS model was slightly better overall to achieve an aggregated estimate, it is recommended that the Williams-type not be eliminated. Williams-type was better for several CRD's and was better in 1974, an extremely poor year for yield (See Appendix 1). These models are quite similar with respect to input requirements and the results of model selection criteria. Further significant improvements are quite likely going to require additional inputs and/or changes in model form.

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TABLE 14
MODEL COMPARISON OF THE
CURRENT INDICATION OF MODELED YIELD RELIABILITY
BASED ON THE CORRELATION COEFFICIENT BETWEEN
BASE PERIOD PREDICTED AND TEST YEAR ACTUAL ACCURACY

TREND AND MONTHLY WEATHER DATA MODELS
BARLEY
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	R	RANK	R	RANK	R	RANK
N.DAKOTA	10	0.33	(1)	-0.09	(2)	-0.37	(3)
	20	0.01	(2)	0.09	(1)	-0.15	(3)
	30	-0.56	(3)	-0.39	(2)	-0.12	(1)
	40	-0.15	(1)	-0.17	(2)	-0.81	(3)
	50	-0.45	(2)	0.16	(1)	-0.46	(3)
	60	-0.50	(2)	0.25	(1)	-0.54	(3)
	70	-0.16	(2)	-0.73	(3)	-0.09	(1)
	80	-0.17	(3)	0.08	(1)	0.06	(2)
	90	-0.48	(2)	-0.60	(3)	0.01	(1)
STATE MODEL		-0.76	(3)	-0.20	(1)	-0.35	(2)
MINNESOTA	10	-0.46	(3)	0.30	(1)	-0.30	(2)
	40	0.10	(1)	-0.60	(3)	-0.52	(2)
STATE MODEL		-0.43	(1)	-0.50	(2)	-0.55	(3)

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APPENDIX 1
BOOTSTRAP TEST RESULTS
FOR BARLEY YIELDS IN
NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN 1   WILMS=WILLIAMS TYPE   CEAS=CEAS MODEL

			ACTUAL YIELD	PREDICTED YIELD (Q/H)			D= PREDICTED-ACTUAL		
STATE	CRD	YEAR	(Q/H)	STMAN	WILMS	CEAS	STMAN	WILMS	CEAS
N.DAKOTA	10	1970	20.1	19.3	17.6	23.5	-0.8	-2.5	3.4
		1971	20.9	20.2	20.0	22.1	-0.7	-0.9	1.2
		1972	21.0	21.0	24.0	23.1	0.0	3.0	2.1
		1973	22.5	21.7	16.1	21.2	-0.8	-6.4	-1.3
		1974	13.8	22.9	17.5	20.0	9.1	3.7	6.2
		1975	16.6	22.0	16.9	21.7	5.4	0.3	5.1
		1976	19.0	21.5	17.8	19.1	2.5	-1.2	0.1
		1977	18.6	21.6	16.2	17.7	3.0	-2.4	-0.9
		1978	25.0	21.6	22.4	23.5	-3.4	-2.6	-1.5
		1979	16.9	22.8	15.3	18.6	5.9	-1.6	1.7
	20	1970	18.6	18.8	17.4	22.6	0.2	-1.2	4.0
		1971	21.4	19.4	20.8	21.5	-2.0	-0.6	0.1
		1972	20.6	20.4	23.1	20.6	-0.2	2.5	0.0
		1973	20.4	20.8	18.1	22.5	0.4	-2.3	2.1
		1974	12.2	21.7	18.1	20.6	9.5	5.9	8.4
		1975	17.7	20.8	16.6	19.6	3.1	-1.1	1.9
		1976	19.8	20.8	17.6	17.7	1.0	-2.2	-2.1
		1977	16.4	21.2	16.3	18.4	4.8	-0.1	2.0
		1978	22.5	20.7	20.7	19.0	-1.8	-1.8	-3.5
		1979	19.7	21.5	16.1	19.8	1.8	-3.6	0.1
	30	1970	19.5	20.4	20.2	21.6	0.9	0.7	2.1
		1971	24.5	20.8	23.6	25.1	-3.7	-0.9	0.6
		1972	21.9	22.1	23.2	23.1	0.2	1.3	1.2
		1973	20.1	22.5	20.2	23.0	2.4	0.1	2.9
		1974	14.8	22.9	19.4	20.5	8.1	4.6	5.7
		1975	22.7	22.1	17.6	21.3	-0.6	-5.1	-1.4
		1976	22.3	22.6	18.2	21.6	0.3	-4.1	-0.7
		1977	21.8	23.1	19.0	23.5	1.3	-2.8	1.7
		1978	24.4	23.4	22.8	24.1	-1.0	-1.6	-0.3
		1979	27.2	24.0	23.5	24.9	-3.2	-3.7	-2.3
	40	1970	17.1	17.9	17.9	19.9	0.8	0.8	2.8
		1971	21.5	18.6	18.5	13.3	-2.9	-3.0	-8.2
		1972	23.9	19.8	23.6	24.0	-4.1	-0.3	0.1
		1973	20.8	21.0	15.2	14.4	0.2	-5.6	-6.4
		1974	11.7	21.8	16.1	20.1	10.1	4.4	8.4
		1975	17.4	20.9	17.1	18.1	3.5	-0.3	0.7
		1976	19.9	20.6	16.9	14.7	0.7	-3.0	-5.2
		1977	16.7	21.1	16.4	14.1	4.4	-0.3	-2.6
		1978	25.5	20.6	21.4	21.6	-4.9	-4.1	-3.9
		1979	19.6	22.0	17.0	15.8	2.4	-2.6	-3.8

APPENDIX
BOOTSTRAP TEST RESULTS FOR BARLEY YIELDS IN NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS

STMAN=STRAWMAN 1 WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
N.DAKOTA	50	1970	17.7	19.6	16.3	17.8	1.9	-1.4	0.1
		1971	24.5	20.1	20.5	21.3	-4.4	-4.0	-3.2
		1972	20.4	21.6	20.2	19.0	1.2	-0.2	-1.4
		1973	14.5	21.8	12.9	19.8	7.3	-1.6	5.3
		1974	12.3	21.3	17.3	17.4	9.0	5.0	5.1
		1975	19.9	20.4	17.3	14.6	0.5	-2.6	-5.3
		1976	18.3	20.7	14.5	15.4	2.4	-3.8	-2.9
		1977	16.7	20.8	16.4	11.2	4.1	-0.3	-5.5
		1978	22.9	20,3	21.1	17.1	-2.6	-1.8	-5.8
		1979	20.9	21.1	18.8	19.5	0.2	-2.1	-1.4
	60	1970	17.5	22.4	19.7	22.7	4.9	2.2	5.2
		1971	26.5	22.3	22.4	25.2	-4.2	-4.1	-1.3
		1972	22.6	23.7	22.4	25.0	1.1	-0.2	2.4
		1973	21.3	23.9	18.4	25.0	2.6	-2.9	3.7
		1974	18.4	24.4	18.4	23.0	6.0	0.[illegible]	4.6
		1975	21.5	24.2	18.0	20.9	2.7	-3.5	-0.6
		1976	22.8	24.2	16.5	24.7	1.4	-6.3	1.9
		1977	24.1	24.4	18.8	23.7	0.3	-5.3	-0.4
		1978	28.6	24.8	22.0	25.3	-3.8	-6.6	-3.3
		1979	29.3	25.7	22.9	24.6	-3.6	-6.4	-4.7
	70	1970	16.4	18.5	17.9	16.9	2.1	1.5	0.4
		1971	21.6	19.1	20.3	15.5	-2.5	-1.3	-6.1
		1972	21.4	20.6	23.3	25.1	-0.8	1.9	3.7
		1973	22.1	21.2	16.6	18.0	-0.9	-5.5	-4.1
		1974	15.3	22.2	16.7	22.4	6.9	1.4	7.1
		1975	16.9	22.0	17.4	16.2	5.1	0.5	-0.7
		1976	19.6	21.6	16.1	17.0	2.0	-3.5	-2.6
		1977	17.2	22.0	17.7	12.3	4.8	0.5	-4.9
		1978	20.8	21.5	20.6	22.2	0.7	-0.2	1.4
		1979	17.7	21.9	16.6	17.2	4.2	-1.1	-0.5
	80	1970	13.0	16.4	15.7	16.4	3.4	2.7	3.4
		1971	21.4	16.5	20.0	15.7	-4.9	-1.4	-5.7
		1972	18.9	17.9	22.0	22.1	-1.0	3.1	3.2
		1973	16.3	18.4	12.5	14.4	2.1	-3.8	-1.2
		1974	10.1	18.6	14.0	16.0	8.5	3.9	5.9
		1975	17.8	17.9	17.5	14.6	0.1	-0.3	-3.2
		1976	14.2	18.3	14.5	16.0	4.1	0.3	1.8
		1977	12.7	18.0	17.3	12.1	5.3	4.6	-0.6
		1978	19.0	17.4	20.0	16.3	-1.6	1.0	-2.7
		1979	16.5	18.1	17.1	12.2	1.6	0.6	-4.3

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APPENDIX
BOOTSTRAP TEST RESULTS
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NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN I WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
N.DAKOTA	90	1970	18.5	20.7	15.9	17.5	2.2	-2.6	-1.0
		1971	24.8	21.2	20.8	20.9	-3.6	-4.0	-3.9
		1972	21.3	22.7	20.8	23.1	1.4	-0.5	1.8
		1973	18.7	23.0	11.5	18.9	4.3	-7.2	0.2
		1974	17.1	23.1	16.5	23.4	6.0	-0.6	6.3
		1975	17.8	23.3	15.5	15.5	5.5	-2.3	-2.3
		1976	13.8	22.8	11.2	13.4	9.0	-2.6	-0.4
		1977	23.1	21.8	19.5	19.1	-1.3	-3.6	-4.0
		1978	22.3	22.3	20.0	19.5	0.0	-2.3	-2.9
		1979	22.9	22.5	19.1	16.5	-0.4	-3.8	-6.4
STATE MODEL		1970	18.3	20.3	19.0	19.7	2.0	0.7	1.4
		1971	24.2	20.7	21.5	19.9	-3.5	-2.7	-4.3
		1972	21.5	22.0	22.1	21.2	0.5	0.6	-0.3
		1973	19.9	22.4	17.1	18.5	2.5	-2.8	-1.4
		1974	15.1	22.8	17.2	19.1	7.7	2.1	4.0
		1975	20.4	22.3	16.3	16.5	1.9	-4.1	-3.9
		1976	20.4	22.4	16.8	17.5	2.0	-3.6	-2.9
		1977	21.0	22.6	16.5	17.2	1.6	-4.5	-3.8
		1978	24.7	22.8	20.4	20.2	-1.9	-4.3	-4.5
		1979	24.7	23.5	20.2	20.7	-1.2	-4.5	-4.0
CRDS AGGR.		1970	18.3	20.2	18.5	20.8	1.9	0.2	2.5
		1971	24.2	20.7	21.9	23.0	-3.5	-2.3	-1.2
		1972	21.5	21.8	22.5	22.9	0.3	1.0	1.4
		1973	19.9	22.2	17.1	21.5	2.3	-2.8	1.6
		1974	15.1	22.8	18.0	21.0	7.7	2.9	5.9
		1975	20.4	22.2	17.3	19.4	1.8	-3.1	-1.0
		1976	20.4	22.5	16.5	20.1	2.1	-3.9	-0.3
		1977	21.0	22.7	18.3	20.8	1.7	-2.7	-0.2
		1978	24.7	22.8	21.8	22.6	-1.9	-2.9	-2.1
		1979	24.7	23.5	20.8	22.1	-1.2	-3.9	-2.6

APPENDIX
BOOTSTRAP TEST RESULTS FOR BARLEY YIELDS IN NORTH DAKOTA AND MINNESOTA COMPARING TREND AND MONTHLY WEATHER DATA MODELS

STMAN=STRAWMAN I WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
MINNESOTA	10	1970	18.4	22.6	20.8	18.3	4.2	2.4	-0.1
		1971	26.9	22.5	24.1	23.8	-4.4	-2.8	-3.1
		1972	24.8	23.9	24.4	24.2	-0.9	-0.4	-0.6
		1973	24.2	24.6	22.2	22.7	0.4	-2.0	-1.5
		1974	20.9	25.3	19.2	18.8	4.4	-1.7	-2.1
		1975	21.5	25.4	19.6	19.6	3.9	-1.9	-1.9
		1976	26.7	25.3	19.7	22.9	-1.4	-7.0	-3.8
		1977	27.4	26.2	19.8	24.1	-1.2	-7.6	-3.3
		1978	28.4	27.0	23.7	26.2	-1.4	-4.7	-2.2
		1979	29.4	27.7	24.5	25.6	-1.7	-4.9	-3.8
	40	1970	22.9	24.1	22.2	20.7	1.2	-0.7	-2.2
		1971	25.2	24.9	23.0	25.9	-0.3	-2.2	0.6
		1972	19.3	25.9	19.4	21.3	6.6	0.1	2.0
		1973	26.3	25.4	22.2	20.0	-0.9	-4.1	-6.3
		1974	21.2	26.5	21.9	21.3	5.3	0.7	0.1
		1975	18.6	26.4	20.4	18.0	7.8	1.8	-0.6
		1976	13.3	25.7	17.7	18.1	12.4	4.4	4.8
		1977	27.7	23.8	21.0	17.0	-3.9	-6.7	-10.7
		1978	22.2	24.6	22.2	20.7	2.4	0.0	-1.5
		1979	26.4	24.4	24.4	19.3	-2.0	-2.0	-7.1
STATE MODEL		1970	19.9	22.9	19.9	20.8	3.0	0.0	0.9
		1971	26.1	23.1	22.8	23.5	-3.0	-3.3	-2.6
		1972	23.1	24.4	24.0	23.8	1.3	0.9	0.7
		1973	24.7	24.8	23.8	22.8	0.1	-0.9	-1.9
		1974	21.0	25.6	20.4	21.5	4.6	-0.6	0.5
		1975	20.4	25.7	21.2	20.0	5.3	0.8	-0.4
		1976	22.1	25.4	19.6	20.2	3.3	-2.5	-1.9
		1977	27.4	25.3	20.6	21.5	-2.1	-6.8	-5.9
		1978	26.6	26.1	23.7	23.6	-0.5	-2.9	-3.0
		1979	28.5	26.5	24.8	23.6	-2.0	-3.7	-4.9
CRDS AGGR.		1970	19.9	23.1	21.3	19.1	3.2	1.4	-0.8
		1971	26.3	23.3	23.7	24.5	-3.0	-2.6	-1.8
		1972	23.3	24.5	23.0	23.4	1.2	-0.3	0.1
		1973	24.8	24.8	22.2	21.9	0.0	-2.6	-2.9
		1974	21.0	25.7	20.2	19.7	4.7	-0.8	-1.3
		1975	20.5	25.7	19.9	19.1	5.2	-0.6	-1.4
		1976	22.2	25.4	19.0	21.3	3.2	-3.2	-0.9
		1977	27.5	25.5	20.1	22.2	-2.0	-7.4	-5.3
		1978	26.8	26.4	23.3	24.8	-0.4	-3.5	-2.0
		1979	28.7	26.9	24.5	24.1	-1.8	-4.2	-4.6

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APPENDIX
BOOTSTRAP TEST RESULTS
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COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN 1 WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

			ACTUAL YIELD	PREDICTED YIELD (Q/H)			D= PREDICTED-ACTUAL		
STATE	CRD	YEAR	(Q/H)	STMAN	WILMS	CEAS	STMAN	WILMS	CEAS
REGION CRDS AGGR.		1970	18.6	20.8	19.1	20.4	2.2	0.5	1.8
		1971	24.8	21.4	22.4	23.4	-3.4	-2.4	-1.4
		1972	21.9	22.4	22.6	23.0	0.5	0.7	1.1
		1973	21.1	22.8	18.3	21.5	1.7	-2.8	0.5
		1974	16.6	23.6	18.6	20.7	7.0	2.0	4.1
		1975	20.5	23.2	18.0	19.3	2.7	-2.5	-1.2
		1976	20.9	23.3	17.2	20.4	2.4	-3.7	-0.5
		1977	22.9	23.5	18.8	21.2	0.6	-4.1	-1.7
		1978	25.4	23.8	22.3	23.2	-1.6	-3.1	-2.2
		1979	26.0	24.6	21.9	22.7	-1.4	-4.1	-3.3
STATES AGGR.		1970	18.7	20.9	19.2	20.0	2.2	0.5	1.3
		1971	24.7	21.4	21.9	20.9	-3.3	-2.8	-3.8
		1972	21.9	22.6	22.5	21.8	0.7	0.6	-0.1
		1973	21.1	23.0	18.7	19.5	1.9	-2.4	-1.6
		1974	16.7	23.6	18.1	19.7	6.9	1.4	3.0
		1975	20.4	23.2	17.7	17.5	2.8	-2.7	-2.9
		1976	20.9	23.3	17.6	18.3	2.4	-3.3	-2.6
		1977	22.9	23.4	17.7	18.5	0.5	-5.2	-4.4
		1978	25.3	23.8	21.4	21.2	-1.5	-3.9	-4.1
		1979	25.9	24.5	21.7	21.5	-1.4	-4.2	-4.3

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