United States
Department of
Agriculture

Statistical
Reporting
Service

Statistical
Research
Division

October 1982

Evaluation of the CEAS Trend and Monthly Weather Data Models for Corn Yields in Iowa, Illinois, and Indiana

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EVALUATION OF THE CEAS TREND AND MONTHLY WEATHER DATA MODELS FOR CORN YIELDS IN IOWA, ILLINOIS, AND INDIANA. By Richard A. Kestle; Statistical Research Division, Statistical Reporting Service, U. S. Department of Agriculture, Columbia, Missouri 65201, October 1982. SRS Staff Report No.

ABSTRACT

The CEAS models evaluated use the basic input variables of year and monthly average temperature and total precipitation to predict corn yields in Iowa, Illinois, and Indiana. Historic trend, meteorological and agroclimatic variables are constructed. Stepwise multiple regression techniques are used to develop both pooled and unpooled models; neither form of model outperformed the other. Evaluated yield reliability at the state level indicated model bias between one and four quintals/hectare and standard deviation between five and seven quintals/hectare. The models are objective, easy to use and understand, and are not costly to operate but would need redevelopment in future years or in other geographic areas. More evidence is needed to show that model results are consistent with scientific knowledge.

Key Words: Model evaluation, crop yield modeling, regression models, pooled models.

ACKNOWLEDGEMENTS

The author wishes to thank Jeanne Sebaugh, Wendell Wilson, and other AgRISTARS Yield Model Development Project personnel for their comments and assistance and Jean Sparks for typing this report.

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by

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This research was conducted as part of the AgRISTARS Yield Model Development Project. It is part of task 4 (subtask 1) in major project element number 1, as identified in the 1982 Yield Model Development Project Implementation Plan. As an internal project document, this report is identified as shown below.

AgRISTARS
Yield Model Development
Project

YMD-1-4-1(82-10.2)

FOREWORD

This report is one of a series of crop yield model evaluation reports being prepared by various staff members at the Joint USDA/NOAA/NASA Modeling Center in Columbia, Missouri. In this initial series of evaluation reports, two alternative and potentially competing models are being evaluated for each of the following crops: spring wheat, barley, corn for grain, and soybeans. The evaluations for spring wheat and barley are being made for North Dakota and Minnesota, while soybean and corn models are evaluated for Indiana, Illinois and Iowa.

Following the evaluation reports, and based upon their findings, a series of model comparison reports are being prepared. These reports (one for each crop) will compare the alternative or competing models for each potential application.

The previously published reports in these series are listed below:

- "Evaluation of the CEAS Trend and Monthly Weather Data Models for Spring Wheat Yields in North Dakota and Minnesota," by Jeanne L. Sebaugh (USDA).
- "Evaluation of the Williams-Type Spring Wheat Model in North Dakota and Minnesota," by Sharon K. LeDuc (NOAA).
- "Comparison of CEAS and Williams-Type Models for Spring Wheat Yields in North Dakota and Minnesota," by Tom L. Barnett (NASA).
- "Evaluation of the CEAS Model for Barley Yields in North Dakota and Minnesota," by Tom L. Barnett (NASA).
- "Evaluation of the Williams-Type Model for Barley Yields in North Dakota and Minnesota," by Tom L. Barnett (NASA).
- "Comparison of CEAS and Williams-Type Barley Yield Models for North Dakota and Minnesota," by Sharon K. LeDuc (NOAA).
- "Evaluation of the Thompson-Type Yield Models for Soybeans in Iowa, Illinois and Indiana," by Richard A. Kestle (USDA).

These reports have been, and the remaining reports in these series will be, prepared in support of tasks in the Yield Model Development Project of AgRISTARS. AgRISTARS is an acronym for "Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing." It is a multi-agency program to meet some current and new information needs of USDA.

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Evaluation of the CEAS Trend and Monthly Weather Data Models for Corn Yields in Iowa, Illinois, and Indiana

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SUMMARY

The CEAS models were developed by stepwise multiple regression procedures to predict corn yields in Iowa, Illinois, and Indiana. Historic trend, meteorological and agroclimatic variables were constructed from the basic input variables of year and monthly average temperature and total precipitation for inclusion in the models. Bootstrap testing was performed to obtain indicators of yield reliability and current measures of modeled yield reliability for pooled state models and individual CRD and state models. Direct comparisons based on several of the yield indicators of reliability were made, and neither the pooled or unpooled models were found to outperform the other. Both were evaluated in this report.

Indicators of yield reliability show that at the state level the bias is between one and four quintals/hectare and the standard deviation between five and seven quintals/hectare. The models are objectively defined and appropriate for short-term use but will probably need redevelopment in future years. More evidence is needed to show that the approach taken by the model developer and the model results are consistent with and reflect scientific knowledge. The models would need to be redeveloped for use in other areas. Timely yield forecasts during the growing season could be made with approximate climatic division data. The models are not costly to operate, but redevelopment costs would need to be considered in future years. Users can easily understand and operate the models. The standard errors of prediction computed by the model do not provide a useful current measure of reliability of the model predicted yields.

DESCRIPTION OF THE MODELS

The corn yield models evaluated in this report were developed by the Climatic and Environmental Assessment Services (CEAS) (LeDuc, 1980) in order to predict crop reporting district (CRD) and state level yields in Iowa, Illinois and Indiana. (CEAS is part of the National Oceanic and Atmospheric Administration (NOAA) within the U. S. Department of Commerce.)

Statistical regression techniques and historic crop and weather data were used to develop the models. The basic historic variables included year, yield in quintals per hectare, monthly average temperature (T) in degrees centigrade and total monthly precipitation (P) in millimeters. A number of weather-related variables are derived from the monthly temperatures and precipitation. Several trend terms (functions of year) and the weather variables were available for inclusion in each CRD or state model. Final model variable selections were made by stepwise regression procedures. A list of the variables included in each state and CRD model is included in the Appendix (pp. 51-53).

Along with individual CRD models developed separately in each CRD and state, an "All CRDs" or "pooled" model was also developed for each state in order to predict yields at the CRD level. This model assumes that "the technology increases are the same for each district as well as . . . a similar effect on yield due to the weather variables" (LeDuc, 1980). Indicator variables representing CRDs in a state are included in the models to allow for higher/lower levels of yields in some individual CRDs.

Some of the meteorological variables included in the models are simple averages of temperatures or cumulations of precipitation over two or more months. Others are defined as deviations from a previously defined variable's long-term 1932-1980 average. These "departures from normal" (DFN) may be entered into the models as linear or quadratic (squared) terms. No temperature variable is included in any model as a DFN. However, average temperature during the July through August period does enter the Illinois CRD 70 and 90 models, and many of the Indiana CRD models (CRDs 10, 20, 40, 70, 80 and 90). The Illinois state model has the only simple precipitation DFN term; it is entered as a linear term for May. Many other models have some form of a cumulative precipitation variable included. This variable enters into models as a linear term in the Iowa CRD 10 model (cumulative precipitation from September through July), the Iowa pooled model (cumulative precipitation from September through June), and the Iowa CRD 20 model (summed June and July precipitation). Cumulative precipitation is also included as a squared DFN term, either cumulated from September through June (Iowa CRDs 50 and 60, and Illinois CRD 10 and pooled models), or cumulated from September through August (Illinois CRD 80 and Indiana CRD 90 models).

Besides the meteorological variables already described, other agroclimatic variables were also derived. These were felt to be representative of the impact of moisture and heat stress. Moisture is supplied by water stored in the soil and is replenished by rainfall. Moisture is lost from the available soil water directly through evaporation and indirectly through transpiration from the plants. Actual evapotranspiration (ET) is defined as the actual water loss by transpiration from the leaves and by evaporation from the soil surface. Potential evapotranspiration (PET) is defined as the maximum possible ET which would occur if soil moisture over a large area were not a limiting factor. An approximation to the monthly PET is calculated using a procedure developed by Thornthwaite (1948). The calculations require the current and "normal" monthly temperature and the latitude of the geographic location. ET can then be calculated as a function of PET, monthly precipitation, and the contents and capacity of a soil moisture budget. The soil moisture budget is maintained according to Palmer (1965). Evapotranspiration which is considered to be "climatically appropriate for existing conditions" (CAFEC) is computed as αPET, where $\alpha = \overline{ET}/\overline{PET}$ and $\overline{ET}$ and $\overline{PET}$ are long term averages for a particular month. This quantity indicates the value ET would have to have in order to be in its historic ratio to PET.

Several quantities are calculated from these moisture stress variables for inclusion in the corn yield models. They are: (1) the ratio of ET to CAFEC(ET), (2) the difference between P and PET, (3) the ratio of P to PET, (4) cumulative PET over several months, (5) average ET during a several month period, and (6) the ratio of cumulative July-August P to cumulative July-August ET.

PET can be thought of as indicating the crop's demand for moisture while ET or P can be thought of as indicating the supply of moisture. Thus, quantities (2) and (3) are measures of the relationship between supply and demand. Moisture stress is indicated if quantity (2) is more negative and if quantity (3) is close to zero. Since CAFEC(ET) represents the value ET should be if it is to have its "normal" relationship to PET, moisture stress would be reflected if quantity (1) is close to zero. Quantities (4) and (5) are straightforward indicators of the demand for, and availability of, moisture, while small values of quantity (6) also indicate moisture stress.

As mentioned previously, the Appendix lists the variables included for each model. Quantity (1) appears in several models for May, June, July, and August. Quantity (2) appears in several models for July and August. Quantity (3) appears in several models for May, July, and August. Quantity (4) appears in the Iowa CRD 70 model for July-August, and in the Iowa pooled model for April-May. Quantity (5) appears only in the Indiana pooled and state models, and quantity (6) appears only in the Indiana CRD 20 model.

Linear trend terms defined on the year number are used as surrogates for technological advances. Iowa and Illinois models use a single trend term, defined as year minus 1950, which allows for a linear increase in yields due to technology from 1951 to 1980. Three trend terms, however, had a possibility of inclusion in the Indiana models. One allows for a linear increase in yields from 1930 to 1980, the second allows for a linear increase between 1930 and 1951, and the third a linear increase from 1951 to 1980. The first two terms are included in Indiana CRDs 20, 40, 50, and 60 models, and the pooled and state model. The first and third terms are included in the Indiana CRDs 10, 30, and 90 models. The third term is the only trend term included in the Indiana CRDs 70 and 80 models. Whenever the second or third term is included with the first term in the same model, the sign and magnitude of the model coefficients will determine whether the contribution to yield from technology has increased or decreased during overlapping time segments. When the third trend term is used in the model alone, contributions to yield from technology are considered nil for the 1930-1951 time period.

A preliminary list of meteorologic and agroclimatic variables that were believed to have some association to corn yields was drawn up prior to model development. To be included in any model, however, the variables had to meet several requirements. First, they had to be linearly correlated to detrended yields. Second, after stepwise regression was performed, the resulting variables were "screened . . . with regard to the physical interpretation of the selected variables and their estimated coefficients." Thus, only one of several closely related variables may have been kept, or a variable would be discarded because the sign of its coefficient was "contrary to the assumed relationship" between it and yield (LeDuc 1980).

State and individual (unpooled) CRD models are currently being operated by NOAA. The Modeling Center Staff decided, however, to compare the pooled models with the unpooled models at the CRD level. This action led to the evaluation of both types of models.

To develop CRD level data sets, published CRD level corn (for grain purposes only) yield data of the Statistical Reporting Service (SRS) and Climatic Division (CD) weather data of NOAA are used. For Iowa, Illinois, and Indiana, CD boundaries exactly match those of CRDs. To develop state level data sets, weather variables and yields at the CRD level are weighted by harvested area and aggregated to the state level.

Weather and yield data from 1932 to 1979 were used to develop Indiana models. For Iowa and Illinois, however, corn for grain yields are only published as far back as 1956 and 1954, respectively. In order to increase the number of years of data available for evaluation purposes, a "special" Iowa and Illinois corn for grain data set was used to extend the weather and yield data set for each state back to 1950 (Kestle, 1982). In this "special" data set, harvested-for-grain areas were estimated based on relationships between areas harvested-for-grain and areas harvested-for-all purposes. Iowa yields were actual for-grain yields, but in Illinois yields for all purposes were used. While CEAS model developers did not have access to these extended years of data when first developing the corn yield models, major differences between model development and model evaluation coefficients due to these extra years of data are not expected.

In all three states, the crop year of 1970 was eliminated from model development because of the effect of corn blight on yields. The 1970 crop year was, therefore, also eliminated during model evaluations.

EVALUATION METHODOLOGY

Eight Model Characteristics To Be Discussed

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

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

Each of these characteristics will be discussed as they pertain to the CEAS trend and monthly weather data corn yield models.

Bootstrap Technique Used to Generate Indicators of Yield Reliability for Comparison and Evaluation of CEAS Models

Indicators of yield reliability (reviewed below) require that the parameters of the regression model be computed for a set of data and that a yield prediction be made based on that data for a given "test" year. The values required to generate indicators of yield reliability include the predicted yield, $\hat{Y}$, the USDA estimate of the actual harvested 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. Years from an earlier base period are used to generate parameter estimates for a prediction equation. Values of the independent variables in the test year following the base period are inserted into the equation to produce a predicted yield for that year. Then, the test year data are added to the base period and a new prediction equation and predicted yield are generated for the following test year. This process is continued over a ten year period (1971-1980) producing ten yield predictions independent of the data used to fit the model. The earliest year in the base period for Indiana is 1932, and for Illinois and Iowa, 1950. Thus, for example, in Indiana the data base period extends from 1932-1969 (38 years) for the development of the prediction model in test year 1971 (crop year 1970 having been omitted), from 1932-1971 (39 years) for the development of the prediction model in test year 1972, etc.

Although the data used to estimate model coefficients and predict yields do not include the test year itself, predicted yields are not entirely independent of the data from the test year, in most cases. This is because the model developer used all available data (through 1979) when first developing the models. Nine of the bootstrap test years were thus included in the data set used to determine the variables retained in the final models and the trend specifications. This situation is difficult to avoid since it is both unrealistic to suggest the model developer create ten different models for each CRD and state, and to ask the model evaluator to recreate the variable selection and trend specification process, which does include some subjective decisions, accurately ten times. The result is that the bootstrap testing procedure can not test the performance effectiveness of the models in future years when redevelopment may need to be reconsidered because of changes in trend and/or the expansion of the data base.

Table 1 shows the average production and yield over the ten-year test period for each state and CRD. The table also contains the percent production each CRD contributes to the state production total and the percent production each CRD contributes to the three-state region production total. The percentage of regional production for each CRD is shown graphically in Figure 1. Darker shades indicate higher average production.

Separate models were derived at the CRD and state level for each state. The CRD models have been labeled "unpooled" in the tables to follow. Pooled models for each state were also derived to predict yields at the CRD level. These models have been labeled "pooled" in the tables to follow. To derive

Table 1

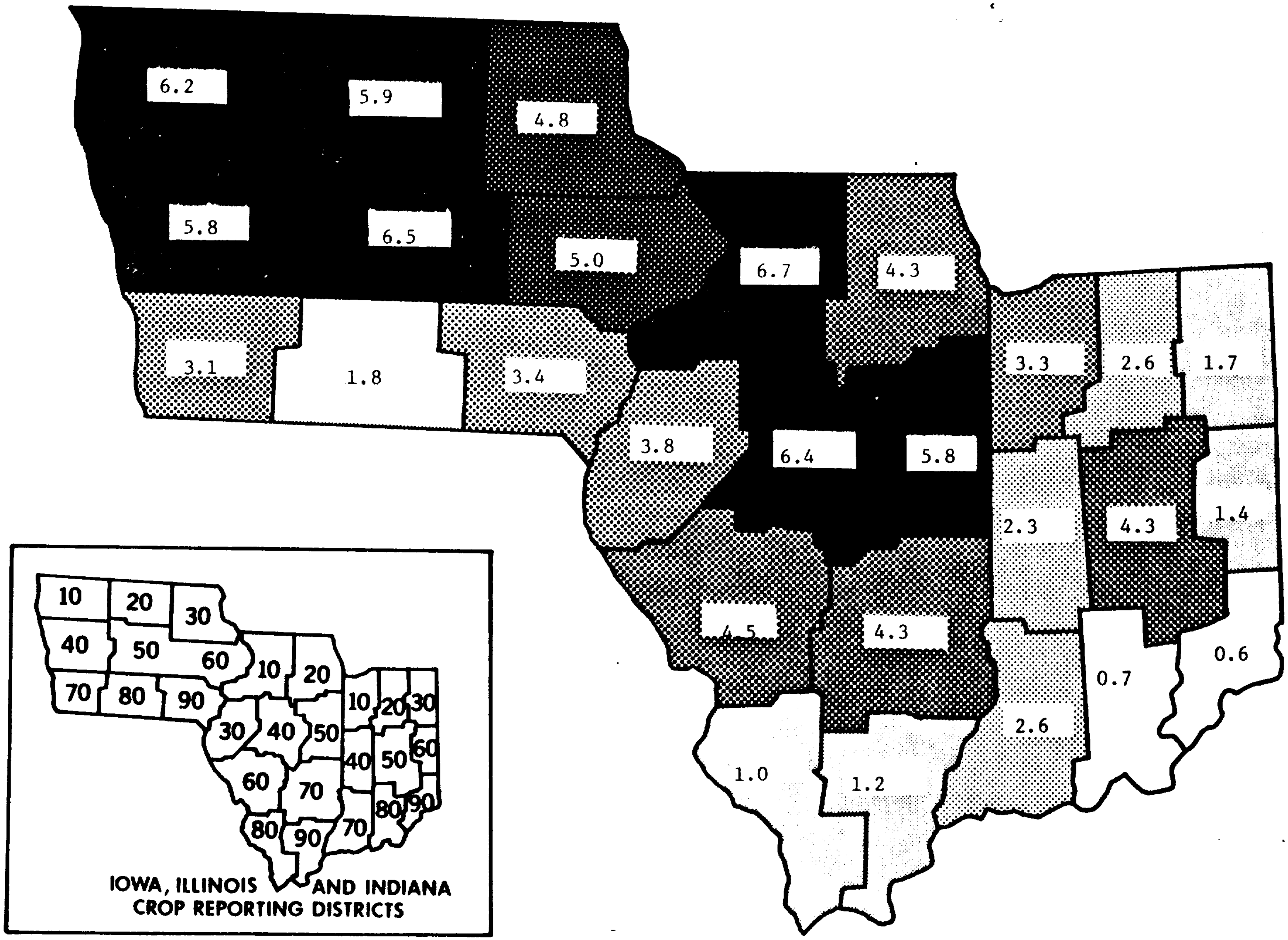
Average Production and Yield
For Test Years 1971-80

Corn

Iowa, Illinois, Indiana

STATE	CRD	PRODUCTION (1,000) QUINTALS	PRODUCTION (1,000) BUSHELS	PERCENT OF STATE	PERCENT OF REGION	YIELD QNTL/HA	YIELD BU/ACRE
IOWA	10	46,530	183,190	14.6	6.2	64.2	102.3
	20	44,543	175,368	14.0	5.9	68.4	109.0
	30	35,941	141,501	11.3	4.8	65.7	106.3
	40	43,409	170,903	13.6	5.6	58.7	93.6
	50	49,051	193,114	15.4	6.5	67.6	107.7
	60	37,453	147,454	11.7	5.0	68.1	108.5
	70	23,069	90,822	7.2	3.1	57.2	91.1
	80	13,333	52,493	4.2	1.8	54.6	87.1
	90	25,974	102,258	8.1	3.4	66.1	105.4
STATE		319,304	1,257,101		42.4	64.3	102.4
ILLINOIS	10	50,811	200,042	17.7	6.7	67.9	108.1
	20	32,060	126,220	11.2	4.3	65.5	106.0
	30	28,847	113,570	10.1	3.8	67.5	107.6
	40	47,942	188,749	16.7	6.4	71.5	113.8
	50	44,044	173,400	15.4	5.8	70.1	111.7
	60	33,595	132,262	11.7	4.5	67.2	107.0
	70	32,185	126,711	11.2	4.3	64.3	102.4
	80	7,698	30,305	2.7	1.0	48.9	77.9
	90	9,182	36,150	3.2	1.2	49.6	79.0
STATE		286,362	1,127,410		38.0	66.6	106.1
INDIANA	10	24,926	98,133	16.9	3.3	64.8	103.2
	20	19,683	77,491	13.3	2.6	60.4	96.3
	30	13,089	51,531	8.9	1.7	58.0	92.5
	40	17,651	69,490	12.0	2.3	65.7	104.7
	50	32,569	128,224	22.1	4.3	66.7	105.2
	60	10,484	41,274	7.1	1.4	62.3	99.2
	70	19,250	75,786	13.0	2.6	63.6	101.3
	80	5,436	21,401	3.7	0.7	57.3	91.3
	90	4,550	17,915	3.1	0.6	56.9	90.7
STATE		147,636	581,245		19.6	63.1	100.6
REGION		753,302	2,965,756			64.9	103.5

Figure 1. Production of corn by CRD (1971-1980 average) as a percentage of the regional total. Darker shades indicate CRDs with higher production.



the state models which predict state level yields, weather and agronomic data were aggregated from the CRD to the state level using a weighted average based on harvested area. Predicted yields at the state level were also calculated by obtaining a weighted average of CRD level predicted yields. No pooling of state data was performed. Therefore, the state model results are identical whether reported along with the pooled CRD results or the unpooled CRD results. Finally, predicted yields at the region level were obtained by calculating weighted averages (using harvested area) of the CRD predicted yields and of the state predicted yields. Results obtained by aggregating from the state level are identified as "state aggr." Results obtained by aggregating from the CRD level are identified as "CRDs aggr." Although models were developed to predict yields before and during the growing season, they were not compared or evaluated in this report; only the reliability of the end-of-season models is examined here.

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 the Differences Between $\hat{Y}$ and Y ($d=\hat{Y}-Y$) 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). Assuming the d values are normally distributed, it is about 68% probable that the absolute value of d for a future year will be less than one RMSE and 95% probable that it will be less than twice the RMSE. So, accurate prediction capability is indicated by a small RMSE.

A non-zero bias means the model is, on the average, overestimating the yield (positive bias) or underestimating the yield (negative bias). The SD is smaller than the RMSE when there is non-zero bias and indicates what the RMSE would be if there were no bias. If the bias is near zero, the SD and the RMSE would be close in value. For the purposes of this report, a model with bias close to zero is preferred.

Indicators Based on Relative Differences Between $\hat{Y}$ and Y ($rd=100d/Y$) Demonstrate Worst and Best Performance

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

Several indicators are derived using relative differences. In order to calculate the proportion of years beyond a critical error limit, the number of years in which the absolute value of the relative difference exceeds a critical limit of 10 percent was counted. The critical limit of 10 percent was used based on earlier investigations made by Sebaugh (1981). The worst and next to worst performances during the test period are defined as the largest and next to largest absolute value of the relative difference. The range of yield indication accuracy is defined by the largest and smallest absolute values of the relative difference.

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

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

Two indicators relate the change in direction of reported 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 reported and predicted values for the test years is computed. It is desirable that $r(-1 \leq r \leq +1)$ be large and positive. A negative r indicates smaller predicted yields occurring with larger observed yields (and vice versa).

Current Measure of Modeled Yield Reliability Defined By a Correlation Coefficient

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

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

For regression models, this suggests the use of a correlation coefficient between two variables generated for each test year. One variable is an indicator of the precision with which a prediction for the next year can be made, based on the model development base period. 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_Y, is used for the first value, and the absolute value of the difference between the predicted and reported yield in the test year, $|d|$, is used as the second variable.

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

MODEL COMPARISON

Pooled and Unpooled Models Are Ranked According to Performance and Compared Using Statistical Tests

For the purpose of comparing pooled and unpooled CEAS corn yield models, three of the indicators of yield reliability are ranked: the root mean square error, the standard deviation and the bias. The model with the smallest indicator value exhibits the best performance in terms of yield reliability and is ranked 1. The other model is given a rank of 2. In case of ties, both are given a rank of 1.

A statistical test has been constructed by considering that one model performs better than another if its predicted yields, $\hat{Y}$'s, are closer to the reported yields, Y's, than the other model. The reliability of each model is related to the absolute value of the discrepancy between reported and predicted yields. Thus, where $|d_1| = |\hat{Y}_1 - Y|$ and $|d_2| = |\hat{Y}_2 - Y|$, for models 1 (pooled) and 2 (unpooled), the statistic of interest is $D = |d_1| - |d_2|$. The null hypothesis to be tested is that there is no difference in the reliability of the two models over the ten test years.

Two types of paired-sample statistical tests are used: a parametric test using Student's "t" test statistic and a nonparametric test using the Wilcoxin signed rank test statistic. Both test statistics are used because the distribution of D may not be a normal. Also, the nonparametric test will allow for the rejection of the null hypothesis if one model slightly, but consistently, outperforms the other model; the parametric test will only reject the null hypothesis if the average D value is large relative to its standard error.

Indicators of Yield Reliability and Statistical Tests Show Neither Model Outperforms the Other

The model values and comparative ranks for the root mean square error (RMSE), standard deviation (SD), and bias are given in the Appendix (p.54). In Iowa, the indicators of reliability rank first in more CRDs for the unpooled models. In Illinois and Indiana the opposite is true, with the pooled models ranking first in more CRDs. A CRD-by-CRD comparison, however, shows no consistent pattern of better performance for either form of model in any state. At the state and region level, the pooled and unpooled RMSE and SD values for the CRDs aggr. results are very similar.

The results of the parametric and nonparametric paired-sample statistical tests are equally inconclusive. The parametric test resulted in only two CRDs (Iowa CRD 70 and Illinois CRD 50) having a significant difference between the pooled and unpooled models. The non-parametric test produced only four such significant differences (in the above two CRDs, plus CRDs 30 and 70 in Indiana).

In summary, neither the pooled or unpooled models can produce consistently more reliable yield predictions at the CRD, state, or region level. For this reason, and because the unpooled models are already in an operational mode despite the fact that generating one pooled model per state is faster than generating nine CRD models, both forms of the models will be evaluated in this report. Evaluation tables are generated for each, but in the interest of reducing the volume of report pages, figures showing CRD values of indicators of reliability have only been included for the unpooled models.

MODEL EVALUATION

Indicators of Yield Reliability Based on $d=\hat{Y}-Y$ Show Bias Generally Between 1 and 4 Quintals/Hectare and Standard Deviations Between 4 and 13 Quintals/Hectare

The CRD, state, and regional values of indicators of yield reliability based on d for the unpooled models are given in Table 2A. For CRD results, bias ranged from practically zero (Indiana CRD 50) to over six (Indiana CRD 10) quintals per hectare, with the majority of values being positive and between one and four quintals per hectare. The six CRDs with biases greater than three quintals per hectare (Iowa CRDs 40 and 80, Illinois CRDs 10, 40, and 50, and Indiana CRD 10) include the five CRDs with a relative bias greater than five percent. The root mean square error is between five and fourteen quintals per hectare (Figure 2) with six CRDs having a root mean square error of greater than ten (CRDs 70, 80, and 90 in Iowa, 40 and 50 in Illinois, and 10 in Indiana). The relative root mean square error is over twenty percent only in CRDs 70 and 80 in Iowa and ranges from seven to seventeen percent in other CRDs. The standard deviation is greater than ten quintals per hectare only in Iowa CRDs 70, 80, and 90, while relative standard deviation percents are comparable to relative root mean square error.

Nearly half of all CRDs in the three states had smaller root mean square error values than those at the state level; state level biases were positive and between one and two quintals per hectare for Iowa and Indiana but over three quintals per hectare in Illinois. Aggregated CRD results were slightly better than state model results for Indiana and Illinois, but not for Iowa. At the region level the method of aggregation did not make much difference in the indicator results. Some CRDs continued to have smaller standard deviation and root mean square error values than region level results.

Table 2A

Indicators of Yield Reliability
Based on D = Predicted - Reported Yield

Unpooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

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
IOWA	10	76.18	8.73	13.6	74.44	8.63	13.2	1.74	1.32	2.1
	20	52.02	7.21	10.5	50.41	7.10	10.2	1.61	1.27	1.9
	30	36.53	6.04	9.1	34.45	5.87	9.0	2.07	-1.44	-2.2
	40	84.78	9.21	15.7	65.06	8.07	12.8	19.71	4.44	7.6
	50	43.47	6.59	9.8	42.70	6.53	9.5	0.77	0.88	1.3
	60	32.82	5.73	8.4	25.91	5.09	7.2	6.92	2.63	3.9
	70	149.88	12.24	21.4	142.59	11.94	20.0	7.29	2.70	4.7
	80	185.21	13.61	24.9	169.77	13.03	22.2	15.44	3.93	7.2
	90	111.97	10.58	16.0	106.31	10.31	15.0	5.66	2.38	3.6
STATE MODEL		43.61	6.60	10.3	41.97	6.48	9.9	1.64	1.28	2.0
CRDS AGGR.		51.94	7.21	11.2	48.33	6.95	10.5	3.61	1.90	3.0
ILLINOIS	10	25.55	5.05	7.4	16.37	4.05	5.7	9.18	3.03	4.5
	20	42.80	6.54	9.8	39.38	6.28	9.2	3.42	1.85	2.8
	30	61.82	7.86	11.6	56.25	7.50	10.7	5.57	2.36	3.5
	40	105.66	10.28	14.4	81.85	9.05	11.9	23.81	4.88	6.8
	50	112.67	10.61	15.1	83.94	9.16	12.1	28.73	5.36	7.6
	60	27.45	5.24	7.8	21.45	4.63	6.6	6.00	2.45	3.6
	70	44.89	6.70	10.4	40.31	6.35	9.6	4.58	2.14	3.3
	80	66.77	8.17	16.7	64.27	8.02	15.9	2.50	1.58	3.2
	90	34.21	5.85	11.8	33.00	5.74	11.3	1.21	1.10	2.2
STATE MODEL		49.33	7.02	10.5	35.34	5.95	8.5	13.99	3.74	5.6
CRDS AGGR.		40.18	6.34	9.5	30.13	5.49	7.9	10.05	3.17	4.8
INDIANA	10	103.26	10.16	15.7	65.44	8.09	11.4	37.82	6.15	9.5
	20	48.93	6.99	11.6	46.40	6.81	11.0	2.53	1.59	2.6
	30	26.57	5.15	8.9	25.99	5.10	8.9	0.58	-0.76	-1.3
	40	71.83	8.48	12.9	64.65	8.04	11.8	7.18	2.68	4.1
	50	40.75	6.38	9.6	40.75	6.38	9.6	0.00	-0.01	-0.0
	60	26.52	5.15	8.3	24.78	4.98	8.2	1.74	-1.32	-2.1
	70	25.98	5.10	8.0	19.52	4.42	6.7	6.45	2.54	4.0
	80	41.02	6.40	11.2	37.52	6.13	10.3	3.50	1.87	3.3
	90	23.51	4.85	8.5	22.93	4.79	8.3	0.58	0.76	1.3
STATE MODEL		38.37	6.19	9.8	34.17	5.85	9.0	4.20	2.05	3.2
CRDS AGGR.		33.75	5.81	9.2	30.62	5.53	8.5	3.13	1.77	2.8
REGION										
CRDS AGGR.		31.18	5.58	8.6	25.75	5.07	7.5	5.43	2.33	3.6
STATES AGGR.		33.65	5.80	8.9	28.08	5.30	7.9	5.57	2.36	3.6

Figure 2. Root mean square error (RMSE) for CEAS unpooled corn models in quintals per hectare based on test years 1971-1980. Darker shades indicate CRDs with higher production.

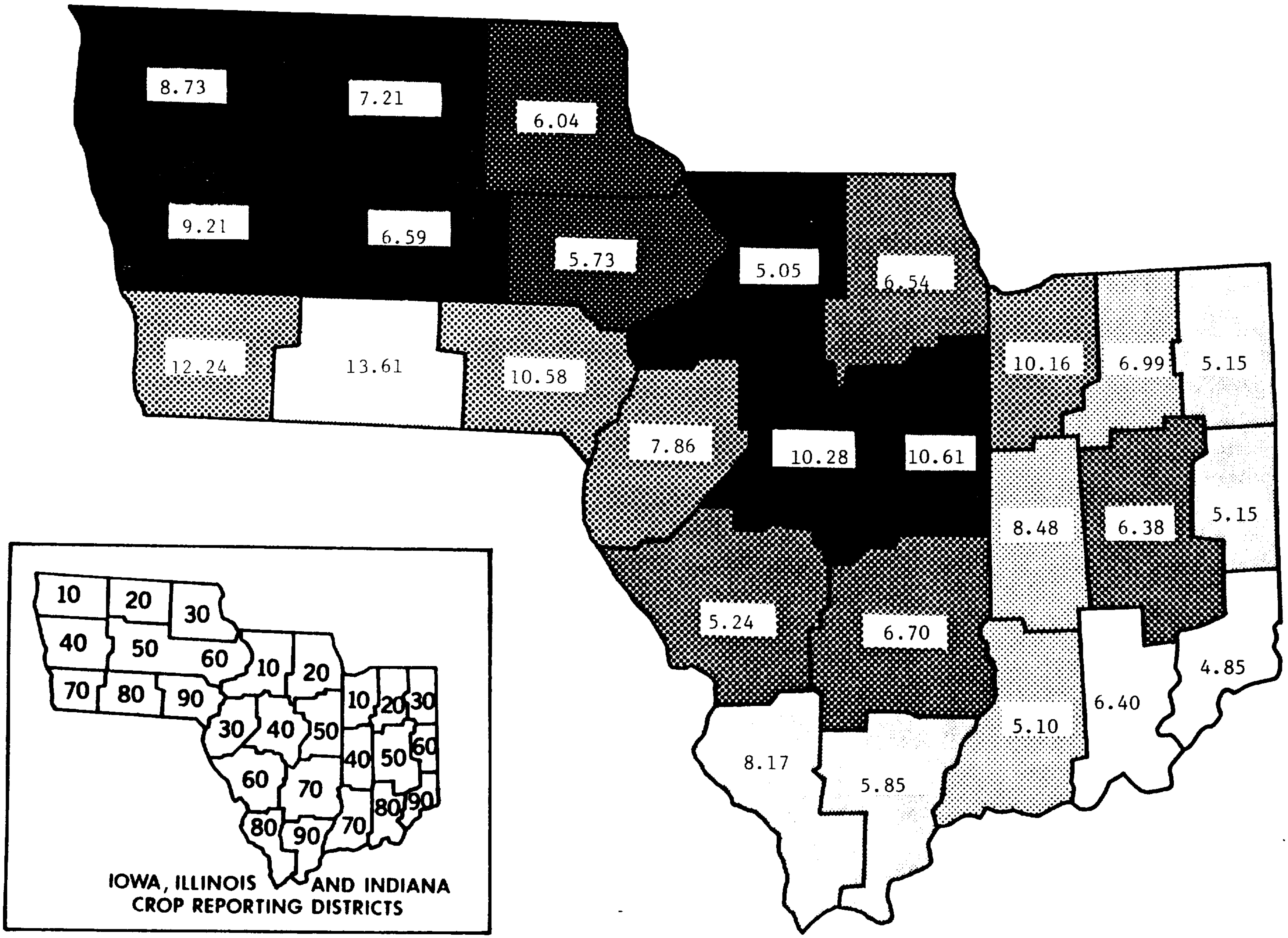


Table 2B

Indicators of Yield Reliability
Based on D = Predicted - Reported Yield

Pooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

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
IOWA	10	84.60	9.20	14.3	79.13	8.90	13.4	5.48	2.34	3.6
	20	43.20	6.57	9.6	43.15	6.57	9.6	0.05	-0.23	-0.3
	30	53.14	7.29	10.9	53.10	7.29	11.0	0.04	-0.19	-0.3
	40	130.16	11.41	19.4	88.55	9.41	14.4	41.60	6.45	11.0
	50	74.24	8.62	12.7	69.40	8.33	11.9	4.84	2.20	3.3
	60	33.55	5.79	8.5	27.69	5.26	7.5	5.86	2.42	3.6
	70	176.63	13.29	23.3	142.75	11.95	19.0	33.87	5.82	10.2
	80	133.83	11.57	21.2	110.79	10.53	17.7	23.04	4.80	8.8
	90	52.90	7.27	11.0	52.04	7.21	11.1	0.86	-0.93	-1.4
STATE MODEL		43.61	6.60	10.3	41.97	6.48	9.9	1.64	1.28	2.0
CRDS AGGR.		54.50	7.38	11.5	48.40	6.96	10.4	6.10	2.47	3.8
ILLINOIS	10	41.98	6.48	9.5	28.51	5.34	7.5	13.47	3.67	5.4
	20	47.97	6.93	10.4	43.80	6.62	9.7	4.16	2.04	3.1
	30	44.03	6.64	9.8	42.18	6.49	9.4	1.85	1.36	2.0
	40	70.98	8.43	11.8	68.03	8.25	11.3	2.96	1.72	2.4
	50	86.38	9.29	13.3	83.62	9.14	12.7	2.76	1.66	2.4
	60	25.94	5.09	7.6	25.39	5.04	7.4	0.55	0.74	1.1
	70	35.60	5.97	9.3	34.32	5.86	9.0	1.28	1.13	1.8
	80	88.50	9.42	19.3	50.60	7.11	12.9	38.19	6.18	12.6
	90	69.44	8.33	16.8	35.80	5.98	10.8	33.64	5.80	11.7
STATE MODEL		49.33	7.02	10.5	35.34	5.95	8.5	13.99	3.74	5.6
CRDS AGGR.		35.91	5.99	9.0	31.07	5.57	8.1	4.84	2.20	3.3
INDIANA	10	60.44	7.77	12.0	59.86	7.74	12.1	0.58	-0.76	-1.2
	20	48.26	6.95	11.5	41.45	6.44	10.2	6.81	2.61	4.3
	30	57.05	7.55	13.0	33.43	5.78	9.2	23.62	4.86	8.4
	40	58.85	7.67	11.7	58.84	7.67	11.7	0.01	0.10	0.2
	50	30.40	5.51	8.3	29.21	5.40	8.0	1.19	1.09	1.6
	60	25.24	5.02	8.1	24.97	5.00	8.0	0.27	0.52	0.8
	70	30.16	5.49	8.6	28.74	5.36	8.6	1.42	-1.19	-1.9
	80	34.20	5.85	10.2	31.00	5.57	9.4	3.20	1.79	3.1
	90	36.63	6.05	10.6	23.60	4.86	8.0	13.03	3.61	6.3
STATE MODEL		38.37	6.19	9.8	34.17	5.85	9.0	4.20	2.05	3.2
CRDS AGGR.		27.34	5.23	8.3	26.32	5.13	8.0	1.02	1.01	1.6
REGION										
CRDS AGGR.		30.16	5.49	8.5	25.87	5.09	7.6	4.28	2.07	3.2
STATES AGGR.		33.65	5.80	8.9	28.08	5.30	7.9	5.57	2.36	3.6

The CRD and aggregated CRD values of indicators of yield reliability for the pooled models are given in Table 2B. The range of bias values is similar to that of the unpooled models, but four CRDs reported relative biases in excess of ten percent (CRDs 40 and 70 in Iowa, and 80 and 90 in Illinois). The root mean square error is between five and thirteen quintals per hectare, with only three CRDs (40, 70 and 80 in Iowa) having a root mean square error of more than ten quintals per hectare. Relative root mean square errors and standard deviations are comparable to the unpooled models, but relative standard deviations do not exceed nineteen percent in any CRD. State and regional values of the aggregated CRD indicators closely resemble those of the unpooled models, showing improved yield prediction reliability in some cases and worse in others.

Indicators of Yield Reliability Based on rd=100d/Y Show 10-60 Percent of the Test Years Have rd Greater Than 10 Percent and the Largest rd Between 13 and 116 Percent

CRD, state, and region values for indicators of yield reliability based on rd for the unpooled models are given in Table 3A. CRD values are shown in Figures 3-5. Most CRDs show the absolute value of the relative difference being greater than ten percent in forty percent or less of the test years. Only CRDs 10, 40, 70 and 90 in Iowa and 80 in Illinois were the exception. But while the absolute value of rd was small in most years, it became very large in some years, reaching over one hundred percent in CRDs 70 and 80 in Iowa. Many of the second largest absolute values remained over thirty percent. Most of the largest absolute values of rd occurred in 1974. Information on yields and growing conditions in the test years can be found in the section of the Appendix, "Brief Description of Growing Conditions for Corn in the Bootstrap Test Years." The smallest absolute values of rd were below one percent in nearly half of the CRDs, and reached the highest value of 4.9 percent in Iowa CRD 40.

The aggregated CRD results are slightly better than the state model results in all three states. At the region level, the aggregated CRD results also do slightly better than aggregated state model results. The only year in which the largest absolute value of rd at the region level was greater than ten percent was 1974.

Indicators of yield reliability based on rd for the pooled models are given in Table 3B. Results are quite similar to the unpooled models. Only six CRDs (Iowa CRDs 40, 70 and 80, Illinois CRDs 80 and 90, and Indiana CRD 90) had more than forty percent of the test years in which the absolute value of rd was greater than ten percent. CRDs 70 and 80 in Iowa again had the highest values for the largest absolute value of rd, 107 and 98 percent respectively.

State and regional values of the aggregated CRD results were close to those of the unpooled models. Pooled largest $|rd|$ values did somewhat better than unpooled values at the state level in Illinois and Indiana but slightly worse in Iowa, and were essentially the same at the region level.

Table 3A

Indicators of Yield Reliability
Based on RD = 100 * ((Predicted-Reported Yield)/Reported Yield)

Unpooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	PERCENT OF YEARS |RD|>10%	LARGEST |RD| RD	(YEAR)	NEXT LARGEST	SMALLEST |RD|	RANGE |RD|
IOWA	10	50	36.7	(1974)	31.6	0.5	36.2
	20	30	26.0	(1974)	14.5	-1.2	24.9
	30	40	18.4	(1974)	-11.5	-1.7	16.7
	40	50	41.1	(1974)	33.4	4.9	36.2
	50	40	18.6	(1975)	-15.0	0.4	18.2
	60	30	16.3	(1974)	15.3	-1.0	15.3
	70	50	111.7	(1974)	31.1	-0.3	111.3
	80	40	115.5	(1977)	64.6	-0.2	115.3
	90	60	44.8	(1977)	23.4	-1.7	43.1
STATE MODEL		20	33.3	(1974)	12.6	1.5	31.8
CRDS AGGR.		30	29.9	(1974)	16.5	0.7	29.2
ILLINOIS	10	20	23.6	(1974)	12.1	-0.1	23.5
	20	10	40.1	(1974)	8.9	-0.4	39.7
	30	30	34.2	(1977)	15.0	1.4	32.8
	40	30	44.5	(1980)	32.2	-2.0	42.5
	50	30	48.2	(1980)	38.3	1.5	46.7
	60	30	13.5	(1974)	11.9	1.1	12.4
	70	20	31.0	(1974)	21.9	1.4	29.5
	80	60	46.7	(1980)	22.1	2.2	44.5
	90	40	20.8	(1971)	16.6	1.8	18.9
STATE MODEL		20	28.0	(1974)	25.7	0.8	27.2
CRDS AGGR.		20	26.8	(1974)	21.2	1.1	25.7
INDIANA	10	20	45.8	(1974)	43.1	-0.1	45.7
	20	20	43.6	(1974)	21.2	-1.3	42.4
	30	10	36.9	(1974)	-7.7	-0.2	36.8
	40	20	51.2	(1974)	19.3	0.1	51.0
	50	10	31.4	(1974)	-10.0	2.0	29.4
	60	20	16.7	(1974)	-12.2	0.4	16.4
	70	20	25.6	(1974)	10.9	0.3	25.3
	80	40	28.2	(1975)	16.0	-0.2	28.0
	90	40	19.2	(1974)	10.6	-2.2	17.0
STATE MODEL		10	39.3	(1974)	9.5	0.1	39.2
CRDS AGGR.		20	35.2	(1974)	10.4	0.0	35.2
REGION							
CRDS AGGR.		10	29.7	(1974)	7.3	0.2	29.6
STATES AGGR.		10	32.3	(1974)	8.4	-0.8	31.6

Figure 3. Percent of test years (1971-1980) the absolute value of the relative difference from the CEAS unpooled corn models is greater than ten percent. Darker shades indicate CRDs with higher production.

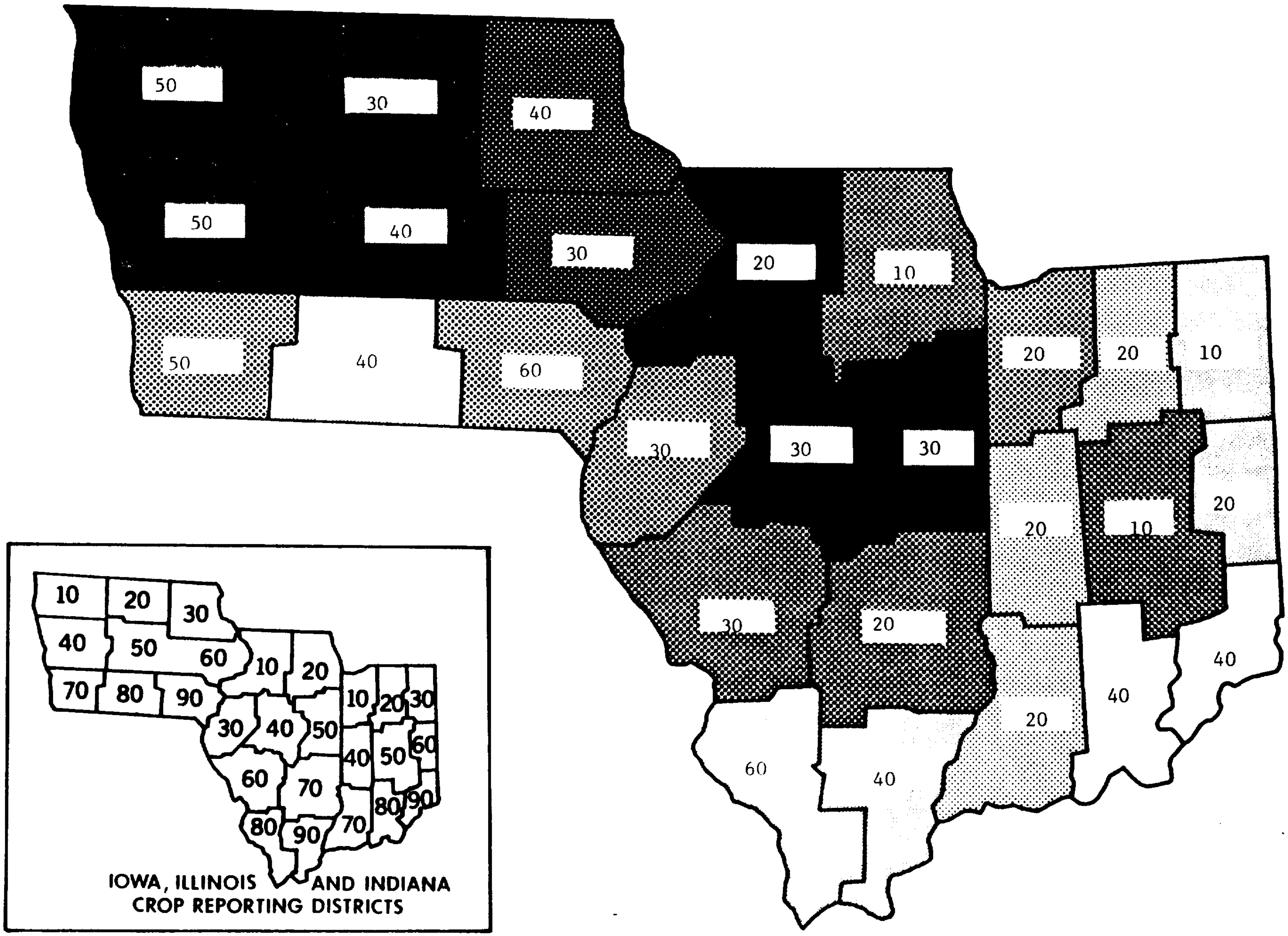


Figure 4. Largest absolute value of the relative difference from the CEAS unpooled corn models during the test years 1971-1980. Darker shades indicate CRDs with higher production.

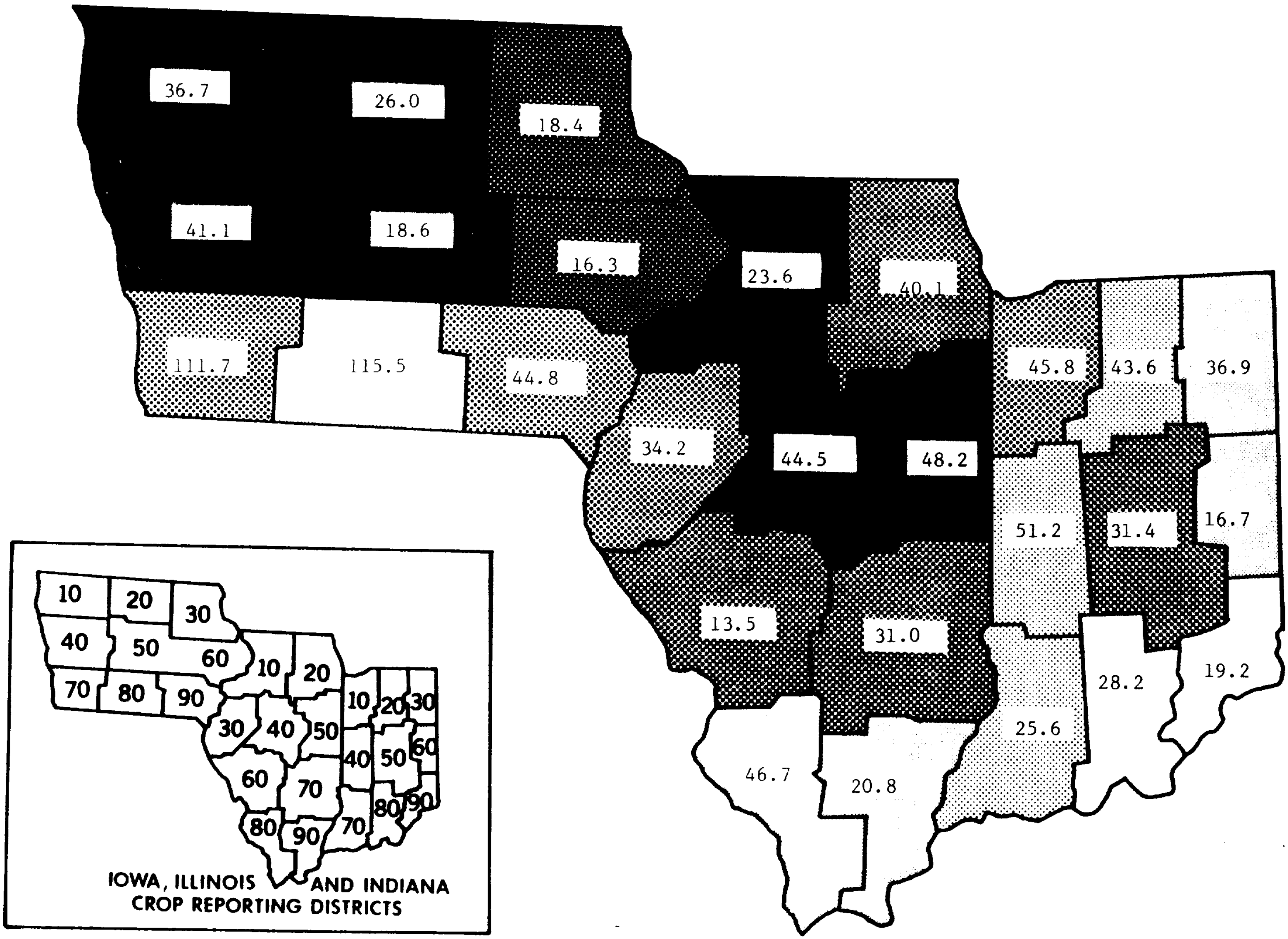


Figure 5. Next largest absolute value of the relative difference from the CEAS unpooled corn models during the test years 1971-1980. Darker shades indicate CRDs with higher production.

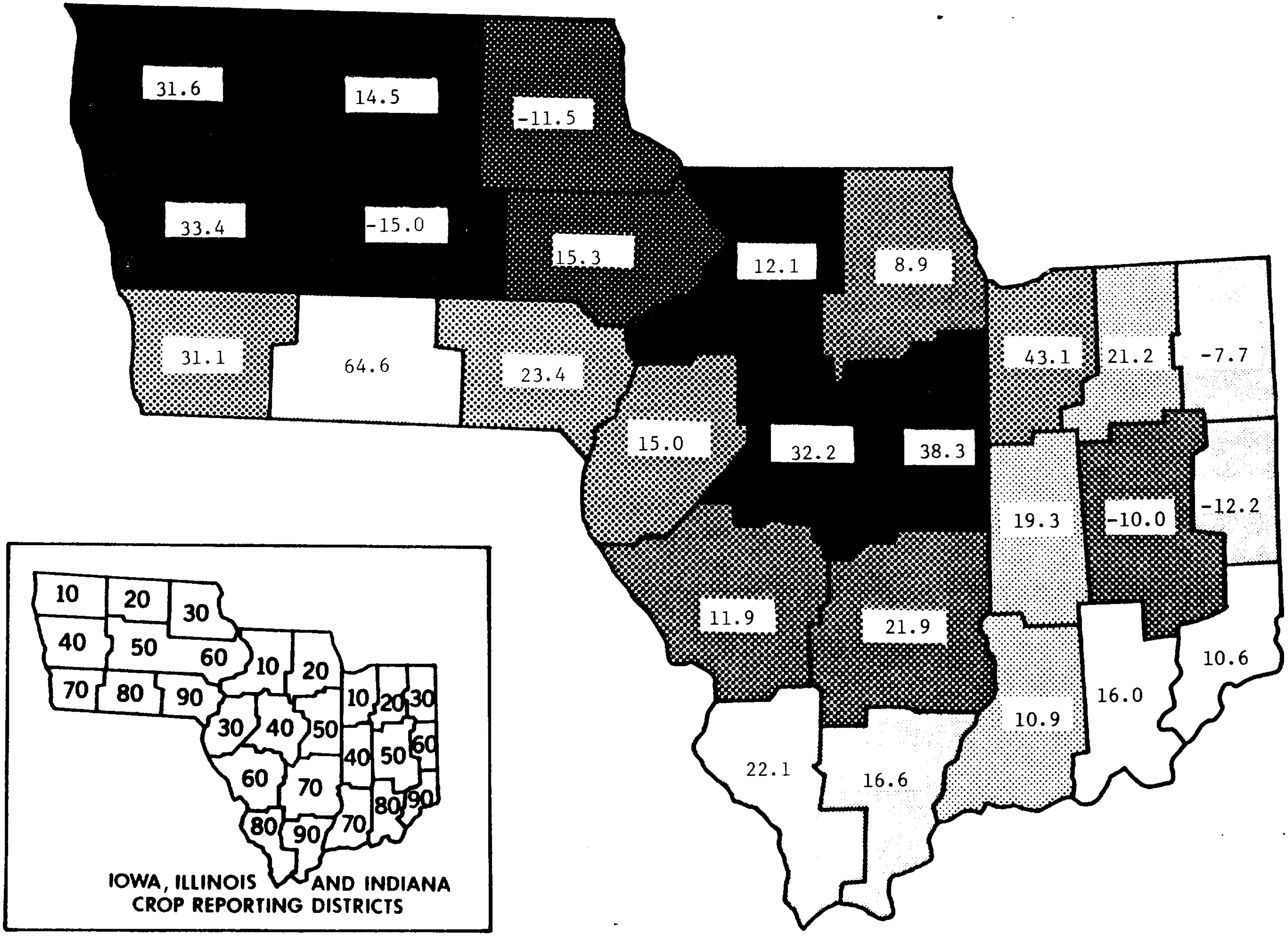


Table 3B

Indicators of Yield Reliability
Based on RD = 100 * ((Predicted-Reported Yield)/Reported Yield)

Pooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	PERCENT OF YEARS |RD|>10%	LARGEST |RD| RD	(YEAR)	NEXT LARGEST	SMALLEST |RD|	RANGE |RD|
IOWA	10	30	41.0	(1974)	35.5	-0.2	40.8
	20	40	22.4	(1974)	13.5	-1.2	21.3
	30	40	21.9	(1974)	-15.5	2.5	19.4
	40	60	45.8	(1974)	41.5	-2.7	43.1
	50	40	49.5	(1977)	14.5	-0.4	49.1
	60	30	23.2	(1974)	11.1	1.0	22.2
	70	50	106.7	(1974)	41.8	1.8	104.9
	80	50	97.6	(1977)	53.4	3.7	93.9
	90	40	21.8	(1977)	14.5	-0.6	21.2
STATE MODEL		20	33.3	(1974)	12.6	1.5	31.8
CRDS AGGR.		40	31.5	(1974)	15.4	-1.3	30.2
ILLINOIS	10	20	35.2	(1974)	14.2	0.4	34.8
	20	10	42.5	(1974)	6.3	-0.4	42.0
	30	30	25.7	(1977)	13.0	-1.1	24.7
	40	30	33.4	(1980)	24.9	-1.3	32.1
	50	40	43.4	(1980)	26.9	0.1	43.2
	60	30	12.5	(1980)	11.1	0.3	12.2
	70	20	25.1	(1974)	24.8	-0.7	24.4
	80	50	56.6	(1980)	35.4	-0.4	56.2
	90	50	43.8	(1980)	25.4	1.9	41.9
STATE MODEL		20	28.0	(1974)	25.7	0.8	27.2
CRDS AGGR.		20	25.4	(1974)	18.8	-0.6	24.8
INDIANA	10	30	28.7	(1980)	27.2	1.5	27.1
	20	20	46.9	(1974)	16.5	-0.5	46.4
	30	20	56.9	(1974)	10.7	0.2	56.7
	40	40	40.7	(1974)	14.5	-1.2	39.4
	50	10	30.6	(1974)	8.5	1.1	29.5
	60	10	24.3	(1974)	-9.1	0.3	23.9
	70	20	16.1	(1979)	-14.0	-0.8	15.3
	80	40	25.9	(1975)	14.1	0.9	24.9
	90	50	21.5	(1974)	20.5	-0.5	21.0
STATE MODEL		10	39.3	(1974)	9.5	0.1	39.2
CRDS AGGR.		10	30.3	(1974)	-9.2	0.3	30.1
REGION							
CRDS AGGR.		10	29.1	(1974)	-7.4	-0.2	29.0
STATES AGGR.		10	32.3	(1974)	8.4	-0.8	31.6

Indicators of Yield Reliability Based on $\hat{Y}$ and Y Show Good Correspondence Between Direction of Change in Predicted as Compared to Reported Yields, but Predicted Yields Are Usually Insensitive to Extreme Changes in Reported Yields

Plots of the reported and predicted corn yields over the ten-year test period using the state level models are shown in Figures 6-8. CRD, state, and region values (using the unpooled models) for the indicators of yield reliability based on the reported and predicted yields are given in Table 4A. CRD values of these indicators are also shown in Figures 9-11.

Except for CRDs 30 and 90 in Indiana, all unpooled CRD models produced a change in direction of predicted yields that agreed with a change in direction of reported yields from the previous year over fifty percent of the time, and only in Iowa CRD 90 did the predicted yield change not agree with the previous three-year average reported yield change over fifty percent of the time. The Pearson correlation coefficient between reported and predicted yields was positive and significantly greater than zero in all but three CRDs in Iowa and three CRDs in Illinois. However, only three CRDs in Indiana had a positive and significantly greater than zero Pearson correlation coefficient.

Although these indications of yield reliability suggest a good correspondence between the direction of change in reported and predicted yields, a review of Figures 6-8 shows that predicted yields rarely reflect the extreme highs or lows of reported yields at the state level in extraordinary years. This is very noticeable for 1974 in all three states. State predicted yields persistently over-estimated reported yields in Iowa over the five-year period, 1973-1977, while Illinois predicted yields over the entire ten-year period seemed even more insensitive to fluctuations in reported yield.

At the state and region level, Pearson correlation coefficients were positive and significantly greater than zero in all cases except for the Indiana state indications. In Iowa there seemed little difference between state model and aggregated CRD results, but in Illinois and Indiana, and at the region level, CRDs aggregation gave slightly more reliable results.

Table 4B contains the indicators of yield reliability based on reported and predicted yields for the pooled models. Results of the percent of years for which predicted yields changed in the same direction as reported yields from both the previous year and three-year base period are comparable to the unpooled models. However, more of the pooled model Pearson correlation coefficients were significantly greater than zero. At the state and region level, aggregated CRD results were nearly identical to unpooled model values, with the exception of Indiana where the pooled aggregated CRD correlation coefficient was substantially larger than the state model correlation coefficient. The two correlation coefficients were not significantly different, however.

Figure 6

Iowa State Model, Reported and Predicted
Corn Yields for the Test Years 1971-1980
(Quintals/Hectare)

A = Reported Yield P = Predicted Yield

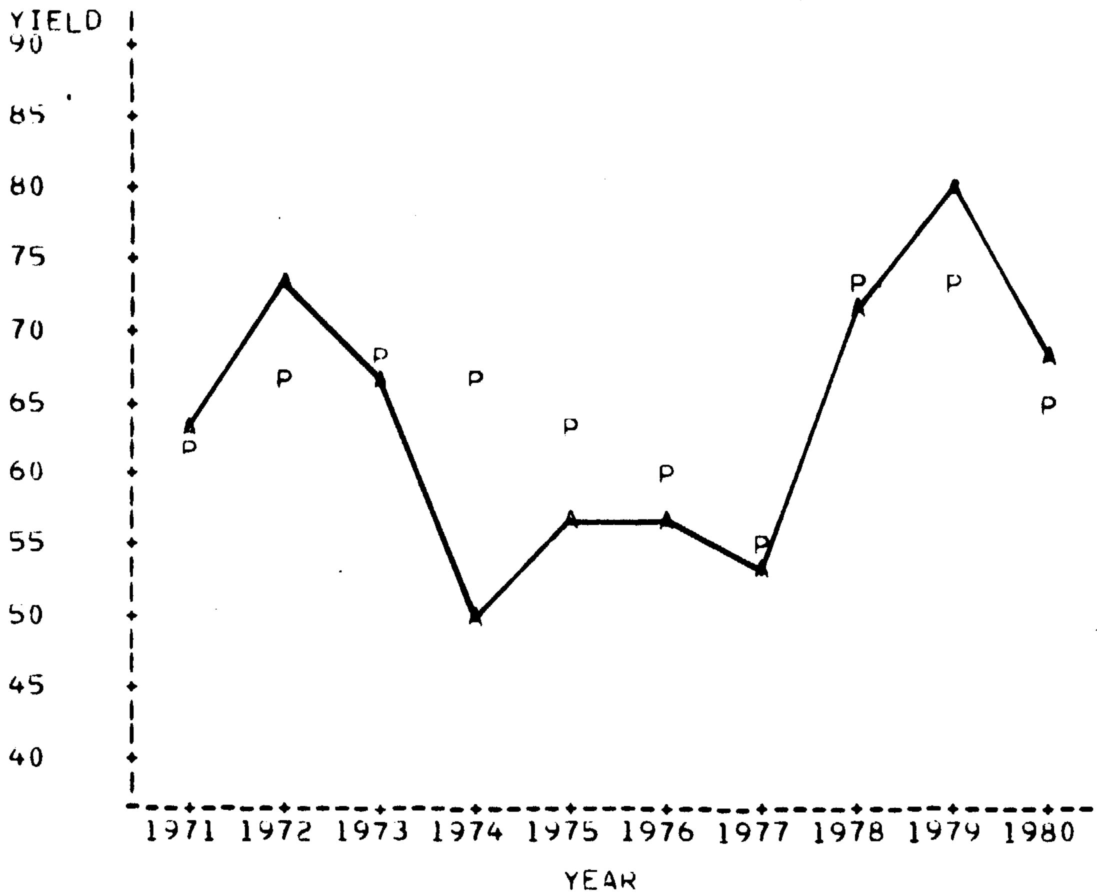


Figure 7

Illinois State Model, Reported and Predicted
Corn Yields for the Test Years 1971-1980
(Quintals/Hectare)

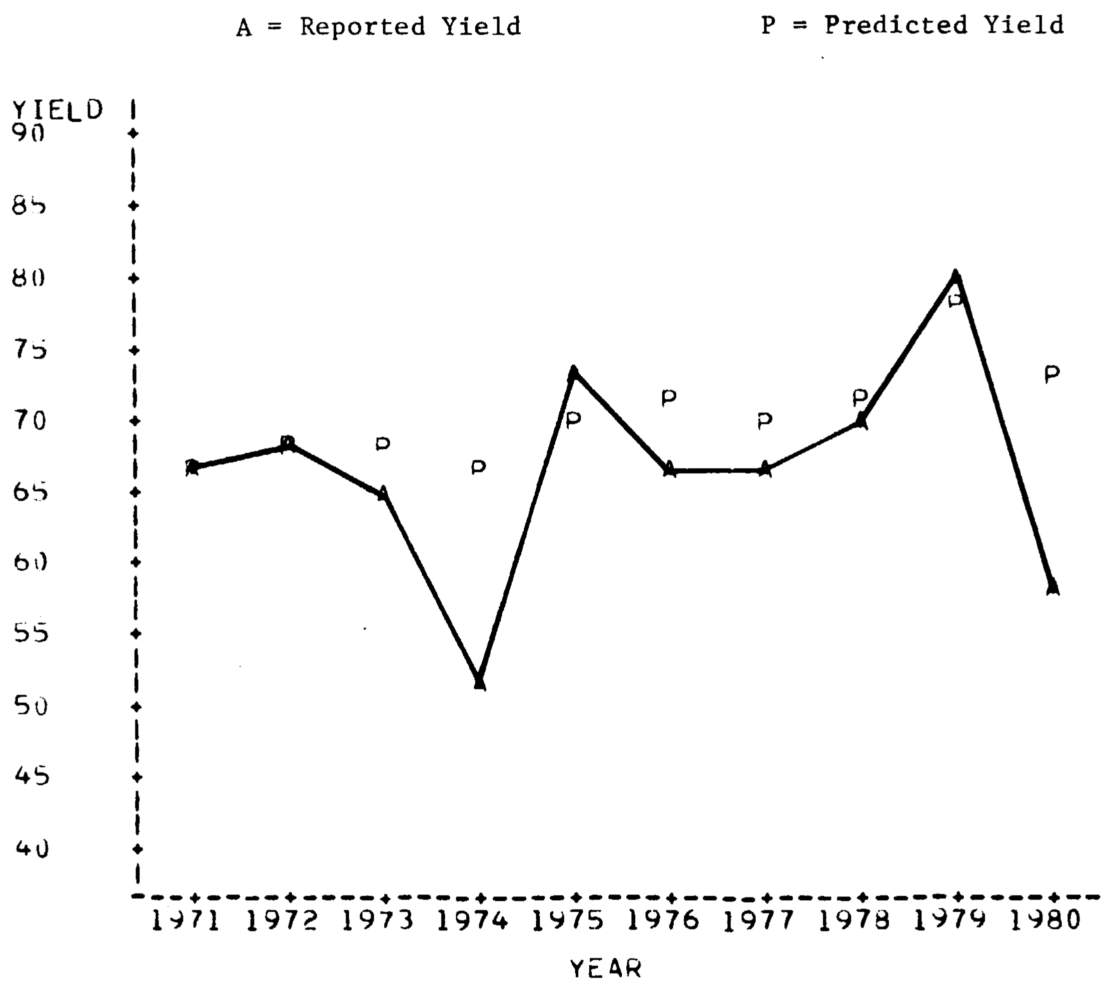


Figure 8

Indiana State Model, Reported and Predicted
Corn Yields for the Test Years 1971-1980
(Quintals/Hectare)

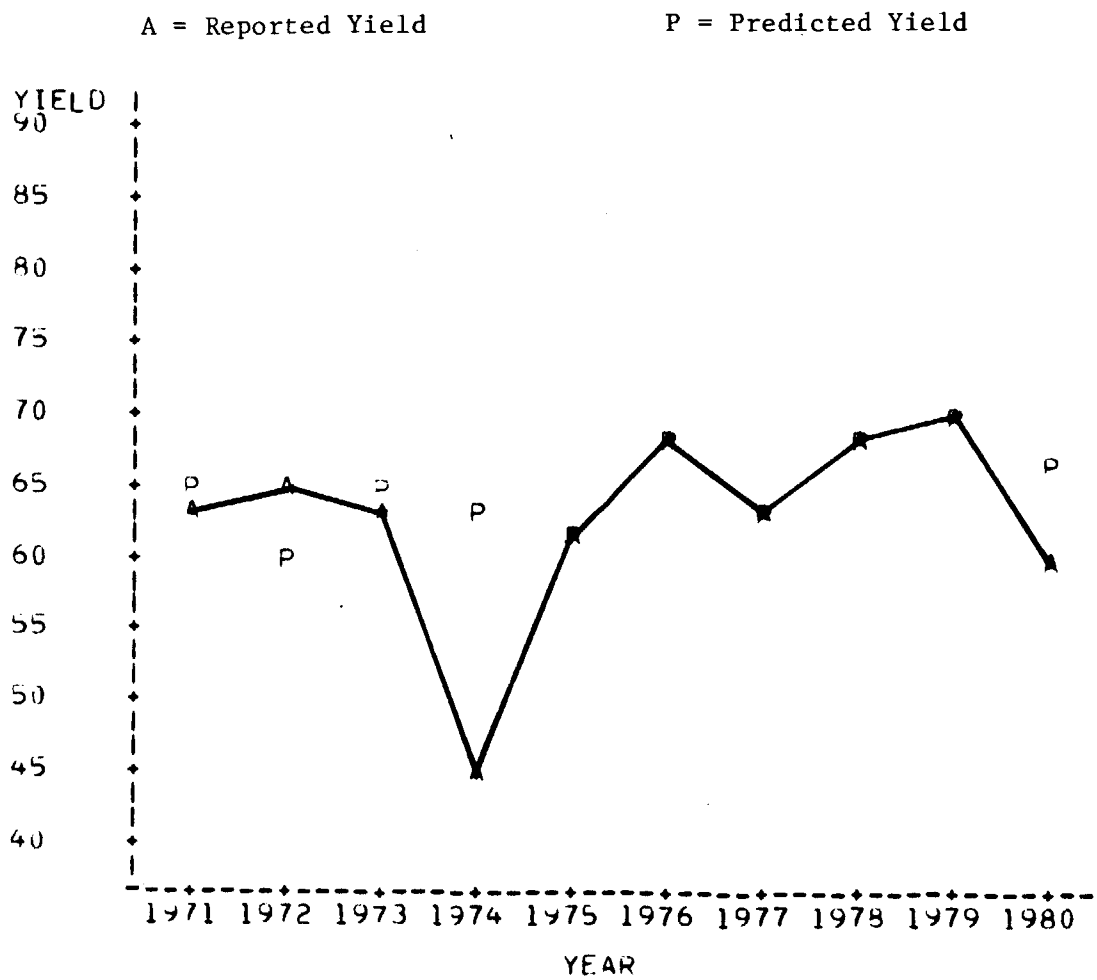


Table 4A

Indicators of Yield Reliability
Based on Reported and Predicted Yields

Unpooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	PERCENT OF YEARS DIRECTION OF CHANGE IS CORRECT FROM PREVIOUS YEAR	FROM BASE PERIOD	PEARSON CORR. COEF.
IOWA	10	67	71	0.65
	20	56	57	0.55
	30	67	71	0.78
	40	67	100	0.81
	50	89	86	0.84
	60	78	71	0.80
	70	78	86	0.48
	80	67	57	0.21
	90	78	43	-0.12
STATE MODEL		67	71	0.71
CRDS AGGR.		67	57	0.70
ILLINOIS	10	89	86	0.87
	20	78	71	0.69
	30	67	71	0.28
	40	78	71	0.36
	50	67	100	0.60
	60	67	57	0.75
	70	56	86	0.65
	80	67	71	0.51
	90	67	86	0.71
STATE MODEL		89	100	0.60
CRDS AGGR.		89	100	0.71
INDIANA	10	78	57	0.26
	20	78	71	0.46
	30	44	86	0.82
	40	67	100	0.41
	50	67	71	0.52
	60	56	100	0.75
	70	56	57	0.42
	80	67	71	0.49
	90	44	57	0.63
STATE MODEL		67	57	0.44
CRDS AGGR.		67	86	0.53
REGION				
CRDS AGGR.		78	86	0.74
STATES AGGR.		67	43	0.67

Figure 9. Percent of test years (1971-1980) the direction of change from the previous year's yield as predicted by the CEAS unpooled corn models agrees with the direction of change in the reported yield. Darker shades indicate CRDs with higher production.

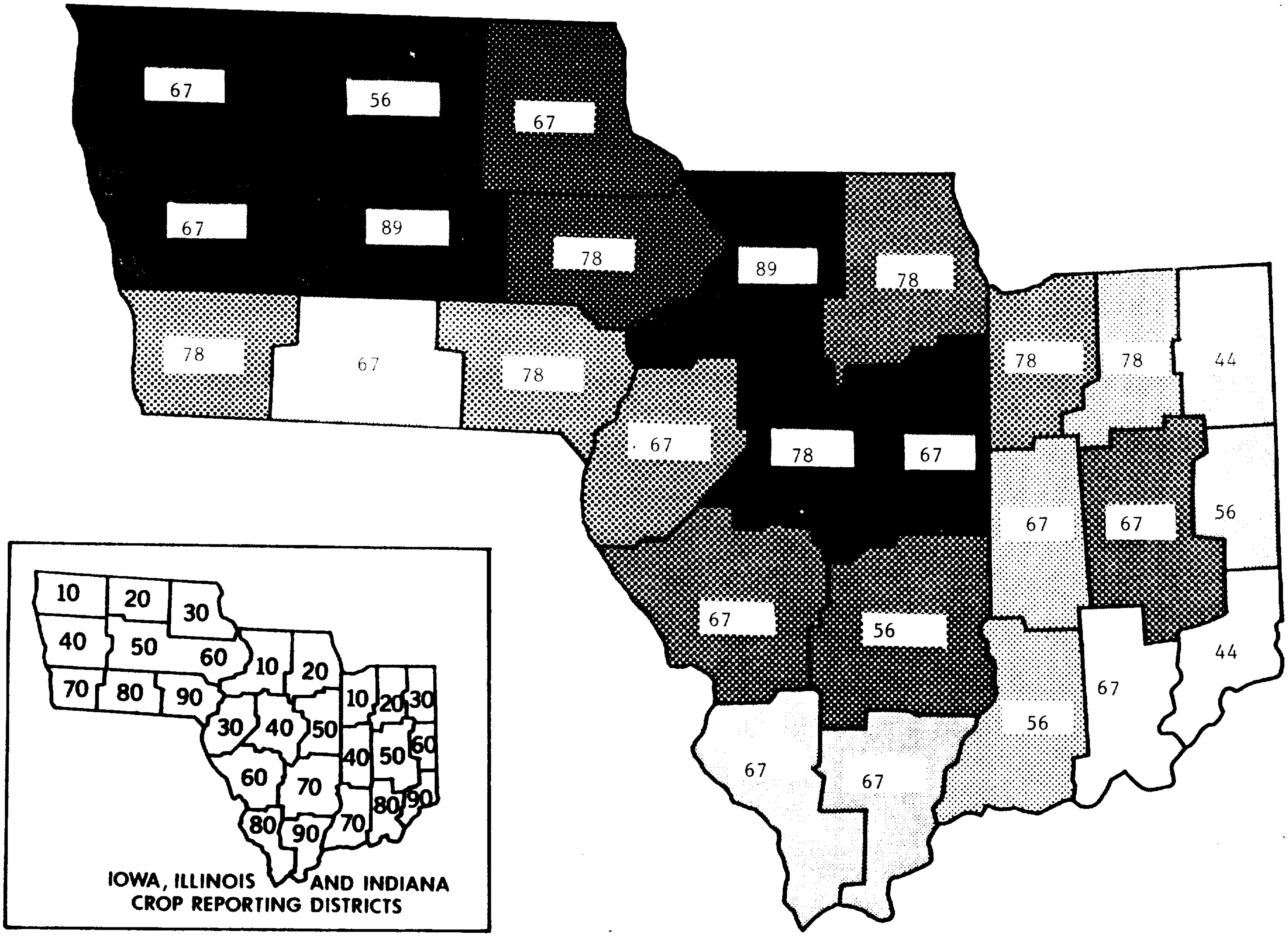


Figure 10. Percent of test years (1971-1980) the direction of change from the previous three years average yield as predicted by the CEAS unpooled corn models agrees with the direction of change in the reported yield. Darker shades indicate CRDs with higher production.

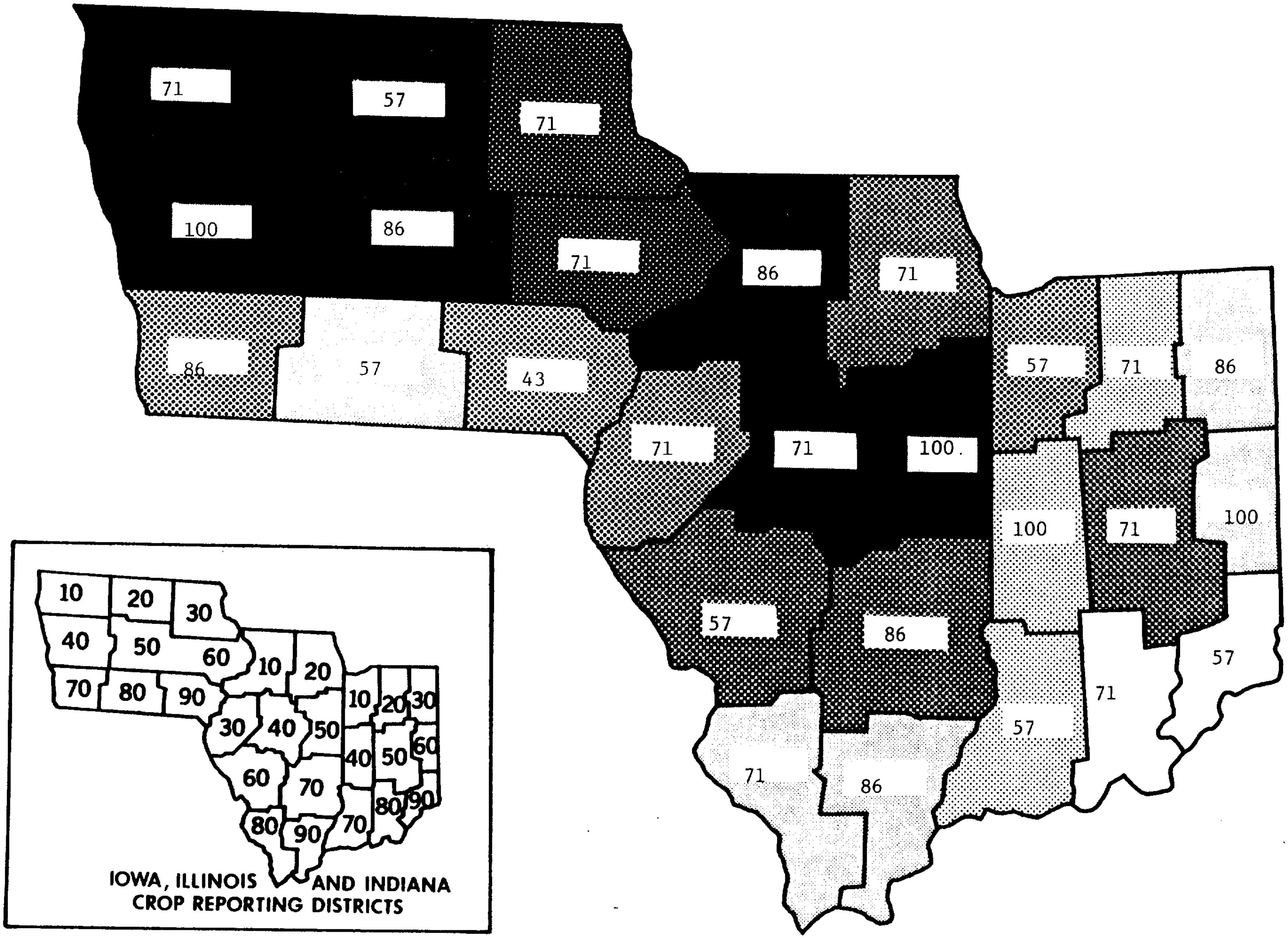


Figure 11. Pearson correlation coefficients between reported yield and yield as predicted by the CEAS unpooled corn models for the test years 1971-1980. Darker shades indicate CRDs with higher production.

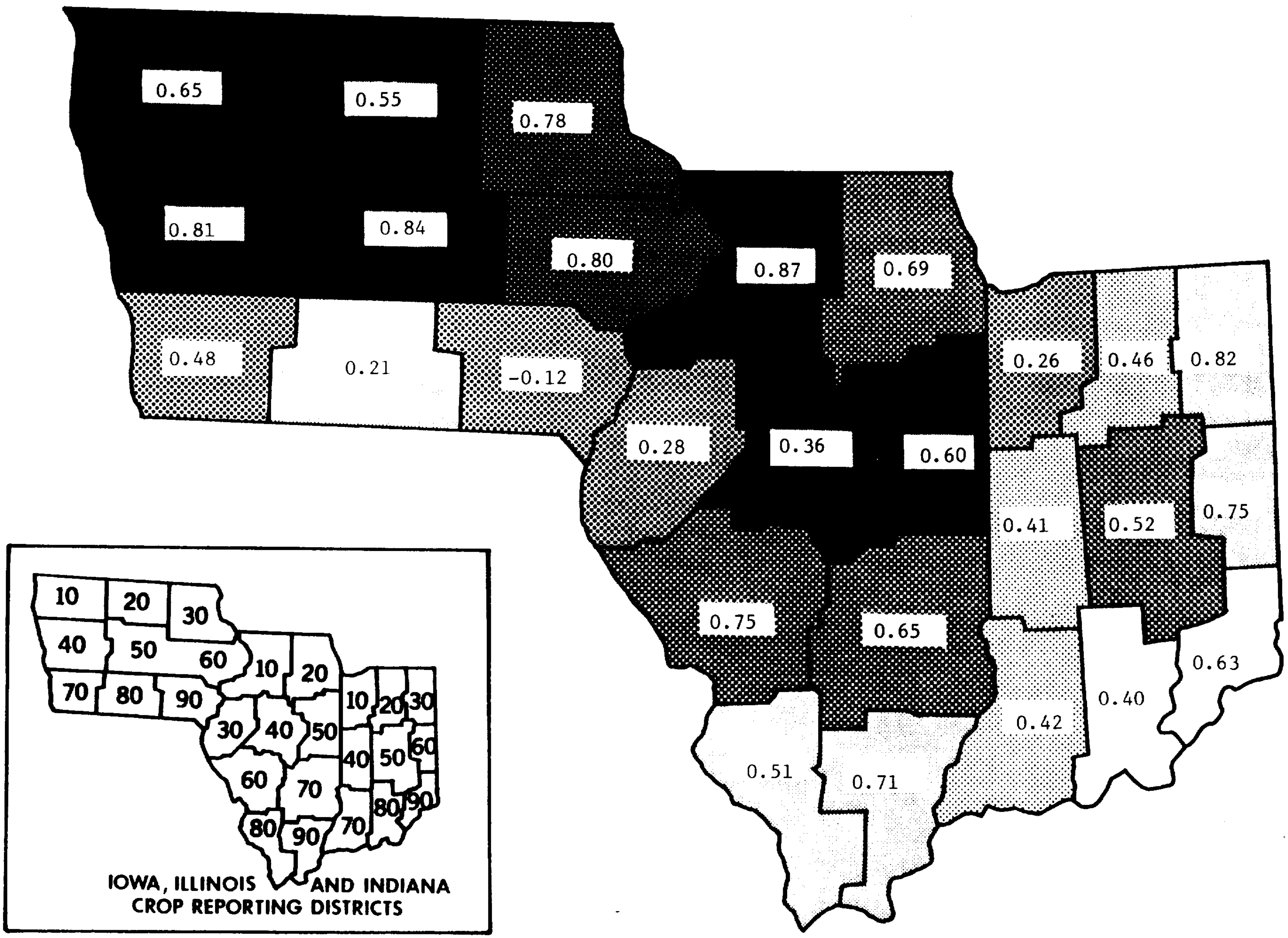


Table 4B

Indicators of Yield Reliability
Based on Reported and Predicted Yields

Pooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	PERCENT OF YEARS DIRECTION OF CHANGE IS CORRECT FROM PREVIOUS YEAR	FROM BASE PERIOD	PEARSON CORR. COEF.
IOWA	10	67	71	0.64
	20	67	57	0.64
	30	67	29	0.53
	40	67	86	0.73
	50	89	86	0.80
	60	89	57	0.78
	70	67	86	0.49
	80	67	86	0.73
	90	78	71	0.70
STATE MODEL		67	71	0.71
CRDS AGGR.		78	57	0.70
ILLINOIS	10	67	100	0.77
	20	33	86	0.65
	30	67	86	0.56
	40	67	71	0.55
	50	78	86	0.54
	60	44	71	0.65
	70	78	100	0.73
	80	56	71	0.73
	90	67	86	0.72
STATE MODEL		89	100	0.60
CRDS AGGR.		67	100	0.68
INDIANA	10	78	71	0.38
	20	78	71	0.55
	30	44	71	0.78
	40	78	86	0.49
	50	78	86	0.65
	60	56	71	0.71
	70	67	86	0.46
	80	56	86	0.60
	90	56	86	0.61
STATE MODEL		67	57	0.44
CRDS AGGR.		67	86	0.62
REGION				
CRDS AGGR.		78	86	0.71
STATES AGGR.		67	43	0.67

Precision During Independent Tests Cannot Be Predicted From Indicators of Base Period Precision

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 (Tables 2A and 2B). The direct analogue for the model development base period is the residual mean square. The residual mean square is obtained by first generating the usual least squares prediction equation using the base period years. Then instead of predicting the yield for the following test year, yields are predicted for each of the base period years. The residual mean square is the sum of squared d values for these base period years divided by the appropriate degrees of freedom (number of years minus number of parameters estimated in fitting the model). Whereas one value of MSE is generated for each geographic area over the entire test period, a value of the residual mean square is generated for each base period corresponding to a test year in that area. The low, high, and average of the base period values for each area from the unpooled models are given in Table 5A, while the corresponding values from the pooled models are given in Table 5B. Because only <u>one</u> pooled model is generated each year in each state for the prediction of CRD level yields, all base period CRD level pooled model values within a state and year are the same.

The MSE values from Tables 2A and 2B are also given in Tables 5A and 5B respectively. In all cases, for both the pooled and unpooled models, the independent test MSEs were greater than the highest corresponding base period residual mean square. Use of the base period residual mean square as indicator of predicted yield reliability, therefore, would be quite misleading.

Another indicator of yield reliability is the correlation coefficient, r, between predicted and observed yields for the independent test years (Tables 4A and 4B). It is desirable for r to be close to +1. The analogue for the model development base period is the square root of R^2, the coefficient of multiple determination. The square root of R^2 (expressed as a proportion), R ($0 \leq R \leq 1$), may be interpreted as the correlation between observed and predicted values of the base period years. The low, high and average values of R for each geographic area for the unpooled models are given in Table 6A, while the corresponding values from the pooled models are given in Table 6B. As with the base period pooled model residual mean square indicators of fit discussed above, all base period pooled model CRD level values of R are the same in a given state and year.

The Pearson correlation coefficients from Tables 4A and 4B are also given in Tables 6A and 6B respectively. Once again, in every case, the independent

Table 5A

Residual Mean Square As An
Indicator of the Fit of the Model
Based on the Model Development Base Period

Unpooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	BASE PERIOD RESIDUAL MEAN SQUARE LOW	HIGH	AVERAGE	INDEPENDENT TEST MSE
IOWA	10	15.93	34.03	25.57	76.18
	20	8.49	20.77	15.58	52.02
	30	16.21	20.43	18.47	36.53
	40	6.57	28.73	18.56	84.78
	50	8.07	17.06	12.31	43.47
	60	8.59	14.63	11.51	32.82
	70	18.49	65.79	44.61	149.88
	80	17.88	59.36	39.01	185.21
	90	9.69	37.99	22.06	111.97
STATE MODEL		6.30	18.19	13.11	43.61
ILLINOIS	10	6.17	9.65	8.01	25.55
	20	5.76	15.69	11.08	42.80
	30	12.16	20.42	15.27	61.82
	40	12.64	22.68	18.45	105.66
	50	15.05	29.86	23.33	112.67
	60	23.14	25.74	24.13	27.45
	70	12.51	21.09	16.99	44.89
	80	12.76	21.86	15.70	66.77
	90	10.50	16.67	13.48	34.21
STATE MODEL		9.05	14.33	12.12	49.33
INDIANA	10	9.17	19.03	14.95	103.26
	20	7.55	13.31	10.88	48.93
	30	10.56	13.95	12.54	26.57
	40	14.13	23.77	19.50	71.83
	50	16.74	21.17	19.25	40.75
	60	14.97	16.65	16.00	26.52
	70	11.62	15.23	13.48	25.98
	80	10.25	15.51	12.82	41.02
	90	9.10	12.17	10.70	23.51
STATE MODEL		9.64	16.62	13.30	38.37

Table 5B

Residual Mean Square As An
Indicator of the Fit of the Model
Based on the Model Development Base Period

Pooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	BASE PERIOD RESIDUAL MEAN SQUARE LOW	HIGH	AVERAGE	INDEPENDENT TEST MSE
IOWA	10	12.66	32.26	22.61	84.60
	20	12.66	32.26	22.61	43.20
	30	12.66	32.26	22.61	53.14
	40	12.66	32.26	22.61	130.16
	50	12.66	32.26	22.61	74.24
	60	12.66	32.26	22.61	33.55
	70	12.66	32.26	22.61	176.63
	80	12.66	32.26	22.61	133.83
	90	12.66	32.26	22.61	52.90
STATE MODEL		6.30	18.19	13.11	43.61
ILLINOIS	10	14.66	20.80	18.18	41.95
	20	14.66	20.80	18.18	47.97
	30	14.66	20.80	18.18	44.03
	40	14.66	20.80	18.18	70.98
	50	14.66	20.80	18.18	86.38
	60	14.66	20.80	18.18	25.94
	70	14.66	20.80	18.18	35.60
	80	14.66	20.80	18.18	88.80
	90	14.66	20.80	18.18	69.44
STATE MODEL		9.05	14.33	12.12	49.33
INDIANA	10	13.69	18.24	16.38	60.44
	20	13.69	18.24	16.38	48.25
	30	13.69	18.24	16.38	57.05
	40	13.69	18.24	16.38	58.85
	50	13.69	18.24	16.38	30.40
	60	13.69	18.24	16.38	25.24
	70	13.69	18.24	16.38	30.15
	80	13.69	18.24	16.38	34.20
	90	13.69	18.24	16.38	36.63
STATE MODEL		9.54	16.62	13.30	38.37

Table 6A

Correlation Between Observed and Predicted Yields As An
Indicator of the Fit of the Model
Based on the Model Development Base Period

Unpooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

TEST STATE	CRD	BASE PERIOD CORRELATION COEF. LOW	HIGH	AVERAGE	INDEPENDENT CORR. COEF.
IOWA	10	0.90	0.96	0.93	0.65
	20	0.94	0.97	0.96	0.55
	30	0.90	0.95	0.93	0.78
	40	0.91	0.98	0.95	0.81
	50	0.96	0.98	0.97	0.84
	60	0.95	0.97	0.96	0.80
	70	0.83	0.95	0.89	0.48
	80	0.83	0.94	0.89	0.21
	90	0.91	0.97	0.94	-0.12
STATE MODEL		0.94	0.98	0.96	0.71
ILLINOIS	10	0.96	0.97	0.97	0.87
	20	0.93	0.97	0.96	0.69
	30	0.94	0.96	0.95	0.28
	40	0.94	0.97	0.96	0.36
	50	0.92	0.96	0.94	0.60
	60	0.93	0.95	0.94	0.75
	70	0.95	0.97	0.96	0.65
	80	0.93	0.95	0.94	0.51
	90	0.94	0.96	0.95	0.71
STATE MODEL		0.96	0.97	0.96	0.60
INDIANA	10	0.97	0.98	0.98	0.26
	20	0.96	0.98	0.97	0.46
	30	0.95	0.96	0.96	0.82
	40	0.95	0.97	0.96	0.41
	50	0.94	0.96	0.95	0.52
	60	0.93	0.96	0.94	0.75
	70	0.96	0.98	0.97	0.42
	80	0.96	0.97	0.97	0.49
	90	0.97	0.98	0.97	0.63
STATE MODEL		0.96	0.98	0.97	0.44

Table 6B

Correlation Between Observed and Predicted Yields As An
Indicator of the Fit of the Model
Based on the Model Development Base Period

Pooled CEAS Corn Model
Iowa, Illinois, **Indiana** 1971-1980

TEST STATE	CRD	BASE PERIOD CORRELATION COEF. LOW	HIGH	AVERAGE	INDEPENDENT CORR. COEF.
IOWA	10	0.91	0.96	0.93	0.64
	20	0.91	0.96	0.93	0.64
	30	0.91	0.96	0.93	0.53
	40	0.91	0.96	0.93	0.73
	50	0.91	0.96	0.93	0.80
	60	0.91	0.96	0.93	0.78
	70	0.91	0.96	0.93	0.49
	80	0.91	0.96	0.93	0.73
	90	0.91	0.96	0.93	0.70
STATE MODEL		0.94	0.98	0.96	0.71
ILLINOIS	10	0.95	0.96	0.96	0.77
	20	0.95	0.96	0.96	0.65
	30	0.95	0.96	0.96	0.56
	40	0.95	0.96	0.96	0.55
	50	0.95	0.96	0.96	0.54
	60	0.95	0.96	0.96	0.65
	70	0.95	0.96	0.96	0.73
	80	0.95	0.96	0.96	0.73
	90	0.95	0.96	0.96	0.72
STATE MODEL		0.96	0.97	0.96	0.60
INDIANA	10	0.95	0.96	0.96	0.38
	20	0.95	0.96	0.96	0.55
	30	0.95	0.96	0.96	0.78
	40	0.95	0.96	0.96	0.49
	50	0.95	0.96	0.96	0.65
	60	0.95	0.96	0.96	0.71
	70	0.95	0.96	0.96	0.46
	80	0.95	0.96	0.96	0.60
	90	0.95	0.96	0.96	0.51
STATE MODEL		0.96	0.98	0.97	0.44

test correlation coefficients are smaller than the lowest base period R values. Thus, the use of base period R values as indications of yield reliability would overestimate the independent performance of these models.

Models Can Be Objectively Used Over Short-Term Time Periods

The variables included in each model were determined by regression analysis performed on all data available at the time of model development. To predict yields in a future year, the value of the trend term and any weather-related variables would be calculated and used with estimated regression coefficients derived during model development. This is an objective and well defined procedure and calls for no subjective decisions by the model user.

However, after several years model redevelopment may be necessary in order to make use of new data and information. Model redevelopment would be a subjective procedure, involving choices to be made about changes in trend terms and the selection or retention of weather-related variables. It is unlikely that someone other than the model developer would make the same kinds of decisions and choices resulting in models similar to those now being evaluated. In fact, it is conceivable that the model developer would produce quite different models.

More Evidence Is Needed to Show Models Are Consistent With and Reflect Scientific Knowledge

The CEAS corn yield models use four types of variables: (1) trend (year) as a surrogate for technology, (2) weather variables, entered either as simple precipitation and temperature or as derived variables such as accumulations over months or departures from normals, (3) derived agroclimatic variables such as the ratio of evapotranspiration to CAFEC evapotranspiration, and (4) indicator variables representing individual CRDs in the pooled models. Each of these types of variables will be discussed with respect to how their inclusion or absence in the models corresponds with scientific knowledge about corn yields.

Trend terms are important components of the CEAS corn yield models. In these models, they are usually the first variable selected by the stepwise procedure and alone explain from 39-91 percent of the total variation in yield. Technological changes have had important impacts on corn yields over time, but the inclusion of technological variables in yield models is often impossible because of the lack of a continuous, long-term data series. For this reason, trend terms are used as surrogates for technological advances. However, the choice of the trend term form is often difficult. Also, specification of the trend term determines the residuals of the trend which are assumed to be dependent on the weather-related variables in the model. Therefore, if trend is incorrectly handled in the model, results may be substantially affected.

For these models, changes in yield due to technology are assumed to be continuous, piecewise linear functions of year. Piecewise functions of year allow for changes in the rate of the contributions to yield from technology and other non-weather influences to occur over various time periods. The contributions to yield may even be zero over some time periods, indicating no increase (or, perhaps decreases) in yield due to technology or other non-weather factors. As long as the various components of technology cannot be separated, this form of the model seems reasonable, but choosing the join-points of the piecewise segments is not easy.

In Iowa and Illinois, a single linear trend term allowing for the increase in yields due to technology between the years 1951-1980 was selected for inclusion in all CRD and state models. Plots of state level yields vs year for these two states are given in Figures 12 and 13. The choice of a simple linear trend term for this time period was a subjective one. From a review of Figures 12 and 13, this choice seems reasonable, although no other alternatives were explored by the model developer. It can be inferred from the original model development report that the model developer did not consider two piecewise trends appropriate for the short data series available in each state.

In Indiana, three trend terms were constructed for possible inclusion in the model; the first term increases from 1930 to 1980, the second from 1930 to 1951, and the third from 1951 to 1980. A plot of the state level yields vs year for Indiana is given in Figure 14. The choice of 1951 as the join point for the linear segments was subjectively made, with no supporting information provided. It was felt by the model developer that two segments were necessary in Indiana "because the time series used was considerably longer than in Illinois and Iowa" and "...because of the increased use of fertilizer and development of corn hybrids...following World War II" (LeDuc, 1980).

Certainly it is difficult to assume the same linear increase in yields due to technology continuing over a fifty year time span. A review of Figure 14, however, does not strongly support the choice of 1951 over other possible years as the likely join-point year. As mentioned in a previous section, several unpooled CRD models (CRDs 20, 40, 50, 60), the pooled model and the state model include the first two trend terms; three unpooled CRD models (CRDs 10, 20, 90) include the first and third trend terms; and the two remaining CRD models (CRDs 70, 80) selected only the third trend term.

The numeric values of the bootstrap coefficients of the trend term in the Iowa and Illinois CRD models varied between 1.0 and 1.9 with most model coefficients close to 1.4. Larger coefficients occurred in Iowa CRDs 10, 20, 50 and 90 and Illinois CRD 50 (ranging from 1.4 to 1.9), while lower coefficients occurred in Iowa CRDs 70 and 80, and Illinois CRDs 80 and 90 (ranging from 1.2 to 1.8). In the pooled and state models the coefficients of the trend term varied between 1.4 and 1.7.

The combination of trend terms in Indiana models reflected a lower (or zero) impact of technology on yields prior to 1951. Those models including the first two trend terms showed coefficients of about 1.2 for the overall 1930-1980 linear trend, offset by coefficients of around -0.9 for the 1930-1951 linear trend. The result was an increase in yields of only about 0.3 quintals/hectare/year due to technology and non-weather effects prior to 1951 and of about 1.2 quintals/hectare after 1951. Those models including the first and

Figure 12

U.S.D.A. Reported State Corn Yields for Iowa
1950-1980 (Quintals/Hectare)

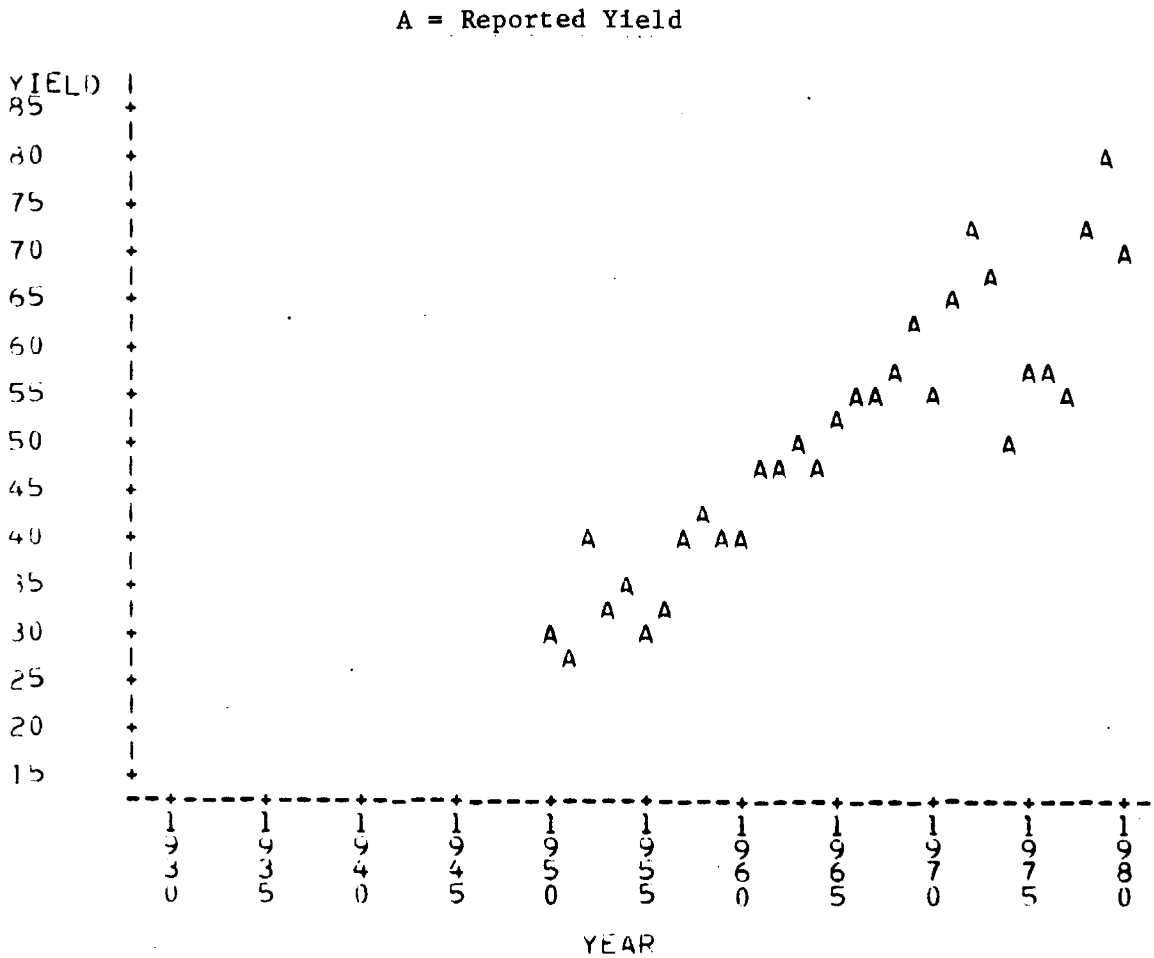


Figure 13

U.S.D.A. Reported State Corn Yields for Illinois
1950-1980 (Quintals/Hectare)

A = Reported Yield

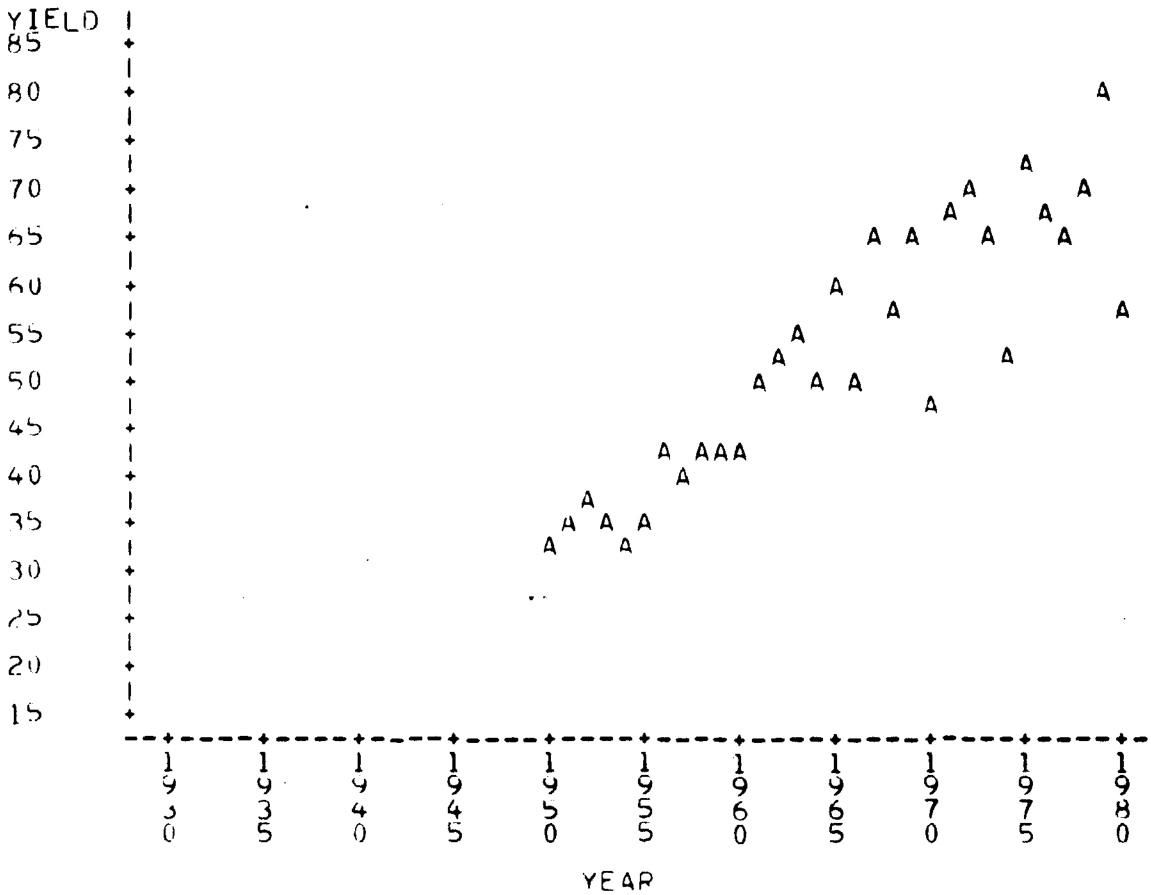
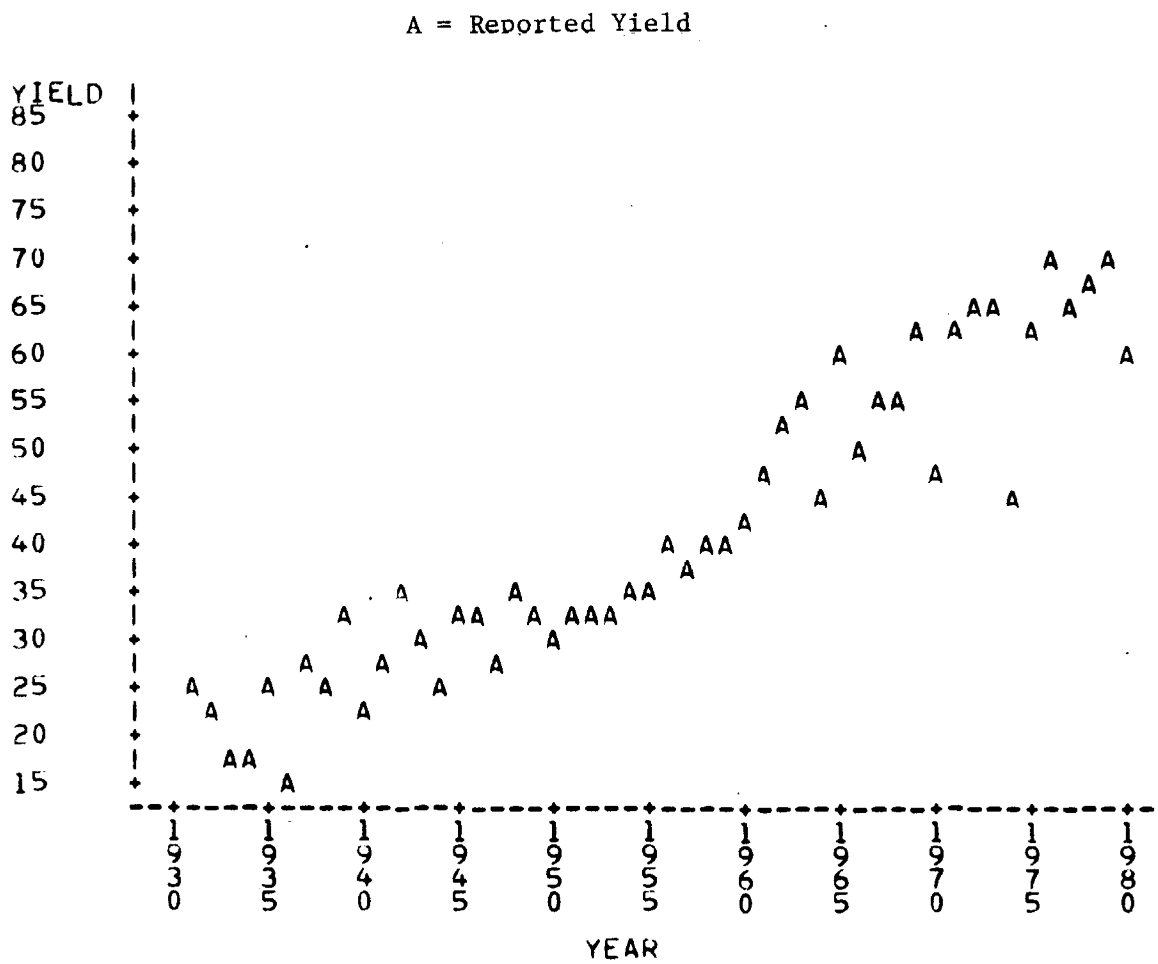


Figure 14

U.S.D.A. Reported State Corn Yields for Indiana
1930-1980 (Quintals/Hectare)



third trend terms resulted in coefficients of about 0.3 for the overall 1930-1980 linear trend and coefficients of around 1.0 (varying from 0.5 to 1.6) for the 1951-1980 linear trend. Again, there is the lower increase of yields due to technology and non-weather effects prior to 1951 (about 0.3 quintals/hectare/year) giving way to a larger increase after 1951 of about 1.0 to 1.6 quintals/hectare/year. In the two CRD models including only the linear trend term from 1951-1980, increases in yield due to technology are nil prior to 1951 and increase from around 1.3 (CRD 80) to 1.6 (CRD 70) quintals/hectare/year after that.

In terms of scientific consistency, one important question left unaddressed is the reason why two CRDs in Indiana were modeled to have absolutely no technological effects on yield prior to 1951 while neighboring CRDs did. It would also be of interest to note how the trend coefficients would change if the join-point were defined other than 1951. Guidelines for redefining the location of the join-point when model redevelopment occurs in the future would be valuable. Finally, entering trend and weather as distinct variables in the model does not succeed in clearly separating out the impact of weather and non-weather effects on yields. More research needs to be done on alternative methods for distinguishing the effects of weather and technology.

The CEAS corn yield models use monthly weather values. Monthly average temperatures and average precipitations are available on a climatic division (corresponding to a CRD) basis. From these two basic inputs a number of weather variables are calculated (see "Description of the Models" earlier in this report); they include cumulations or averages over two or more months, departures from long-term averages or normals, and squared departure from normals. A listing of the individual weather variables entered into each model and their accompanying coefficient sign over the bootstrap testing years is given in the Appendix (pp. 51-53).

The use of monthly weather data does involve some problems. Inherent in the use of a single monthly weather value is the assumption that each year the value is representative of the entire area for the entire month. For example, in one year the precipitation may have occurred only during the first week of the month, or it may have been distributed uniformly throughout the month. Also, precipitation in a year may have been distributed uniformly over a CRD, but in another year only occurred over part of the CRD, even though the CRD average for the month's precipitation was the same. Another problem has to do with the lack of year-to-year agronomic correspondence between the beginning and ending of developmental stages in a corn plant (and thus its changing moisture and temperature requirements). Since corn plants do not begin the various development stages at the same time each year, a model based on certain monthly weather variables may not always be the most appropriate in a given year.

Weather terms were selected for inclusion in the models using the stepwise regression procedure and all the data available to the model developer. A common result of this method was the selection of certain weather variables in a particular CRD model but <u>not</u> in any of the surrounding CRDs; no scientific explanation for this was presented. Another problem arises from the fact that some weather terms selected for inclusion in the models produced coefficients which changed sign (from positive to negative, or vice versa) during the ten-year testing period. A third problem occurred when the models were run with data through 1980. In this case some weather variable coefficients were no longer significantly greater than zero at the 10% level. The latter two problems address the issue of when model redevelopment may need to occur in future years; this issue was recognized but not explored by the model developer.

The interpretation of the precipitation coefficients with respect to scientific expectations seems reasonable. Precipitation in May enters the models with negative coefficients, reflecting the fact that, since mid-May is the normal planting date over much of the three-state region, excess moisture in May will delay planting and reduce yields. Cumulative precipitation from the preceding September through June or July enters the models with small, positive coefficients (+0.01 to +0.02) while squared departure from normal precipitations for the same periods enter the model as small negative coefficients (-0.0001). These results demonstrate the association between higher yields and large, but not excessive, amounts of rainfall.

July temperature, either alone or averaged with August temperature, appeared in nearly every model in Illinois and Indiana. Model coefficients for July temperature ranged from -1.0 to -4.0 while coefficients for the average of July and August temperature were from -1.0 to -3.0. All other temperature variables appearing in any model were negative as well, with one exception--in the Illinois pooled CRD model, October temperature was included with a positive coefficient. There is some question as to the appropriateness of this variable. Not only is its presence difficult to explain scientifically (although it may be related to a reduction in harvest loss associated with warm autumn weather), but its coefficient value was negative during part of the bootstrap years and it was not significant at the 10% level in the model developed with all available data. No direct temperature variables appeared in any of the Iowa models.

The six different agroclimatic variables considered for inclusion in the models were defined earlier in this report. In order to calculate these variables, PET and a soil moisture budget are estimated. Monthly PET is calculated by using Thornthwaite's (1948) procedure. ET is estimated with the use of PET, P, and the contents and capacity of a soil moisture budget. Running a soil moisture budget on a monthly basis is a difficult task, in part because runoff cannot be determined accurately without daily precipitation as input to the budget. An available water capacity of ten inches (254 mm) is assumed for all CRDs and states. Palmer (1965) recommends ten inches as a reasonable figure for central Iowa, but made no suggestions for areas further east. No evidence is presented by the CEAS model developer to justify a uniform ten-inch capacity for CRDs in Illinois and Indiana.

As with the weather variables discussed above, questions may be raised as to why a certain agroclimatic variable would be selected for inclusion in models for one area but not in other neighboring areas. Also, some agroclimatic terms produced coefficients which changed sign (positive and negative) during the ten-year test period or which proved not to be significantly greater than zero at the 10% level when all available data (through 1980) were used. No reason was given why the agroclimatic variables were not also considered as deviations from normal or in the quadratic form.

The ratio of ET to CAFEC(ET) for July and August enters several models with positive coefficients which indicate, as expected, that normal supplies of moisture during these months are associated with higher yields. The ratio for May enters several models with negative coefficients, which would indicate some moisture stress at planting is preferable. The ratio for June, however, enters the Indiana CRD 90 model with a negative coefficient and the Iowa CRD 40 model with a positive coefficient. Since these two areas are widely separated on an east-west basis, the coefficients may be scientifically plausible, but this situation was not discussed by the model developer.

The difference, P-PET, for July enters many models, all with a positive coefficient indicating higher yields associated with greater moisture supply than demand. In Iowa CRDs 70 and 80, however, this difference for August results in negative coefficients, a result which seems contrary to scientific expectations (the CRD 80 model did give positive coefficients in some of the bootstrap test years). The ratio, P/PET, for August is also negative in most (but not all) of the test years indicating lower yields when moisture supply exceeds demand. This ratio is also negative in May, but positive in July.

Cumulative PET, both from April to May and from July to August, gave negative coefficients when entered in the models, indicating lower yields associated with greater demands for moisture. From previous results mentioned above, it may have been reasonable to expect the April-to-May PET coefficient to have been positive instead. Average ET from June to July produced positive coefficients, indicating increased yields correspond with increased moisture supply during those months. The ratio of cumulative P to cumulative ET from July to August produced a positive coefficient in the one model it entered.

In the pooled models which were developed to predict CRD level yields, indicator variables were introduced to represent the CRDs in a state. The presence of indicator variables in the models is based on the assumption that weather, trend and agronomic variables alone cannot accurately account from the differences in yield levels which may exist between CRDs in a state. This assumption may be valid since there are other variables, such as soil characteristics, which may affect corn yields, but the issue was not discussed or defended by the model developer.

Each state's pooled model had different indicator variables, representing different CRDs, entered into the model. Those with positive coefficients represented CRDs with an associated higher level of yield, while negative coefficients represented CRDs with an associated lower level of yield. These associations can be compared with yield levels as recorded earlier in Table 1. In Iowa, CRDs 20, 50, and 60 were represented with positive indicator variable coefficients; these three CRDs do have the highest average yields of any CRDs in Iowa over the ten-year test period. Similarly CRDs 70 and 80, represented with negative coefficients in the models, have the lowest average yields over the ten-year test period.

In Illinois seven of the nine CRDs have positive indicator variable coefficients--all but CRDs 80 and 90, which are not represented in the pooled models. These two CRDs do have much lower yields (around 20 quintals/hectare lower) than the CRDs north of them.

In the Indiana pooled model, CRDs 10, 40, 50 and 70 were represented by indicator variables with positive coefficients. These four CRDs do have the highest average yields of any CRDs in Indiana over the ten-year test period. CRDs 30 and 80 are represented with negative coefficients in the models, and they do have the second and third lowest yield among CRDs in the ten-year test period.

When the CEAS pooled models were developed, CRD 90 was chosen in all three states as the CRD not represented with an indicator variable. This resulted in difficulty in interpreting the model coefficients when, as in Illinois and Indiana, CRD 90 had a very low level of yield and yet could not be represented with a negative coefficient. If the model developer had defined the indicator variables differently, omitting the "middle yielding" CRD in each state (the CRD whose model coefficient one would expect stepwise regression to eliminate for being not significantly different from zero in the model), the coefficient values and relative sizes would be easier to interpret. It could then more truly be said that positive coefficients were associated with CRDs having higher levels of yields and negative coefficients with CRDs having lower levels of yield. This change in defining the indicator variables would not affect model precision.

A review of the stepwise model coefficients also suggest that some CRDs could be grouped together because of having similar levels of yields. Thus, instead of having eight indicator variables representing the nine CRDs, one could develop models using only two or three indicator variables representing three or four groups of CRDs. More questions would then be raised; pooling of all CRDs into one model might be replaced with two or more pooled models, one for each separate group of CRDs found to have similar yield levels.

In conclusion, a variety of possible methods and techniques useful in variable selection are now available. The use of these techniques does not guarantee better models but could, perhaps, lead to a better understanding of the limitations of the models. Based on the results of these models and the scientific evidence available, it is likely that corn yield models could be developed that use different combinations of weather, trend, and indicator variables and might better reflect agronomic and meteorological interactions.

Model Redevelopment Would Be Required to Predict Yields in Other Geographic Areas

CEAS trend and monthly weather data models could be developed for any geographic area for which an historic data series of yearly yield and monthly weather values was available. The models evaluated in this report, however, are only adequate at the CRD and state level within Iowa, Illinois and Indiana. For areas other than these, complete model redevelopment would be necessary. Also, the CRD and state models use climatic division weather data; the number of weather stations per division varies. In Indiana, for instance, there are from seven to nineteen stations per division. Comparable results may be less stable in areas with fewer numbers of stations.

Timely Estimates Can Be Made Using Approximated Weather Data

Pre-season models using only trend were developed for each CRD and state. The development of models using weather data through each of the months April through August was also documented. However, five different models were not necessarily derived for each CRD and state. In most cases, the models for some of the adjacent months did not contain different variables so that, for example, the June model might be identical to the May model. In many CRDs the end of the season yield model estimate is obtained using the July model, in one instance (Illinois, CRD 20) using a May model, and in another (Illinois pooled model) using an October model.

It takes about three months after the end of a month to obtain that month's average temperature and precipitation at the climatic division level from the National Climatic Center in Asheville, N.C. Estimates of these climatic division values can be prepared earlier; these weather data approximations could then be used in the regression equations in the first week of the month following the month for which the data pertains. The yield forecast would not change if the model for a particular month is the same as for the previous month.

CEAS Corn Yield Models Are Not Costly to Operate

Operational costs of running these models, both pooled and unpooled, through a growing season in Iowa, Illinois, and Indiana are not high. The monthly weather data are currently prepared for other users on a routine basis, so that conceptually the cost could be shared. All that is required to obtain the yield estimates is to have someone responsible for acquiring the weather data and performing the regression equation calculations. The necessary computer programs are written in SAS and could be run on a computer system having that capability. Because the pooled state models were developed with nine times as many observations as the individual CRD models, more computer memory would be required to develop the pooled models using SAS procedures.

The more expensive part of the process is the maintenance of the historic agricultural and meteorological data bases and the redevelopment of models as required. The maintenance of the data bases requires the part-time efforts of persons familiar with meteorological data, agricultural data, and the computer system being used. The redevelopment of the models in future years, incorporating more recent yield and weather data, would require the skills of a person familiar with statistical regression methodology and agronomic modeling using meteorological variables.

It is difficult to say how expensive it would be to develop a model for a geographic area other than Iowa, Illinois or Indiana. The availability and form of the weather and yield data, along with the available computer capacity, would be the determining factor.

Models Are Easy to Understand and Use

The variables contained in these trend and monthly weather data models are fairly simple and easy to understand. A computer program would usually be necessary for the calculation of the stress (agronomic) variables and for the departures from normal for the weather variables. Values of the soil moisture budget contents can be saved from the previous year for use in the next year, or the budget can be assumed to be filled to capacity each winter. The variety of stress variables (six different forms) can be confusing to the user, as can interpretation when more than one stress variable enters a model. Once the historic weather and yield data bases are created they can be saved and used repeatedly. Perhaps an important consideration with the use of these models is deciding if or when they need redevelopment.

Standard Errors of Prediction Provide Poor Current Measures of Modeled Yield Reliability

The CRD (unpooled) and state values for the Spearman correlation coefficient between the estimate of the standard error of a predicted yield value ($s_{\hat{y}}$) and the absolute value of the difference between the predicted and reported yield are given in Table 7A. The correlation coefficients are displayed in Figure 15. Similar correlation coefficients for the pooled models are given in Table 7B. Most of the models produced negative correlation coefficients, and none of the coefficients were significantly greater than zero. The largest positive value is 0.53 for the Illinois state model. Thus, in a given geographic area, instances of test years with small prediction intervals about the predicted yield are all too often associated with large discrepancies between reported and predicted yield values. The use of $s_{\hat{y}}$ as an indicator of the accuracy of predicted yields is not appropriate.

CONCLUSIONS

Although the models are objectively defined and easily understood and used, some of the model results indicate a lack of correspondence with scientific knowledge. This includes inconsistencies in the choice of variables for retention in the models and differences in modeled variable coefficient signs (positive/negative) from what was expected or is probable. More information about the expression of trend terms in the models and their relationship to the agronomic and weather variables is also necessary. As the models now stand, it is difficult to reasonably and consistently account for the selection of certain variables and their interrelated effects on predicted model results.

It is suggested that the unpooled models be used for the prediction of CRD yields rather than the pooled CRD models. Although one pooled model may be operationally easier to run than nine individual CRD models, development of the pooled models requires more computer memory and time. Also, the differences in the composition of the pooled model could hinder comparison with

Table 7A

Current Indication of
Modeled Yield Reliability

Agreement Between Base Period Predicted
and Test Year Reported Accuracy

Unpooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	SPEARMAN CORRELATION COEF.
IOWA	10	-0.19
	20	-0.12
	30	-0.32
	40	0.19
	50	-0.04
	60	0.17
	70	0.04
	80	0.01
	90	-0.29
STATE MODEL		-0.14
ILLINOIS	10	-0.09
	20	-0.33
	30	0.52
	40	0.53
	50	0.14
	60	-0.09
	70	0.08
	80	0.26
	90	-0.67
STATE MODEL		0.53
INDIANA	10	0.28
	20	-0.11
	30	-0.20
	40	0.25
	50	0.05
	60	-0.17
	70	-0.64
	80	-0.10
	90	-0.15
STATE MODEL		-0.26

Figure 15. Spearman correlation coefficients between the estimate of a standard error of predicted yield from the CEAS unpooled corn yield base period model and the absolute value of the difference between the predicted and reported yield in the test years 1971-1980. Darker shades indicate CRDs with higher production.

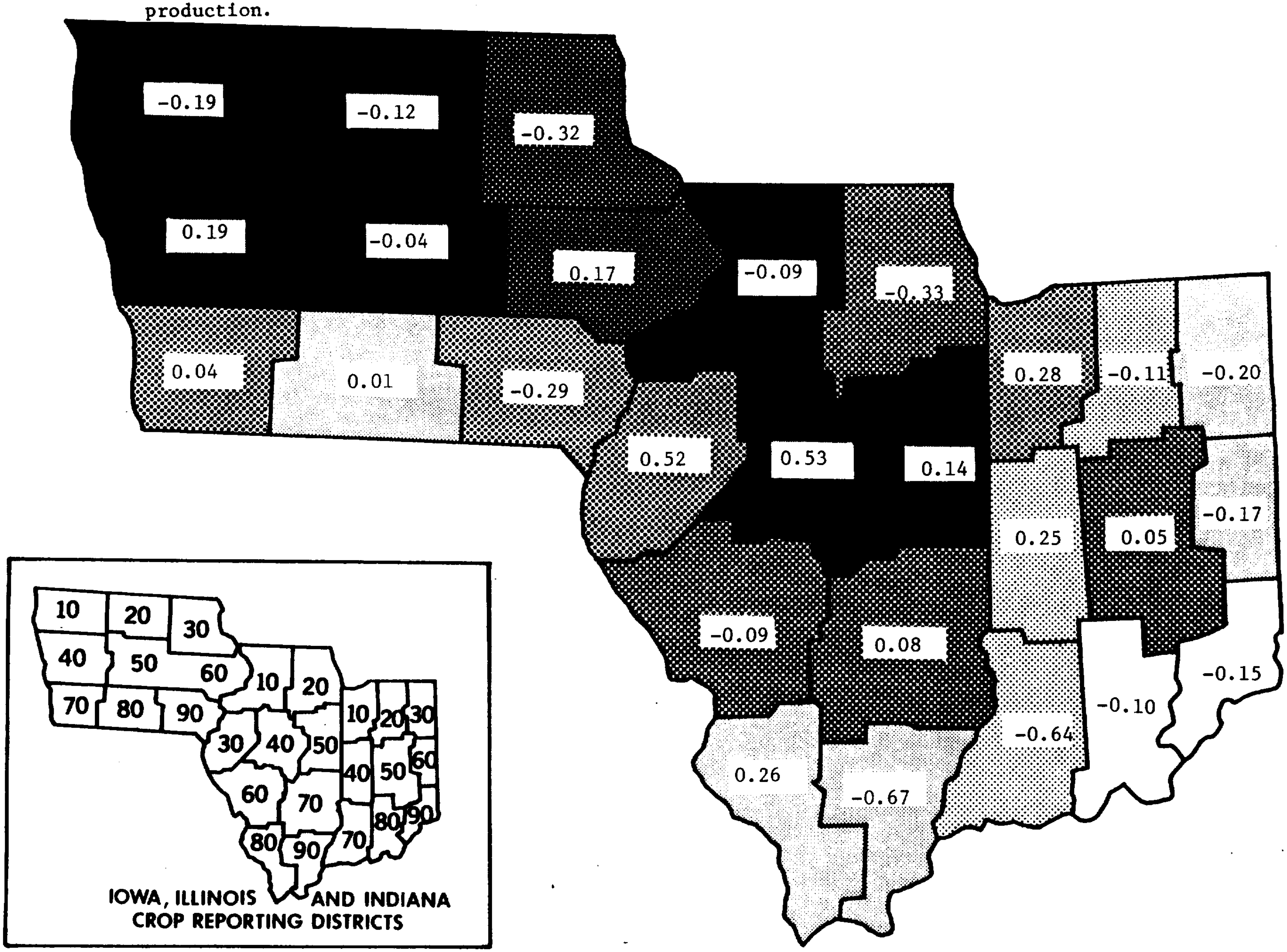


Table 7B

Current Indication of
Modeled Yield Reliability

Agreement Between Base Period Predicted
and Test Year Reported Accuracy

Pooled CEAS Corn Model
Iowa, Illinois, Indiana 1971-1980

STATE	CRD	SPEARMAN CORRELATION COEF.
IOWA	10	-0.20
	20	-0.26
	30	0.22
	40	-0.15
	50	-0.12
	60	0.20
	70	-0.12
	80	-0.25
	90	-0.08
STATE MODEL		-0.14
ILLINOIS	10	-0.10
	20	-0.10
	30	0.26
	40	0.21
	50	-0.03
	60	0.26
	70	-0.07
	80	-0.14
	90	-0.03
STATE MODEL		0.53
INDIANA	10	-0.45
	20	-0.08
	30	-0.24
	40	-0.20
	50	0.16
	60	-0.19
	70	0.30
	80	0.05
	90	-0.49
STATE MODEL		-0.26

other trend and monthly weather models. Of more importance, uncertainty over the proper definition of the pooled model indicator variables, and the effects on all model coefficients that could occur if the indicator variables were defined differently, suggest the use of the unpooled models.

Model redevelopment would be necessary in future years for the three states and could result in quite different models, with elimination of certain variables currently included in the models and the inclusion of other variables. As more years are added to the data sets for Iowa and Illinois, it is probable that the trend terms might need to be respecified, perhaps even to the inclusion of second and third trend terms such as are now used in the Indiana models.

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APPENDIX

Variables Included in CEAS Individual CRD, Pooled CRD and State
Iowa Corn Yield Models
+ Means a Positive Coefficient and
- Means a Negative Coefficient

	CRD 10	CRD 20	CRD 30	CRD 40	CRD 50	CRD 60	CRD 70	CRD 80	CRD 90	All[p] CRDs	State
<u>Trend Variables</u>											
Linear between 1951 and 1980	+	+	+	+	+	+	+	+	+	+	+
<u>Meteorological Variables</u>											
Cumulative precipitation-Sept to June										+	
-Sept to July	+										
-June to July		+									
Cumulative precipitation DFN squared -Sept. to June					-	-			-	-	
<u>Agroclimatic Variables</u>											
ET/Climatically Appropriate ET -May					+						
-June				+							
-July			+								+
Precipitation/PET -August									-*		
Precipitation-PET -July	+			+	+	+				+	
-August							-	-*			
Cumulative PET-April to May										-	
-July to August							-				
<u>Indicator Variables</u>											
CRD 20										+	
CRD 50										+	
CRD 60										+	
CRD 70										-	
CRD 80										-	

* - Coefficient sign changes occurred during the ten-year testing period.
p - Pooled model

APPENDIX

Variables Included in CEAS Individual CRD, Pooled CRD and State
Illinois Corn Yield Models
+ Means a Positive Coefficient and
- Means a Negative Coefficient

	CRD 10	20	30	40	50	60	70	80	90	All^{p} CRDs	State
Trend Variables											
Linear between 1951 and 1980	+	+	+	+	+	+	+	+	+	+	+
Meteorological Variables											
Temperature-April		-^{t}									
-May				-^{t}							
-July			-	-	-	-		-		-	-
-August										-	
-October										+^{*t}	
Precipitation-May			-^{t}								
Precipitation DFN-May											-^{t}
Cumulative Precipitation DFN squared											
-Sept. to June	-									-	
-Sept. to August							-				
Average temperature-July & August							-		-		
Agroclimatic Variables											
ET/Climatically Appropriate ET -May									-		
-Aug.	+										
Precipitation/PET -May		-								-	
-Aug.			-*								
Precipitation-PET -July	+									+	
Indicator Variables											
CRD 10										+	
CRD 20										+	
CRD 30										+	
CRD 40										+	
CRD 50										+	
CRD 60										+	
CRD 70										+	

* - Coefficient sign changes occurred during the ten-year testing period.
t - Coefficient was not significant at 10% level for model developed with all available data (1950-1980).
p - Pooled model.

APPENDIX

Variables Included in CEAS Individual CRD, Pooled CRD and State
Indiana Corn Yield Models
+ Means a Positive Coefficient and
- Means a Negative Coefficient

	CRD									All[p]	
	10	20	30	40	50	60	70	80	90	CRDs	State
Trend Variables											
Linear between 1930 and 1980	+	+	+	+	+	+			+	+	+
Linear between 1930 and 1951		-		-	-	-				-	-
Linear between 1951 and 1980	+		+				+	+	+		
Meteorological Variables											
Temperature-August			-		-						
Average temperature-July and Aug.	-	-		-			-	-	-	-	-
Precipitation-May										-	
-July								+		+	
Cumulative precipitation DFN squared											
-Sept. to Aug.				-							
Agroclimatic Variables											
ET/Climatically Appropriate ET -June										-	
-July	+	+								+	
-Aug.	+[t]										
Average ET -June and July										+	+
Precipitation-PET -July			+	+		+					
Precipitation/PET -July					+						
Cumulative precip./Cumulative ET											
-July to August		+									
Indicator Variables											
CRD 10										+[t]	
CRD 30										-	
CRD 40										+	
CRD 50										+	
CRD 70										+	
CRD 80										-	

t - Coefficient was not significant at the 10% level for model developed with all available data (1950-1980).

p - Pooled model.

APPENDIX

Model Comparison Based on the Root Mean Square Error, Standard Deviation, and Bias (all in Quintals/Hectare) Derived from Independent Test Years

CEAS Pooled and Unpooled Corn Yield Models Iowa, Illinois, Indiana

		MODEL Pooled		Unpooled		Pooled		Unpooled		Pooled		Unpooled	
State	CRD	RMSE	Rank	RMSE	Rank	SD	Rank	SD	Rank	Bias	Rank	Bias	Rank
Iowa	10	9.20	(2)	8.73	(1)	8.90	(2)	8.63	(1)	2.34	(2)	1.32	(1)
	20	6.57	(1)	7.21	(2)	6.57	(1)	7.10	(2)	-0.23	(1)	1.27	(2)
	30	7.29	(2)	6.04	(1)	7.29	(2)	5.87	(1)	-0.19	(1)	-1.44	(2)
	40	11.41	(2)	9.21	(1)	9.41	(2)	8.07	(1)	6.45	(2)	4.44	(1)
	50	8.62	(2)	6.59	(1)	8.33	(2)	6.53	(1)	2.20	(2)	0.88	(1)
	60	5.79	(2)	5.73	(1)	5.26	(2)	5.09	(1)	2.42	(1)	2.63	(2)
	70	13.29	(2)	12.24	(1)	11.95	(2)	11.94	(1)	5.82	(2)	2.70	(1)
	80	11.57	(1)	13.61	(2)	10.53	(1)	13.03	(2)	4.80	(2)	3.93	(1)
	90	7.27	(1)	10.58	(2)	7.21	(1)	10.31	(2)	-0.93	(1)	2.38	(2)
State Model CRDs Aggr.		7.38	(2)	7.21	(1)	6.96	(2)	6.95	(1)	2.47	(2)	1.90	(1)
Illinois	10	6.48	(2)	5.05	(1)	5.34	(2)	4.05	(1)	3.67	(2)	3.03	(1)
	20	6.93	(2)	6.54	(1)	6.62	(2)	6.28	(1)	2.04	(2)	1.85	(1)
	30	6.64	(1)	7.86	(2)	6.49	(1)	7.50	(2)	1.36	(1)	2.36	(2)
	40	8.43	(1)	10.28	(2)	8.25	(1)	9.05	(2)	1.72	(1)	4.88	(2)
	50	9.29	(1)	10.61	(2)	9.14	(1)	9.16	(2)	1.66	(1)	5.36	(2)
	60	5.09	(1)	5.24	(2)	5.04	(2)	4.63	(1)	0.74	(1)	2.45	(2)
	70	5.97	(1)	6.70	(2)	5.86	(1)	6.35	(2)	1.13	(1)	2.14	(2)
	80	9.42	(2)	8.17	(1)	7.11	(1)	8.02	(2)	6.18	(2)	1.58	(1)
	90	8.33	(2)	5.85	(1)	5.98	(2)	5.74	(1)	5.80	(2)	1.10	(1)
State Model CRDs Aggr.		5.99	(1)	6.34	(2)	5.57	(2)	5.49	(1)	2.20	(1)	3.17	(2)
Indiana	10	7.77	(1)	10.16	(2)	7.74	(1)	8.09	(2)	-0.76	(1)	6.15	(2)
	20	6.95	(1)	6.99	(2)	6.44	(1)	6.81	(2)	2.61	(2)	1.59	(1)
	30	7.55	(2)	5.15	(1)	5.78	(2)	5.10	(1)	4.86	(2)	-0.76	(1)
	40	7.67	(1)	8.48	(2)	7.67	(1)	8.04	(2)	0.10	(1)	2.68	(2)
	50	5.51	(1)	6.38	(2)	5.40	(1)	6.38	(2)	1.09	(2)	-0.01	(1)
	60	5.02	(1)	5.15	(2)	5.00	(2)	4.98	(1)	0.52	(1)	-1.32	(2)
	70	5.49	(2)	5.10	(1)	5.36	(2)	4.42	(1)	-1.19	(1)	2.54	(2)
	80	5.85	(1)	6.40	(2)	5.57	(1)	6.13	(2)	1.79	(1)	1.87	(2)
	90	6.05	(2)	4.85	(1)	4.86	(2)	4.79	(1)	3.61	(2)	0.76	(1)
State Model CRDs Aggr.		5.23	(1)	5.81	(2)	5.13	(1)	5.53	(2)	1.01	(1)	1.77	(2)
Region CRDs Aggr.		5.49	(1)	5.58	(2)	5.09	(2)	5.07	(1)	2.07	(1)	2.33	(2)

Model Comparison Based on
Paired-Sample Statistical Tests
CEAS Pooled-CRD vs Unpooled-CRD Models
(*=P<.10, **=P<.05, ***=P<.01)

CEAS Corn Yield Models
Iowa, Illinois, Indiana

STATE	CRD	PARAMETRIC T-TEST: AVERAGE |D| MODEL POOLED	INDIVL	DIFFERENCE OF AVERAGES		NONPARAMETRIC RANK TEST: % SMALLER |D| MODEL POOLED	INDIVL	DIFFERENCE OF PERCENTAGE	
IOWA	10	6.6	6.9	0.3		70	30	40	
	20	5.6	6.1	0.4		60	30	30	
	30	6.2	5.1	1.1		30	70	40	
	40	9.3	8.0	1.3		30	60	30	
	50	6.8	5.8	1.0		40	60	20	
	60	4.7	4.8	0.2		50	40	10	
	70	10.0	7.9	2.2	*	30	70	40	*
	80	8.9	9.7	0.8		70	30	40	
	90	6.4	8.7	2.3		60	40	20	
STATE MODEL		4.9	4.9	0.0		0	0	0	
CRDS AGGR.		5.9	5.7	0.3		40	60	20	
ILLINOIS	10	4.0	3.7	0.3		50	50	0	
	20	4.6	4.1	0.5		30	70	40	
	30	5.5	6.4	0.9		70	30	40	*
	40	6.7	7.3	0.6		50	50	0	
	50	6.8	7.2	0.3		50	50	0	
	60	4.6	4.5	0.1		50	50	0	
	70	4.1	5.0	0.9		60	30	30	*
	80	7.5	6.8	0.6		30	70	40	
	90	6.8	4.9	1.9		30	70	40	
STATE MODEL		4.9	4.9	0.0		0	0	0	
CRDS AGGR.		4.5	4.6	0.1		60	30	30	
INDIANA	10	6.4	6.6	0.2		40	60	20	
	20	4.2	4.6	0.4		60	40	20	
	30	4.9	3.5	1.4		30	70	40	
	40	5.9	5.9	0.1		50	50	0	
	50	3.8	5.2	1.5	***	100	0	100	***
	60	3.8	4.4	0.6		50	50	0	
	70	4.3	3.2	1.1		30	70	40	
	80	4.9	5.2	0.3		50	30	20	
	90	5.0	4.2	0.8		40	60	20	
STATE MODEL		3.3	3.3	0.0		0	0	0	
CRDS AGGR.		3.4	3.6	0.1		40	60	20	
REGION MODEL									
CRDS AGGR.		3.9	4.0	0.0		50	50	0	
STATES AGGR.		3.9	3.9	0.0		0	0	0	

APPENDIX

Brief Description of Growing Conditions for Corn in the Bootstrap Test Years*

Year	State	Description
1971	Iowa	Record yield up 19%, production up 36%. Early planting due to cool and dry spring. June very hot, but July very cool. August very dry. Early harvest with excellent conditions. Nitrogen rate/acre down 6%.
	Illinois	Record yield up 27%, production up 30%. Planting completed early. Crop growth and development continue ahead of schedule. Early harvest with excellent conditions. Nitrogen rate/acre down 5%.
	Indiana	Record yield (up 33%) and production (up 49%). Planting completed early due to cool temperatures. June warm, but July-mid August cool. Harvest completed early with excellent conditions. Nitrogen rate/area down 11%.
1972	Iowa	Record yield up 14%, production up 4%. Frequent rains delay planting. Growing and harvest season very cool and wet. Some hail and flood losses occur. Harvest delayed beyond end of year by rain. Nitrogen rate/acre unchanged from 1971.
	Illinois	Record yield up 4%, production down 5%. Planting delayed by wet weather. Harvest also delayed into 1973 by rains. Nitrogen rate/acre up 12%.
	Indiana	Record yield up 3%, production down 9%. Wet, cool spring delays planting. Cool July, with dry weather in south. Harvest delayed by cool, wet weather. Nitrogen rate/acre up 12%.
1973	Iowa	Yield down 8%, production down 2%. Planting delayed by frequent rains. Growing season very wet and warm. Harvest also delayed by rains, but excellent weather in October allowed an early finish. Nitrogen rate/acre down 1%.

APPENDIX

Brief Description of Growing Conditions for Corn in the Bootstrap Test Years*

Year	State	Description
	Illinois	Yield down 6%, production down 3%. Planting delayed by spring rains. Summer growing conditions good. Harvest occurred on time with excellent conditions. Nitrogen rate/acre down 4%.
	Indiana	Yield down 2%, production up 5%. Planting behind schedule due to rains. Summer moisture mostly adequate. Normal harvest timing. Nitrogen rate/acre down 10%.
1974	Iowa	Yield down 25%, production down 20%. Heavy rains in May, early June delay planting. Hot, dry late June, July. Early frost in September. Excellent harvest conditions once begun. Nitrogen rate/acre down 7%.
	Illinois	Yield down 20%, production down 17%. Excess rain and late freeze delay planting. Wet fields and early freezes delay maturity. Larger than usual abandonment and cut for silage. Harvest delayed by wet weather. Nitrogen rate/acre down 8%.
	Indiana	Yield down 28%, production down 27%. Heavy May rains delay planting. Most of spring wet and cool, stalling development. July very hot and dry. Early freeze and heavy fall rains hurt harvest. Nitrogen rate/acre down 11%.
1975	Iowa	Yield up 13%, production up 15%. Excellent May weather ideal for planting. Flooding, heavy rains in June. Hot, dry July and August. Harvest conditions very good. Nitrogen rate/acre up 1%.
	Illinois	Record yield (up 41%) and production (up 54%). Planting completed on schedule. Ideal summer weather conditions. Harvesting completed on time. Nitrogen rate/acre up 3%.

APPENDIX

Brief Description of Growing Conditions for Corn in the Bootstrap Test Years*

Year	State	Description
	Indiana	Yield up 34%, production up 42%. Excellent spring planting conditions. Warm temperatures and rainfall in June and August give excellent growing season conditions. Harvesting completed normally. Nitrogen rate/acre up 3½%.
1976	Iowa	Yield up 1%, production up 5%. Planting delayed due to rains. June and July warm and dry. Harvest completed early. Nitrogen rate/acre up 23%.
	Illinois	Yield down 8%, production down 1%. Planting completed ahead of schedule. Dry growing season reduces crop prospects. Dry fall allows early harvest completion. Nitrogen rate/acre up 21%.
	Indiana	Record yield (up 12%) and production (up 26%). Cold, dry weather for planting. Heavy rains in June, but long dry spells July-September. Near normal or cool temperatures all season. Near normal harvest schedule. Nitrogen rate/acre up 22½%.
1977	Iowa	Yield down 2%, production down 7%. Warm spring, planting completed early. Hot, dry June and July - much crop stress with long drought in central areas. Cool, wet fall weather delays harvest. Nitrogen rate/acre up 1½%.
	Illinois	Yield down 2%, production down 4%. Planting completed early. Dry summer weather. Harvest ahead of schedule through October, then slowed by rains. Nitrogen rate/acre down 8%.

APPENDIX

Brief Description of Growing Conditions for Corn in the Bootstrap Test Years*

Year	State	Description
	Indiana	Yield down 7%, production down 9%. Warm spring - planting completed early. Hot and dry late June through July - some crop stress. Wet, warm fall - harvest delayed. Nitrogen rate/acre up 8%.
1978	Iowa	Record yield (up 36%) and production (up 35%). Above normal spring rains - planting on normal schedule. Warm, muggy June and July, rains in late August. Excellent growing season conditions. Harvest completed very early. Nitrogen rate/acre up 1%.
	Illinois	Yield up 6%, production up 5%. Planting a little later than usual. Weather generally cool and dry. Harvest completed ahead of normal. Nitrogen rate/acre up 7%.
	Indiana	Yield up 6%, production up 6%. Planting delayed slightly by freeze in early May. Warm, moist summer weather-excellent conditions. September warm - helped crop maturity. Harvest completed early due to dry conditions. Nitrogen rate/acre down 6½%.
1979	Iowa	Record yield (up 8%) and production (up 13%). Planting delayed by cool, rainy weather. Favorable June and cooler July weather help crop. Warm, dry September brings early harvest. Nitrogen rate/acre up 6%.
	Illinois	Record yield (up 15%) and production (up 14%). Planting begins late but finishes ahead of normal. Dry, cooler weather June to July - good growing conditions. Excellent harvest conditions allow early completion. Nitrogen rate/acre up 4½%.
	Indiana	Record yield up 6%, production up 1%. Planting delayed by cold, wet April. Summer cool and moist with heavy rains in some areas. Harvest period cool and dry, with early freeze. Nitrogen rate/acre up 14½%.

APPENDIX

Brief Description of Growing Conditions for Corn in the Bootstrap Test Years*

Year	State	Description
1980	Iowa	Yield down 13%, production down 12%. Planting over on schedule. Heavy June rains, some hail. July hot dry; August hot, humid. Harvest completed earliest ever. Nitrogen rate/acre down 3%.
	Illinois	Yield down 27% (lowest since 1974), production down 25%. Excellent spring weather allows early planting. Very hot, dry in southern 2/3 of state hampers growth during early summer. Good fall weather allows very early harvest. Nitrogen rate/acre up ½%.
	Indiana	Yield down 16%, production down 11%. Planting completed early. June cool, wet with some hail and flooding. Very hot, dry July stresses crop. Fall weather very favorable - harvest completed early. Nitrogen rate/acre down 1%.

* The following references served as source for the growing condition data described in this Appendix:

Illinois Agricultural Statistics, Bulletin No.'s 72-1 to 81-1, Illinois Cooperative Crop Reporting Service, USDA and Illinois Dept. of Agriculture.

Iowa Weather and Field Crops from Planting to Harvest, reports for years 1970 to 1977 and 1979, Iowa Crop and Livestock Reporting Service, USDA and Iowa Dept. of Agriculture.

Iowa Agricultural Statistics, 1979 and 1981, Iowa Crop and Livestock Reporting Service, USDA and Iowa Dept. of Agriculture.

Indiana Annual Crop and Livestock Summary, Bulletin No.'s A75-1 to A81-1, USDA and Purdue University, Agricultural Experiment Station.

Weekly Weather and Crop Bulletin, Volumes 58, 59, and 60, USDA Statistical Reporting Service and USDC National Oceanic and Atmospheric Administration.

Fertilizer Situation, reports for years 1971 to 1980, USDA Statistical Reporting Service.

APPENDIX
BOOTSTRAP TEST RESULTS
FOR CORN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING AN UNPOOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E.* PRED.
IOWA	10	1971	61.6	61.9	0.3	0.5	4.72
		1972	72.8	63.6	-9.2	-12.6	4.72
		1973	69.1	65.6	-3.5	-5.1	4.75
		1974	47.1	64.4	17.3	36.7	4.94
		1975	55.0	60.6	5.6	10.2	6.10
		1976	45.9	60.4	14.5	31.6	5.99
		1977	64.6	65.4	0.8	1.2	6.42
		1978	75.0	77.6	2.6	3.5	6.98
		1979	77.8	69.5	-8.3	-10.7	6.04
		1980	73.3	66.4	-6.9	-9.4	6.20
	20	1971	67.0	64.4	-2.6	-3.9	3.31
		1972	73.8	66.5	-7.3	-9.9	3.24
		1973	68.9	68.1	-0.8	-1.2	3.63
		1974	55.7	70.2	14.5	26.0	3.49
		1975	59.9	68.6	8.7	14.5	4.63
		1976	58.5	66.4	7.9	13.5	5.00
		1977	64.3	68.6	4.3	6.7	4.95
		1978	75.9	77.3	1.4	1.8	5.16
		1979	81.6	74.2	-7.4	-9.1	4.78
		1980	78.6	72.6	-6.0	-7.6	4.95
	30	1971	60.9	59.5	-1.4	-2.3	4.62
		1972	68.9	61.6	-7.3	-10.6	4.52
		1973	65.0	63.2	-1.8	-2.8	4.75
		1974	55.3	65.5	10.2	18.4	4.52
		1975	58.1	63.1	5.0	8.6	5.54
		1976	56.9	60.1	3.2	5.6	6.05
		1977	70.0	68.8	-1.2	-1.7	4.94
		1978	74.1	70.4	-3.7	-5.0	4.78
		1979	81.9	72.5	-9.4	-11.5	4.69
		1980	76.2	68.2	-8.0	-10.5	5.06
	40	1971	57.8	61.4	3.6	6.2	2.87
		1972	72.7	66.0	-6.7	-9.2	3.07
		1973	66.7	70.0	3.3	4.9	3.32
		1974	44.5	62.8	18.3	41.1	3.37
		1975	53.2	61.4	8.2	15.4	5.02
		1976	44.3	59.1	14.8	33.4	5.17
		1977	46.6	53.9	7.3	15.7	6.84
		1978	72.2	66.2	-6.0	-8.3	5.85
		1979	74.7	69.7	-5.0	-6.7	5.81
		1980	54.5	61.1	6.6	12.1	5.83

* No standard error of prediction values were calculated for aggregated CRD or state results.

APPENDIX
BOOTSTRAP TEST RESULTS FOR CORN YIELDS IN IOWA, ILLINOIS, AND INDIANA USING AN UNPOOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
IOWA	50	1971	68.3	68.6	0.3	0.4	3.34
		1972	78.2	71.1	-7.1	-9.1	3.22
		1973	71.1	69.2	-1.9	-2.7	3.71
		1974	59.9	65.0	5.1	8.5	4.46
		1975	61.8	73.3	11.5	18.6	3.85
		1976	65.0	73.8	8.8	13.5	4.18
		1977	41.2	35.0	-6.2	-15.0	18.68
		1978	72.9	80.5	7.6	10.4	4.35
		1979	84.9	78.6	-6.3	-7.4	4.41
		1980	72.8	69.8	-3.0	-4.1	4.58
	60	1971	69.2	68.5	-0.7	-1.0	3.65
		1972	71.6	69.5	-2.1	-2.9	3.33
		1973	63.8	68.0	4.2	6.6	3.83
		1974	53.9	62.7	8.8	16.3	4.68
		1975	62.8	72.4	9.6	15.3	3.73
		1976	64.0	72.2	8.2	12.8	3.99
		1977	64.4	69.4	5.0	7.8	4.10
		1978	73.9	75.4	1.5	2.0	4.26
		1979	83.0	76.9	-6.1	-7.3	4.14
		1980	74.0	71.9	-2.1	-2.8	4.21
	70	1971	61.5	61.3	-0.2	-0.3	5.01
		1972	70.1	61.8	-8.3	-11.8	4.77
		1973	66.1	63.6	-2.5	-3.8	5.03
		1974	30.0	63.5	33.5	111.7	5.06
		1975	42.8	56.1	13.3	31.1	8.89
		1976	61.8	61.1	-0.7	-1.1	8.88
		1977	42.9	49.0	6.1	14.2	12.33
		1978	65.7	64.3	-1.4	-2.1	8.45
		1979	75.3	67.7	-7.6	-10.1	8.30
		1980	55.3	50.1	-5.2	-9.4	8.90
	80	1971	59.9	55.0	-4.9	-8.2	4.77
		1972	68.3	57.0	-11.3	-16.5	4.83
		1973	61.5	61.4	-0.1	-0.2	5.20
		1974	38.4	63.2	24.8	64.6	5.11
		1975	46.3	59.8	13.5	29.2	7.32
		1976	59.5	60.4	0.9	1.5	7.57
		1977	25.2	54.3	29.1	115.5	10.43
		1978	62.6	58.8	-3.8	-6.1	8.31
		1979	69.3	64.0	-5.3	-7.6	8.25
		1980	55.5	51.9	-3.6	-6.5	8.41

APPENDIX
BOOTSTRAP TEST RESULTS
FOR CORN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING AN UNPOOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
IOWA	90	1971	69.7	62.4	-7.3	-10.5	3.52
		1972	74.1	66.6	-7.5	-10.1	3.83
		1973	66.2	63.3	-2.9	-4.4	4.53
		1974	56.6	69.4	12.8	22.6	4.25
		1975	58.5	72.2	13.7	23.4	4.88
		1976	67.1	71.7	4.6	6.9	5.42
		1977	47.8	69.2	21.4	44.8	6.22
		1978	66.9	69.8	2.9	4.3	6.40
		1979	83.5	70.8	-12.7	-15.2	6.31
		1980	70.9	69.7	-1.2	-1.7	6.93
STATE MODEL		1971	64.0	61.8	-2.2	-3.4	2.86
		1972	72.8	66.3	-6.5	-8.9	2.85
		1973	67.2	68.2	1.0	1.5	3.06
		1974	50.2	66.9	16.7	33.3	3.09
		1975	56.5	63.6	7.1	12.6	4.73
		1976	57.1	59.8	2.7	4.7	5.10
		1977	54.0	55.8	1.8	3.3	5.27
		1978	72.2	73.6	1.4	1.9	4.61
		1979	79.7	73.7	-6.0	-7.5	4.43
		1980	69.0	65.8	-3.2	-4.6	4.51
CRDS AGGR.		1971	64.0	63.3	-0.7	-1.1	
		1972	72.8	65.6	-7.2	-9.9	
		1973	67.2	66.6	-0.6	-0.9	
		1974	50.2	65.2	15.0	29.9	
		1975	56.5	65.8	9.3	16.5	
		1976	57.1	65.3	8.2	14.4	
		1977	54.0	58.9	4.9	9.1	
		1978	72.2	72.7	0.5	0.7	
		1979	79.7	72.3	-7.4	-9.3	
		1980	69.0	66.0	-3.0	-4.3	

APPENDIX
BOOTSTRAP TEST RESULTS
FOR CORN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING AN UNPOOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	10	1971	66.3	64.7	-1.6	-2.4	3.15
		1972	68.7	70.9	2.2	3.2	3.08
		1973	62.8	64.9	2.1	3.3	4.00
		1974	49.1	60.7	11.6	23.6	4.19
		1975	72.2	72.1	-0.1	-0.1	3.47
		1976	63.5	71.2	7.7	12.1	3.34
		1977	72.5	72.4	-0.1	-0.1	3.57
		1978	71.7	76.8	5.1	7.1	3.37
		1979	79.5	78.2	-1.3	-1.6	3.56
		1980	72.5	77.2	4.7	6.5	3.41
	20	1971	63.1	64.1	1.0	1.6	2.85
		1972	66.8	65.1	-1.7	-2.5	2.81
		1973	61.5	65.5	4.0	6.5	3.09
		1974	45.9	64.3	18.4	40.1	3.17
		1975	69.4	65.9	-3.5	-5.0	4.60
		1976	65.4	65.0	-0.4	-0.6	4.33
		1977	71.9	71.6	-0.3	-0.4	4.66
		1978	71.1	70.1	-1.0	-1.4	4.04
		1979	80.2	76.0	-4.2	-5.2	4.17
		1980	69.9	76.1	6.2	8.9	3.98
	30	1971	69.5	65.7	-3.8	-5.5	4.17
		1972	72.6	67.0	-5.6	-7.7	4.00
		1973	65.9	66.8	0.9	1.4	4.29
		1974	57.9	66.6	8.7	15.0	4.48
		1975	73.8	69.2	-4.6	-6.2	4.18
		1976	66.7	71.7	5.0	7.5	4.21
		1977	54.4	73.0	18.6	34.2	5.84
		1978	69.2	72.7	3.5	5.1	5.04
		1979	82.7	76.4	-6.3	-7.6	5.09
		1980	62.4	69.6	7.2	11.5	5.31
	40	1971	74.7	73.2	-1.5	-2.0	4.36
		1972	76.5	73.6	-2.9	-3.8	4.13
		1973	72.3	74.5	2.2	3.0	4.03
		1974	54.7	72.3	17.6	32.2	4.54
		1975	81.9	76.1	-5.8	-7.1	5.05
		1976	78.2	76.3	-1.9	-2.4	5.10
		1977	66.0	75.0	9.0	13.6	5.20
		1978	72.7	77.1	4.4	6.1	5.22
		1979	83.3	86.9	3.6	4.3	5.45
		1980	54.2	78.3	24.1	44.5	5.56

APPENDIX
BOOTSTRAP TEST RESULTS
FOR CORN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING AN UNPOOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	50	1971	75.3	72.6	-2.7	-3.6	4.66
		1972	75.2	73.1	-2.1	-2.8	4.39
		1973	67.9	73.7	5.8	8.5	4.35
		1974	52.8	73.0	20.2	38.3	4.50
		1975	78.8	75.9	-2.9	-3.7	6.00
		1976	75.6	76.7	1.1	1.5	5.82
		1977	64.7	73.6	8.9	13.8	5.86
		1978	76.0	78.6	2.6	3.4	5.81
		1979	84.6	83.3	-1.3	-1.5	5.82
		1980	49.8	73.8	24.0	48.2	5.95
	60	1971	65.7	71.2	5.5	8.4	5.80
		1972	69.4	68.0	-1.4	-2.0	5.61
		1973	69.1	67.6	-1.5	-2.2	5.48
		1974	57.9	65.7	7.8	13.5	5.49
		1975	71.6	72.4	0.8	1.1	5.39
		1976	61.5	68.6	7.1	11.5	5.32
		1977	68.0	66.6	-1.4	-2.1	5.46
		1978	66.7	73.1	6.4	9.6	5.18
		1979	82.1	76.2	-5.9	-7.2	5.23
		1980	59.9	67.0	7.1	11.9	5.58
	70	1971	63.1	66.5	3.4	5.4	4.17
		1972	62.9	63.8	0.9	1.4	4.05
		1973	63.4	57.1	-6.3	-9.9	4.31
		1974	47.8	62.6	14.8	31.0	4.15
		1975	70.0	66.1	-3.9	-5.6	5.01
		1976	67.3	69.1	1.8	2.7	5.01
		1977	67.3	68.5	1.2	1.8	4.88
		1978	69.8	72.0	2.2	3.2	4.72
		1979	78.3	74.0	-4.3	-5.5	4.63
		1980	52.9	64.5	11.6	21.9	5.10
	80	1971	44.4	52.5	8.1	18.2	4.05
		1972	49.9	51.0	1.1	2.2	4.29
		1973	44.6	47.5	2.9	6.5	4.23
		1974	41.5	46.4	4.9	11.8	4.20
		1975	53.2	51.7	-1.5	-2.8	4.08
		1976	42.9	52.4	9.5	22.1	3.98
		1977	55.0	46.4	-8.6	-15.6	4.52
		1978	56.2	51.8	-4.4	-7.8	4.59
		1979	67.6	55.8	-11.8	-17.5	4.54
		1980	33.4	49.0	15.6	46.7	5.57

APPENDIX
BOOTSTRAP TEST RESULTS
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IOWA, ILLINOIS, AND INDIANA
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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	90	1971	43.8	52.9	9.1	20.8	3.70
		1972	53.2	51.4	-1.8	-3.4	4.20
		1973	44.0	46.2	2.2	5.0	4.14
		1974	42.2	49.2	7.0	16.6	3.92
		1975	53.8	48.6	-5.2	-9.7	4.11
		1976	54.5	55.5	1.0	1.8	4.17
		1977	53.6	52.6	-1.0	-1.9	4.83
		1978	46.5	50.9	4.4	9.5	4.01
		1979	65.7	54.9	-10.8	-16.4	3.94
		1980	38.4	44.5	6.1	15.9	5.13
STATE MODEL		1971	66.5	67.0	0.5	0.8	3.66
		1972	69.0	67.7	-1.3	-1.9	3.54
		1973	64.6	67.5	2.9	4.5	3.46
		1974	51.5	65.9	14.4	28.0	4.06
		1975	72.8	69.8	-3.0	-4.1	4.13
		1976	67.2	71.2	4.0	6.0	4.12
		1977	65.9	70.3	4.4	6.7	4.28
		1978	69.7	71.7	2.0	2.9	4.06
		1979	80.3	78.8	-1.5	-1.9	4.21
		1980	58.4	73.4	15.0	25.7	4.22
CRDS AGGR.		1971	66.5	67.2	0.7	1.1	
		1972	69.0	67.8	-1.2	-1.7	
		1973	64.6	66.0	1.4	2.2	
		1974	51.5	65.3	13.8	26.8	
		1975	72.8	70.0	-2.8	-3.8	
		1976	67.2	70.2	3.0	4.5	
		1977	65.9	70.1	4.2	6.4	
		1978	69.7	72.9	3.2	4.6	
		1979	80.3	77.3	-3.0	-3.7	
		1980	58.4	70.8	12.4	21.2	

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	10	1971	71.6	69.3	-2.3	-3.2	3.50
		1972	69.6	69.5	-0.1	-0.1	3.43
		1973	67.5	70.2	2.7	4.0	3.47
		1974	47.8	69.7	21.9	45.8	3.47
		1975	65.2	69.8	4.6	7.1	4.82
		1976	70.6	71.5	0.9	1.3	4.78
		1977	65.7	69.8	4.1	6.2	4.72
		1978	66.1	71.9	5.8	8.8	4.62
		1979	73.6	76.0	2.4	3.3	4.69
		1980	49.9	71.4	21.5	43.1	4.78
	20	1971	62.8	59.9	-2.9	-4.6	3.15
		1972	61.8	60.0	-1.8	-2.9	3.13
		1973	62.3	61.5	-0.8	-1.3	3.22
		1974	40.1	57.6	17.5	43.6	3.30
		1975	62.3	60.7	-1.6	-2.6	4.05
		1976	67.5	62.3	-5.2	-7.7	3.94
		1977	62.4	61.5	-0.9	-1.4	4.20
		1978	61.7	63.4	1.7	2.8	3.88
		1979	68.6	66.9	-1.7	-2.5	3.89
		1980	54.7	66.3	11.6	21.2	4.18
	30	1971	55.1	54.3	-0.8	-1.5	3.70
		1972	59.3	55.5	-3.8	-6.4	3.64
		1973	58.1	57.3	-0.8	-1.4	3.67
		1974	37.1	50.8	13.7	36.9	3.81
		1975	52.5	49.1	-3.4	-6.5	4.19
		1976	62.9	60.9	-2.0	-3.2	4.10
		1977	63.8	58.9	-4.9	-7.7	3.96
		1978	59.9	59.1	-0.8	-1.3	3.98
		1979	67.3	62.6	-4.7	-7.0	3.93
		1980	64.1	64.0	-0.1	-0.2	4.13
	40	1971	67.7	67.8	0.1	0.1	4.35
		1972	69.6	64.6	-5.0	-7.2	4.19
		1973	67.5	63.8	-3.7	-5.5	4.59
		1974	42.8	64.7	21.9	51.2	4.35
		1975	69.3	64.4	-4.9	-7.1	5.41
		1976	71.1	68.8	-2.3	-3.2	5.31
		1977	64.5	67.5	3.0	4.7	5.28
		1978	72.5	73.0	0.5	0.7	5.21
		1979	74.0	80.0	6.0	8.1	5.48
		1980	58.1	69.3	11.2	19.3	5.45

APPENDIX
BOOTSTRAP TEST RESULTS FOR CORN YIELDS IN IOWA, ILLINOIS, AND INDIANA USING AN UNPOOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	50	1971	65.9	62.7	-3.2	-4.9	4.59
		1972	67.3	60.6	-6.7	-10.0	4.61
		1973	68.5	64.7	-3.8	-5.5	4.62
		1974	48.1	63.2	15.1	31.4	4.81
		1975	64.6	60.5	-4.1	-6.3	5.25
		1976	72.7	67.9	-4.8	-6.6	4.99
		1977	64.7	67.5	2.8	4.3	4.93
		1978	74.5	70.9	-3.6	-4.8	4.90
		1979	73.9	80.8	6.9	9.3	5.60
		1980	66.4	67.7	1.3	2.0	5.15
	60	1971	57.9	55.3	-2.6	-4.5	4.33
		1972	62.1	54.5	-7.6	-12.2	4.30
		1973	61.7	59.1	-2.6	-4.2	4.36
		1974	47.8	55.8	8.0	16.7	4.48
		1975	55.8	56.0	0.2	0.4	4.48
		1976	65.6	59.2	-6.4	-9.8	4.33
		1977	59.9	59.4	-0.5	-0.8	4.42
		1978	69.7	64.4	-5.3	-7.6	4.33
		1979	71.1	78.1	7.0	9.8	5.24
		1980	71.1	67.7	-3.4	-4.8	4.36
	70	1971	60.1	64.0	3.9	6.5	3.81
		1972	65.8	63.0	-2.8	-4.3	3.81
		1973	61.5	62.8	1.3	2.1	3.83
		1974	52.3	65.7	13.4	25.6	3.71
		1975	63.4	64.3	0.9	1.4	4.25
		1976	70.2	69.6	-0.6	-0.9	4.14
		1977	65.6	65.8	0.2	0.3	4.17
		1978	68.1	68.5	0.4	0.6	4.06
		1979	65.8	73.0	7.2	10.9	3.96
		1980	62.8	64.3	1.5	2.4	4.40
	80	1971	52.8	58.2	5.4	10.2	3.52
		1972	60.5	54.6	-5.9	-9.8	3.62
		1973	57.3	57.5	0.2	0.3	3.72
		1974	48.7	56.5	7.8	16.0	3.84
		1975	42.9	55.0	12.1	28.2	3.83
		1976	64.9	60.2	-4.7	-7.2	4.13
		1977	62.5	56.7	-5.8	-9.3	4.18
		1978	64.5	65.1	0.6	0.9	4.23
		1979	61.8	70.9	9.1	14.7	4.52
		1980	57.3	57.2	-0.1	-0.2	4.49

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	90	1971	54.5	58.2	3.7	6.8	3.41
		1972	56.5	54.9	-1.6	-2.8	3.41
		1973	50.8	56.2	5.4	10.6	3.47
		1974	47.5	56.6	9.1	19.2	3.43
		1975	48.3	53.2	4.9	10.1	3.74
		1976	64.4	58.7	-5.7	-8.9	3.66
		1977	61.9	55.6	-6.3	-10.2	3.84
		1978	63.6	61.2	-2.4	-3.8	3.77
		1979	62.3	64.1	1.8	2.9	3.71
		1980	59.7	58.4	-1.3	-2.2	4.06
STATE MODEL		1971	63.4	64.4	1.0	1.6	3.62
		1972	65.3	60.5	-4.8	-7.4	3.46
		1973	64.0	64.8	0.8	1.3	3.70
		1974	45.8	63.8	18.0	39.3	3.42
		1975	61.5	62.3	0.8	1.3	4.49
		1976	69.0	67.7	-1.3	-1.9	4.40
		1977	64.0	63.8	-0.2	-0.3	4.36
		1978	67.8	68.2	0.4	0.6	4.25
		1979	70.3	70.4	0.1	0.1	4.16
		1980	60.3	66.0	5.7	9.5	4.41
CRDS AGGR.		1971	63.4	62.4	-1.0	-1.6	
		1972	65.3	61.5	-3.8	-5.8	
		1973	64.0	63.2	-0.8	-1.3	
		1974	45.8	61.9	16.1	35.2	
		1975	61.5	61.1	-0.4	-0.7	
		1976	69.0	66.1	-2.9	-4.2	
		1977	64.0	64.5	0.5	0.8	
		1978	67.8	67.8	0.0	0.0	
		1979	70.3	74.0	3.7	5.3	
		1980	60.3	66.6	6.3	10.4	

APPENDIX
BOOTSTRAP TEST RESULTS FOR CORN YIELDS IN IOWA, ILLINOIS, AND INDIANA USING AN UNPOOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
REGION CRDS AGGR.		1971	64.8	64.5	-0.3	-0.5	
		1972	69.9	65.6	-4.3	-6.2	
		1973	65.6	65.7	0.1	0.2	
		1974	49.8	64.6	14.8	29.7	
		1975	63.6	66.5	2.9	4.6	
		1976	63.3	67.3	4.0	6.3	
		1977	60.5	64.2	3.7	6.1	
		1978	70.3	71.7	1.4	2.0	
		1979	78.1	74.5	-3.6	-4.6	
		1980	63.3	67.9	4.6	7.3	
STATES AGGR.		1971	64.8	64.3	-0.5	-0.8	
		1972	69.9	65.7	-4.2	-6.0	
		1973	65.6	67.3	1.7	2.6	
		1974	49.8	65.9	16.1	32.3	
		1975	63.6	65.7	2.1	3.3	
		1976	63.3	65.7	2.4	3.8	
		1977	60.5	62.9	2.4	4.0	
		1978	70.3	71.8	1.5	2.1	
		1979	78.1	74.9	-3.2	-4.1	
		1980	63.3	68.6	5.3	8.4	

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
IOWA	10	1971	61.6	61.5	-0.1	-0.2	3.64
		1972	72.8	65.7	-7.1	-9.8	3.64
		1973	69.1	67.8	-1.3	-1.9	3.82
		1974	47.1	66.4	19.3	41.0	3.82
		1975	55.0	63.7	8.7	15.8	5.00
		1976	45.9	62.2	16.3	35.5	5.23
		1977	64.6	64.3	-0.3	-0.5	5.49
		1978	75.0	75.5	0.5	0.7	5.83
		1979	77.8	71.9	-5.9	-7.6	5.74
		1980	73.3	66.6	-6.7	-9.1	5.71
	20	1971	67.0	63.5	-3.5	-5.2	3.72
		1972	73.8	67.6	-6.2	-8.4	3.69
		1973	68.9	65.4	-3.5	-5.1	4.00
		1974	55.7	68.2	12.5	22.4	3.87
		1975	59.9	66.6	6.7	11.2	5.06
		1976	58.5	66.4	7.9	13.5	5.26
		1977	64.3	62.1	-2.2	-3.4	5.63
		1978	75.9	75.0	-0.9	-1.2	5.86
		1979	81.6	77.7	-3.9	-4.8	5.79
		1980	78.6	69.4	-9.2	-11.7	5.76
	30	1971	60.9	62.4	1.5	2.5	3.66
		1972	68.9	66.5	-2.4	-3.5	3.64
		1973	65.0	62.9	-2.1	-3.2	3.98
		1974	55.3	67.4	12.1	21.9	3.79
		1975	58.1	65.8	7.7	13.3	4.97
		1976	56.9	65.7	8.8	15.5	5.18
		1977	70.0	63.8	-6.2	-8.9	5.54
		1978	74.1	71.9	-2.2	-3.0	5.77
		1979	81.9	74.6	-7.3	-8.9	5.70
		1980	76.2	64.4	-11.8	-15.5	5.72
	40	1971	57.8	61.4	3.6	6.2	3.65
		1972	72.7	65.4	-7.3	-10.0	3.63
		1973	66.7	64.9	-1.8	-2.7	3.92
		1974	44.5	64.9	20.4	45.8	3.82
		1975	53.2	63.9	10.7	20.1	4.98
		1976	44.3	62.7	18.4	41.5	5.20
		1977	46.6	62.5	15.9	34.1	5.52
		1978	72.2	70.1	-2.1	-2.9	5.77
		1979	74.7	71.6	-3.1	-4.1	5.69
		1980	54.5	64.3	9.8	18.0	5.71

APPENDIX
BOOTSTRAP TEST RESULTS FOR CORN YIELDS IN IOWA, ILLINOIS, AND INDIANA USING A POOLED CEAS CORN MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	YIELD (Q/H) PRED.	D	RD	S.E. PRED.
IOWA	50	1971	68.3	66.9	-1.4	-2.0	3.72
		1972	78.2	69.4	-8.8	-11.3	3.68
		1973	71.1	70.8	-0.3	-0.4	3.93
		1974	59.9	68.6	8.7	14.5	3.93
		1975	61.8	69.1	7.3	11.8	5.04
		1976	65.0	70.2	5.2	8.0	5.24
		1977	41.2	61.6	20.4	49.5	5.71
		1978	72.9	76.1	3.2	4.4	5.85
		1979	84.9	77.2	-7.7	-9.1	5.77
		1980	72.8	68.2	-4.6	-6.3	5.78
	60	1971	69.2	69.9	0.7	1.0	3.72
		1972	71.6	70.7	-0.9	-1.3	3.69
		1973	63.8	68.7	4.9	7.7	3.99
		1974	53.9	66.4	12.5	23.2	4.04
		1975	62.8	69.8	7.0	11.1	5.07
		1976	64.0	70.6	6.6	10.3	5.26
		1977	64.4	66.1	1.7	2.6	5.63
		1978	73.9	75.9	2.0	2.7	5.85
		1979	83.0	78.7	-4.3	-5.2	5.77
		1980	74.0	68.0	-6.0	-8.1	5.81
	70	1971	61.5	58.6	-2.9	-4.7	3.72
		1972	70.1	63.2	-6.9	-9.8	3.70
		1973	66.1	58.7	-7.4	-11.2	4.29
		1974	30.0	62.0	32.0	106.7	3.90
		1975	42.8	60.7	17.9	41.8	5.05
		1976	61.8	62.9	1.1	1.8	5.24
		1977	42.9	56.4	13.5	31.5	5.59
		1978	65.7	71.9	6.2	9.4	5.88
		1979	75.3	71.4	-3.9	-5.2	5.78
		1980	55.3	63.9	8.6	15.6	5.77
	80	1971	59.9	56.2	-3.7	-6.2	3.72
		1972	68.3	59.9	-8.4	-12.3	3.69
		1973	61.5	57.2	-4.3	-7.0	4.22
		1974	38.4	58.9	20.5	53.4	3.89
		1975	46.3	58.4	12.1	26.1	5.06
		1976	59.5	61.7	2.2	3.7	5.24
		1977	25.2	49.8	24.6	97.6	5.68
		1978	62.6	66.0	3.4	5.4	5.85
		1979	69.3	65.3	-4.0	-5.8	5.76
		1980	55.5	61.1	5.6	10.1	5.77

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
IOWA	90	1971	69.7	63.0	-6.7	-9.6	3.65
		1972	74.1	63.7	-10.4	-14.0	3.63
		1973	66.2	63.2	-3.0	-4.5	4.07
		1974	56.6	64.8	8.2	14.5	3.86
		1975	58.5	62.3	3.8	6.5	4.99
		1976	67.1	66.7	-0.4	-0.6	5.17
		1977	47.8	58.2	10.4	21.8	5.55
		1978	66.9	71.7	4.8	7.2	5.77
		1979	83.5	71.9	-11.6	-13.9	5.68
		1980	70.9	66.5	-4.4	-6.2	5.69
STATE MODEL		1971	64.0	61.8	-2.2	-3.4	2.86
		1972	72.8	66.3	-6.5	-8.9	2.65
		1973	67.2	68.2	1.0	1.5	3.06
		1974	50.2	66.9	16.7	33.3	3.09
		1975	56.5	63.6	7.1	12.6	4.73
		1976	57.1	59.8	2.7	4.7	5.10
		1977	54.0	55.8	1.8	3.3	5.27
		1978	72.2	73.6	1.4	1.9	4.61
		1979	79.7	73.7	-6.0	-7.5	4.43
		1980	69.0	65.8	-3.2	-4.6	4.51
CRDS AGGR.		1971	64.0	63.2	-0.8	-1.3	
		1972	72.8	66.4	-6.4	-8.8	
		1973	67.2	65.4	-1.8	-2.7	
		1974	50.2	66.0	15.8	31.5	
		1975	56.5	65.2	8.7	15.4	
		1976	57.1	65.8	8.7	15.2	
		1977	54.0	61.7	7.7	14.3	
		1978	72.2	73.3	1.1	1.5	
		1979	79.7	74.1	-5.6	-7.0	
		1980	69.0	66.3	-2.7	-3.9	

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	10	1971	66.3	67.0	0.7	1.1	4.09
		1972	68.7	69.6	0.9	1.3	4.07
		1973	62.8	66.2	3.4	5.4	4.22
		1974	49.1	66.4	17.3	35.2	4.27
		1975	72.2	71.1	-1.1	-1.5	4.58
		1976	63.5	72.5	9.0	14.2	4.60
		1977	72.5	72.8	0.3	0.4	4.71
		1978	71.7	76.2	4.5	6.3	4.69
		1979	79.5	79.0	-0.5	-0.6	4.68
		1980	72.5	74.7	2.2	3.0	4.68
	20	1971	63.1	67.1	4.0	6.3	4.04
		1972	66.8	66.5	-0.3	-0.4	4.05
		1973	61.5	62.1	0.6	1.0	4.26
		1974	45.9	65.4	19.5	42.5	4.13
		1975	69.4	65.4	-4.0	-5.8	4.57
		1976	65.4	69.3	3.9	6.0	4.59
		1977	71.9	68.4	-3.5	-4.9	4.71
		1978	71.1	74.4	3.3	4.6	4.70
		1979	80.2	75.2	-5.0	-6.2	4.67
		1980	69.9	71.8	1.9	2.7	4.68
	30	1971	69.5	68.7	-0.8	-1.2	4.03
		1972	72.6	65.9	-6.7	-9.2	4.07
		1973	65.9	65.2	-0.7	-1.1	4.21
		1974	57.9	65.4	7.5	13.0	4.16
		1975	73.8	67.9	-5.9	-8.0	4.59
		1976	66.7	70.3	3.6	5.4	4.61
		1977	54.4	68.4	14.0	25.7	4.70
		1978	69.2	72.1	2.9	4.2	4.69
		1979	82.7	76.0	-6.7	-8.1	4.67
		1980	62.4	68.8	6.4	10.3	4.72
	40	1971	74.7	72.6	-2.1	-2.8	4.02
		1972	76.5	69.6	-6.9	-9.0	4.07
		1973	72.3	69.6	-2.7	-3.7	4.13
		1974	54.7	68.3	13.6	24.9	4.13
		1975	81.9	73.6	-8.3	-10.1	4.57
		1976	78.2	74.6	-3.6	-4.6	4.60
		1977	66.0	72.3	6.3	9.5	4.69
		1978	72.7	76.6	3.9	5.4	4.69
		1979	83.3	82.2	-1.1	-1.3	4.69
		1980	54.2	72.3	18.1	33.4	4.73

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	50	1971	75.3	70.8	-4.5	-6.0	4.04
		1972	75.2	67.4	-7.8	-10.4	4.07
		1973	67.9	66.6	-1.3	-1.9	4.20
		1974	52.8	67.0	14.2	26.9	4.11
		1975	78.8	71.2	-7.6	-9.6	4.59
		1976	75.6	73.7	-1.9	-2.5	4.60
		1977	64.7	71.3	6.6	10.2	4.69
		1978	76.0	76.1	0.1	0.1	4.68
		1979	84.6	81.8	-2.8	-3.3	4.70
		1980	49.8	71.4	21.6	43.4	4.73
	60	1971	65.7	67.3	1.6	2.4	4.02
		1972	69.4	64.5	-4.9	-7.1	4.10
		1973	69.1	64.8	-4.3	-6.2	4.14
		1974	57.9	64.3	6.4	11.1	4.09
		1975	71.6	67.6	-4.0	-5.6	4.58
		1976	61.5	68.3	6.8	11.1	4.61
		1977	68.0	68.2	0.2	0.3	4.66
		1978	66.7	70.9	4.2	6.3	4.70
		1979	82.1	76.0	-6.1	-7.4	4.68
		1980	59.9	67.4	7.5	12.5	4.75
	70	1971	63.1	64.2	1.1	1.7	4.03
		1972	62.9	60.4	-2.5	-4.0	4.09
		1973	63.4	60.8	-2.6	-4.1	4.14
		1974	47.8	59.8	12.0	25.1	4.12
		1975	70.0	66.1	-3.9	-5.6	4.57
		1976	67.3	66.8	-0.5	-0.7	4.62
		1977	67.3	65.0	-2.3	-3.4	4.69
		1978	69.8	68.8	-1.0	-1.4	4.71
		1979	78.3	76.2	-2.1	-2.7	4.76
		1980	52.9	66.0	13.1	24.8	4.73
	80	1971	44.4	53.9	9.5	21.4	3.98
		1972	49.9	53.5	3.6	7.2	4.05
		1973	44.6	50.2	5.6	12.6	4.11
		1974	41.5	52.2	10.7	25.8	4.03
		1975	53.2	56.3	3.1	5.8	4.52
		1976	42.9	58.1	15.2	35.4	4.59
		1977	55.0	54.8	-0.2	-0.4	4.66
		1978	56.2	57.8	1.6	2.8	4.65
		1979	67.6	61.4	-6.2	-9.2	4.64
		1980	33.4	52.3	18.9	56.6	4.74

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	90	1971	43.8	54.6	10.8	24.7	3.98
		1972	53.2	54.2	1.0	1.9	4.03
		1973	44.0	50.3	6.3	14.3	4.08
		1974	42.2	52.9	10.7	25.4	4.01
		1975	53.8	55.7	1.9	3.5	4.52
		1976	54.5	58.7	4.2	7.7	4.56
		1977	53.6	55.0	1.4	2.6	4.66
		1978	46.5	56.2	9.7	20.9	4.65
		1979	65.7	60.9	-4.8	-7.3	4.64
		1980	38.4	55.2	16.8	43.8	4.72
STATE MODEL		1971	66.5	67.0	0.5	0.8	3.66
		1972	69.0	67.7	-1.3	-1.9	3.54
		1973	64.6	67.5	2.9	4.5	3.46
		1974	51.5	65.9	14.4	28.0	4.06
		1975	72.8	69.8	-3.0	-4.1	4.13
		1976	67.2	71.2	4.0	6.0	4.12
		1977	65.9	70.3	4.4	6.7	4.28
		1978	69.7	71.7	2.0	2.9	4.06
		1979	80.3	78.8	-1.5	-1.9	4.21
		1980	58.4	73.4	15.0	25.7	4.22
CRDS AGGR.		1971	66.5	67.2	0.7	1.1	
		1972	69.0	65.6	-3.4	-4.9	
		1973	64.6	64.2	-0.4	-0.6	
		1974	51.5	64.6	13.1	25.4	
		1975	72.8	68.4	-4.4	-6.0	
		1976	67.2	70.1	2.9	4.3	
		1977	65.9	68.7	2.8	4.2	
		1978	69.7	72.6	2.9	4.2	
		1979	80.3	77.1	-3.2	-4.0	
		1980	58.4	69.4	11.0	18.8	

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	10	1971	71.6	64.5	-7.1	-9.9	3.81
		1972	69.6	59.6	-10.0	-14.4	3.81
		1973	67.5	62.0	-5.5	-8.1	3.91
		1974	47.8	60.8	13.0	27.2	3.91
		1975	65.2	60.3	-4.9	-7.5	4.33
		1976	70.6	67.0	-3.6	-5.1	4.36
		1977	65.7	63.9	-1.8	-2.7	4.34
		1978	66.1	67.1	1.0	1.5	4.29
		1979	73.6	70.6	-3.0	-4.1	4.28
		1980	49.9	64.2	14.3	28.7	4.32
	20	1971	62.8	63.7	0.9	1.4	3.78
		1972	61.8	59.5	-2.3	-3.7	3.78
		1973	62.3	62.6	0.3	0.5	3.87
		1974	40.1	58.9	18.8	46.9	3.89
		1975	62.3	58.3	-4.0	-6.4	4.30
		1976	67.5	66.7	-0.8	-1.2	4.34
		1977	62.4	62.1	-0.3	-0.5	4.31
		1978	61.7	66.7	5.0	8.1	4.26
		1979	68.6	68.1	-0.5	-0.7	4.25
		1980	54.7	63.7	9.0	16.5	4.29
	30	1971	55.1	61.0	5.9	10.7	3.80
		1972	59.3	59.4	0.1	0.2	3.80
		1973	58.1	62.5	4.4	7.6	3.90
		1974	37.1	58.2	21.1	56.9	3.93
		1975	52.5	57.5	5.0	9.5	4.33
		1976	62.9	66.5	3.6	5.7	4.36
		1977	63.8	64.1	0.3	0.5	4.35
		1978	59.9	65.3	5.4	9.0	4.29
		1979	67.3	68.7	1.4	2.1	4.27
		1980	64.1	65.5	1.4	2.2	4.32
	40	1971	67.7	66.4	-1.3	-1.9	3.81
		1972	69.6	60.2	-9.4	-13.5	3.81
		1973	67.5	65.6	-1.9	-2.8	3.91
		1974	42.8	60.2	17.4	40.7	3.94
		1975	69.3	60.5	-8.8	-12.7	4.32
		1976	71.1	66.9	-4.2	-5.9	4.37
		1977	64.5	63.7	-0.8	-1.2	4.35
		1978	72.5	69.8	-2.7	-3.7	4.30
		1979	74.0	78.3	4.3	5.8	4.34
		1980	58.1	66.5	8.4	14.5	4.34

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	YIELD (Q/H) PRED.	D	RD	S.E. PRED.
INDIANA	50	1971	65.9	66.6	0.7	1.1	3.81
		1972	67.3	62.1	-5.2	-7.7	3.81
		1973	68.5	66.9	-1.6	-2.3	3.90
		1974	48.1	62.8	14.7	30.6	3.92
		1975	64.6	63.1	-1.5	-2.3	4.32
		1976	72.7	70.0	-2.7	-3.7	4.37
		1977	64.7	66.2	1.5	2.3	4.35
		1978	74.5	72.2	-2.3	-3.1	4.30
		1979	73.9	80.2	6.3	8.5	4.35
		1980	66.4	67.4	1.0	1.5	4.33
	60	1971	57.9	61.8	3.9	6.7	3.78
		1972	62.1	57.6	-4.5	-7.2	3.78
		1973	61.7	61.9	0.2	0.3	3.87
		1974	47.8	59.4	11.6	24.3	3.89
		1975	55.8	56.4	0.6	1.1	4.30
		1976	65.6	64.6	-1.0	-1.5	4.34
		1977	59.9	59.2	-0.7	-1.2	4.33
		1978	69.7	66.2	-3.5	-5.0	4.27
		1979	71.1	76.2	5.1	7.2	4.32
		1980	71.1	64.6	-6.5	-9.1	4.28
	70	1971	60.1	59.6	-0.5	-0.8	3.80
		1972	65.8	56.6	-9.2	-14.0	3.81
		1973	61.5	59.6	-1.9	-3.1	3.91
		1974	52.3	57.2	4.9	9.4	3.93
		1975	63.4	59.2	-4.2	-6.6	4.31
		1976	70.2	63.2	-7.0	-10.0	4.36
		1977	65.6	62.7	-2.9	-4.4	4.36
		1978	68.1	66.9	-1.2	-1.8	4.32
		1979	65.8	76.4	10.6	16.1	4.41
		1980	62.8	62.3	-0.5	-0.8	4.36
	80	1971	52.8	58.0	5.2	9.8	3.80
		1972	60.5	53.5	-7.0	-11.6	3.81
		1973	57.3	58.5	1.2	2.1	3.90
		1974	48.7	54.0	5.3	10.9	3.93
		1975	42.9	54.0	11.1	25.9	4.32
		1976	64.9	60.2	-4.7	-7.2	4.36
		1977	62.5	58.8	-3.7	-5.9	4.35
		1978	64.5	65.1	0.6	0.9	4.32
		1979	61.8	70.5	8.7	14.1	4.36
		1980	57.3	58.5	1.2	2.1	4.33

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	90	1971	54.5	60.9	6.4	11.7	3.78
		1972	56.5	54.7	-1.8	-3.2	3.79
		1973	50.8	61.2	10.4	20.5	3.92
		1974	47.5	57.7	10.2	21.5	3.89
		1975	48.3	54.4	6.1	12.6	4.32
		1976	64.4	62.0	-2.4	-3.7	4.33
		1977	61.9	59.6	-2.3	-3.7	4.36
		1978	63.6	65.9	2.3	3.6	4.30
		1979	62.3	69.8	7.5	12.0	4.27
		1980	59.7	59.4	-0.3	-0.5	4.37
STATE MODEL		1971	63.4	64.4	1.0	1.6	3.62
		1972	65.3	60.5	-4.8	-7.4	3.46
		1973	64.0	64.8	0.8	1.3	3.70
		1974	45.8	63.8	18.0	39.3	3.42
		1975	61.5	62.3	0.8	1.3	4.49
		1976	69.0	67.7	-1.3	-1.9	4.40
		1977	64.0	63.8	-0.2	-0.3	4.36
		1978	67.8	68.2	0.4	0.6	4.25
		1979	70.3	70.4	0.1	0.1	4.16
		1980	60.3	66.0	5.7	9.5	4.41
CRDS AGGR.		1971	63.4	63.6	0.2	0.3	
		1972	65.3	59.3	-6.0	-9.2	
		1973	64.0	63.1	-0.9	-1.4	
		1974	45.8	59.7	13.9	30.3	
		1975	61.5	59.5	-2.0	-3.3	
		1976	69.0	66.4	-2.6	-3.8	
		1977	64.0	63.3	-0.7	-1.1	
		1978	67.8	68.0	0.2	0.3	
		1979	70.3	74.1	3.8	5.4	
		1980	60.3	64.5	4.2	7.0	

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STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
REGION CRDS	AGGR.	1971	64.8	64.7	-0.1	-0.2	
		1972	69.9	64.7	-5.2	-7.4	
		1973	65.6	64.5	-1.1	-1.7	
		1974	49.8	64.3	14.5	29.1	
		1975	63.6	65.3	1.7	2.7	
		1976	63.3	67.5	4.2	6.6	
		1977	60.5	64.6	4.1	6.8	
		1978	70.3	72.0	1.7	2.4	
		1979	78.1	75.2	-2.9	-3.7	
		1980	63.3	67.1	3.8	6.0	
STATES	AGGR.	1971	64.8	64.3	-0.5	-0.8	
		1972	69.9	65.7	-4.2	-6.0	
		1973	65.6	67.3	1.7	2.6	
		1974	49.8	65.9	16.1	32.3	
		1975	63.6	65.7	2.1	3.3	
		1976	63.3	65.7	2.4	3.8	
		1977	60.5	62.9	2.4	4.0	
		1978	70.3	71.8	1.5	2.1	
		1979	78.1	74.9	-3.2	-4.1	
		1980	63.3	68.6	5.3	8.4	