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Comparison of the CEAS and Thompson-type Models for Soybean Yields in Iowa, Illinois, and Indiana

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ABSTRACT

The CEAS and Thompson-type regression models compared in this report use the basic input variables of year and monthly average temperature and total precipitation to predict soybean yields in Iowa, Illinois, and Indiana. Individual CEAS models are developed for each CRD and State using stepwise methods, often including stress variables based on estimates of PET and ET. The Thompson-type models pool CRD observations within each State and pool State-level observations within the region. The fixed weather variables consist of 12 linear and quadratic terms expressed as deviations from normal weather. There is little difference in the models based on the comparisons according to eight model characteristics. The accuracy of the CEAS model's predictions is somewhat higher in Iowa and Indiana. However, both models tend to underestimate in above-average yielding years and overestimate in below-average yielding years.

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

This paper was prepared for limited distribution to the research community outside the U. S. Department of Agriculture. The views expressed herein are not necessarily those of SRS or USDA.

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COMPARISON OF THE CEAS AND THOMPSON-TYPE MODELS FOR SOYBEAN YIELDS IN IOWA, ILLINOIS AND INDIANA

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*AgRISTARS is an acronym for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing. It is a multi-agency research program to meet some current and new information needs for the U. S. Department of Agriculture.

AgRISTARS
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Project

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INTRODUCTION

Correlational studies of the relationship between crop yields and weather variables have a long history (Hooker, 1970; Fisher, 1924; Sanderson, 1942). The advent of the computer, advances in statistical methodology and the growth of yield/weather time series have led to increased activity in these types of investigations. The expanded data base and the use of variable selection techniques allow the study of many more potential explanatory (weather) variables than previously possible. Methods of estimating evapotranspiration on a monthly (Thornthwaite, 1948) or daily (Penman, 1948 and 1963) basis have been developed and used to define weather related stress variables for use in yield models.

The U. S. Department of Agriculture (USDA) uses yield prediction models which incorporate weather variables along with crop condition as an aide in forecasting and estimating state-level yields for some crops. The acquisition of the weather data inputs required for such models should become more reliable and timely as communications and remote-sensing technologies advance. Therefore, the use of yield prediction models which require weather data may be expected to increase.

In preparation for this eventuality, the Yield Evaluation Section (of the Statistical Reporting Service [SRS]) located in the Modeling Center, Columbia, Missouri, along with NOAA (National Oceanic and Atmospheric Administration, Department of Commerce) and NASA (National Aeronautics and Space Administration) has been identifying potential crop yield models, developing methodologies for model evaluation and comparison, and documenting the evaluation and comparison of particular models. The initial effort, conducted as part of the AgRISTARS Project, has concentrated on the very simplest of such models for estimating the yields of corn and soybeans in Iowa, Illinois, and Indiana and the yields of spring wheat and barley in North Dakota and Minnesota.

Two yield/weather models were identified for each crop to be evaluated individually and then compared. The models in this first set are simple in several ways. The basic weather variables used are for calendar months and consist of the average monthly temperature and total precipitation. Planting dates and crop calendars are not used. Each of the weather values is an average over a climatic division, which corresponds to a crop reporting district for the above states. The long-term increases in yield levels are simply accounted for by linear or quadratic trend terms which are a function of the year number.

Even though these models are simplistic, they are inexpensive to use and the methodology is easily transportable to any area with a long time series (at least twenty to thirty years) of yield and weather data. Therefore, it is important to document their accuracy as their performance may be considered to be a reference level that other, more sophisticated models, requiring more costly inputs, would be expected to exceed.

The purpose of this report is to compare the performance of Thompson-type and CEAS models for estimating end-of-season soybean yields in Iowa, Illinois, and Indiana. At this time, operational use of these models by SRS is not being considered.

DESCRIPTION OF THE MODELS

The models compared in this report are all based on the historic statistical relationships between yield per harvested area and technology expressed as a function of the year number, and/or monthly weather related variables. Primary interest is in the comparison between the CEAS and Thompson-type models. The "straw man," simple linear trend model is also included in the comparison since, as stated by Sebaugh (1981), "Any candidate model which cannot substantially outperform a straw man model is of questionable value."

Although CEAS models have been developed for use before and during the growing season, they are not included in this discussion and only the reliability of the end-of-season models is examined here.

Thompson-Type Models

Louis M. Thompson developed soybean models (1970, 1980) for the purpose of studying the relationship between weather and soybean yields. He used state level yield and weather data from five states (Iowa, Illinois, Indiana, Ohio, and Missouri). The independent variables used by Thompson included a linear trend term (year minus 1929) and six weather terms which appear in both linear and squared form. The linear terms are expressed as deviations from the regional normal values and are: (1) cumulative rainfall from the previous September through June, (2) July monthly rainfall, (3) August monthly rainfall, (4) June average temperature, (5) July average temperature, and (6) August average temperature.

Kestle (1982) compared the yield prediction ability of two regression analysis procedures Thompson has used and reported somewhat better results using "pooled" models. For state level predicted yields, state level weather variables are computed as deviations from the three state regional normals and are pooled so that one set of state level weather variable regression coefficients is estimated. For CRD level predicted yields, CRD weather variables are computed as deviations from their state's normals and are pooled within each state so that a set of CRD level weather variable regression coefficients is estimated for all CRDs within each state. For more details, see Kestle (1982).

CEAS Models

The models were developed by the Center for Environmental Assessment Services (CEAS) (Motha, 1980) specifically for yield prediction purposes. CEAS (now known as the Assessment and Information Services Center [AISC]) is a part of the National Oceanic and Atmospheric Administration (NOAA) within the U. S. Department of Commerce.

Separate models were developed for each CRD and state using stepwise regression methods. Two linear trend terms are used in the Iowa and Illinois models, one for prior to 1960 and one for the time period after 1960. A single trend term, year minus 1930, is used in the Indiana models for the entire time period. The weather related variables vary from model to model but were chosen from a list of meteorological and agroclimatic variables. The meteorological variables considered include the average monthly temperature, cumulative precipitation, monthly deviations from normal temperature and precipitation, and squared monthly deviations from normal precipitation. The agroclimatic variables are based on estimates of monthly potential evapotranspiration (PET) and actual evapotranspiration (ET) using the methods of Thornthwaite (1948) and Palmer (1965). For more details see French (1982) and Motha (1980).

Straw Man Models

The straw man model is a simple linear regression of yield on year (1950=0). Kestle (1981) and Sebaugh (1981) used the previous twenty-three years of data to estimate the coefficients in the prediction equation for a given test year. These models were developed as an exercise in developing and applying procedures for model evaluation and comparison. They are considered to be simple, inexpensive, and objective but not necessarily optimum for yield prediction even among the class of models which do not incorporate weather.

COMPARISON METHODOLOGY

Eight Model Characteristics To Be Compared

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

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

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

Bootstrap Technique Used to Generate Indicators of Yield Reliability for the End-of-Season 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 actual (reported) yield, Y, and the difference between them, $d = \hat{Y}-Y$, for each test year. It is desirable that the data used to generate the parameters for the model not include data from the test year.

To accomplish this, the "bootstrap" technique is used. Years from an earlier base period are used to fit the model and obtain a prediction equation. The values of the independent variables for the test year following the base period are inserted into the equation and a predicted yield is generated. Then, that test year is added to the base period and the process is repeated for the next sequential test year. Continuing in this way, ten (1970-1979) predictions of yield are obtained, each independent of the data used to fit the model. Data through 1969 are used to fit prediction models for 1970, data through 1970 are used to fit prediction models for 1971, etc.

Even though the data used to estimate the regression coefficients do not include the test year, this procedure does not result in a predicted yield which is totally independent of the data from the test year. Data from the seventies were used to select the variables which are included in the CEAS models and to determine the break points for trend. It is unrealistic to require model developers to develop ten models for each CRD and state which truly use only data up to but not including each test year. Since the procedures used by CEAS for variable selection and break point determination include subjective decisions, the process cannot be simulated accurately by the model evaluator. Therefore, the bootstrap procedure described above neither tests how well these models can perform in the future if the variable selection procedure is repeated nor how well the model developer can incorporate future changes in trend using the present weather variables.

Quantitative Model Comparisons Are Based on the Same Data

Direct quantitative comparisons between models will be made for two of the previously mentioned criteria: (1) yield indication reliability and (2) accurate current measures of modeled yield reliability. The quantities involved are derived from the observed yields and the model predicted yields and standard errors of prediction obtained from independent bootstrap tests for each of ten years (1970-1979). The predicted yields for the CEAS and Thompson-type models are derived using climatic division weather data published by the National Climatic Data Center in Asheville, North Carolina. Yield data are available in Iowa from 1950, in Illinois from 1932, and Indiana from 1937 (Figures 1, 2, 3). Matching weather data are available for all these years.

The average production and yield over the ten year test period are listed in Table 1 for each goegraphic area. Also shown is the percent production each crop reporting district (CRD) contributes to its state and the three state

Figure 1

U.S.D.A. Reported State Soybean Yields for Iowa
1950-1979 (Quintals/Hectare)

A = Reported Yield

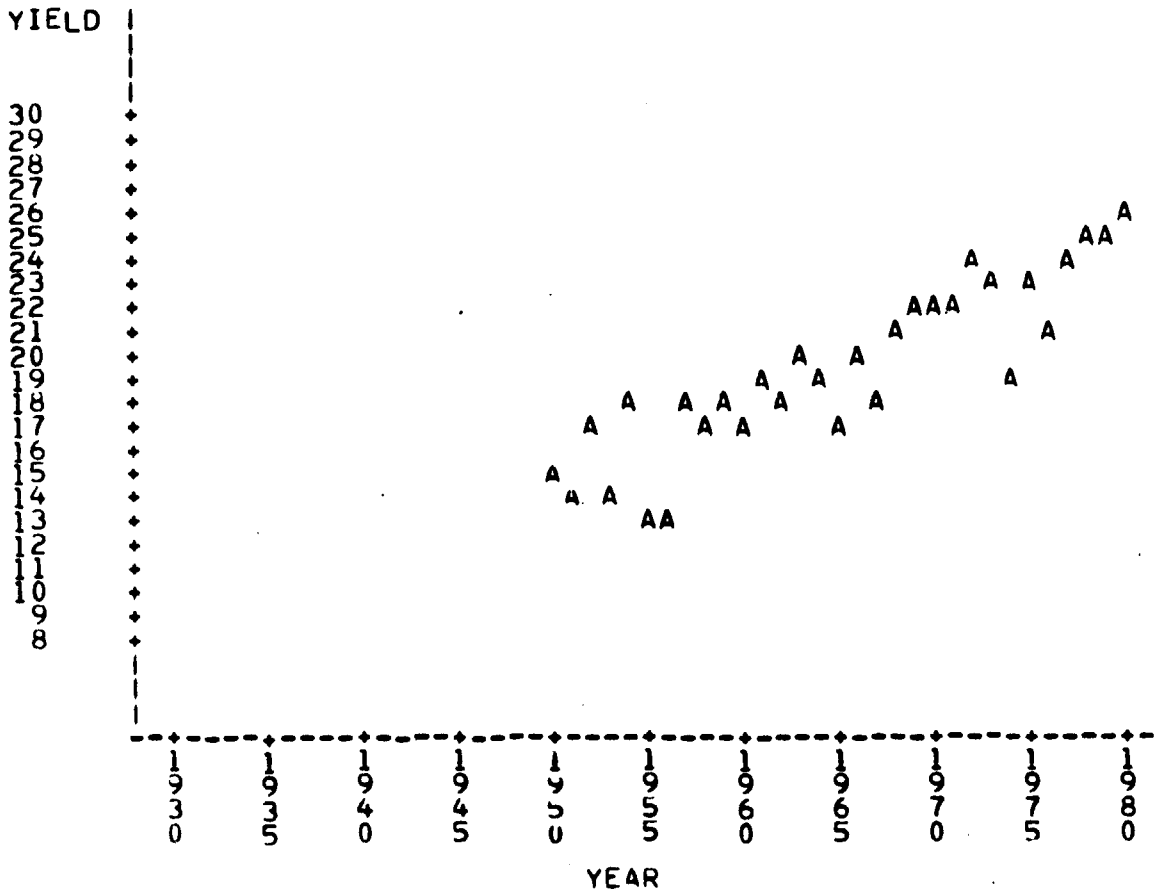


Figure 2

U.S.D.A. Reported State Soybean Yields for Illinois
1931-1979 (Quintals/Hectare)

A = Reported Yield

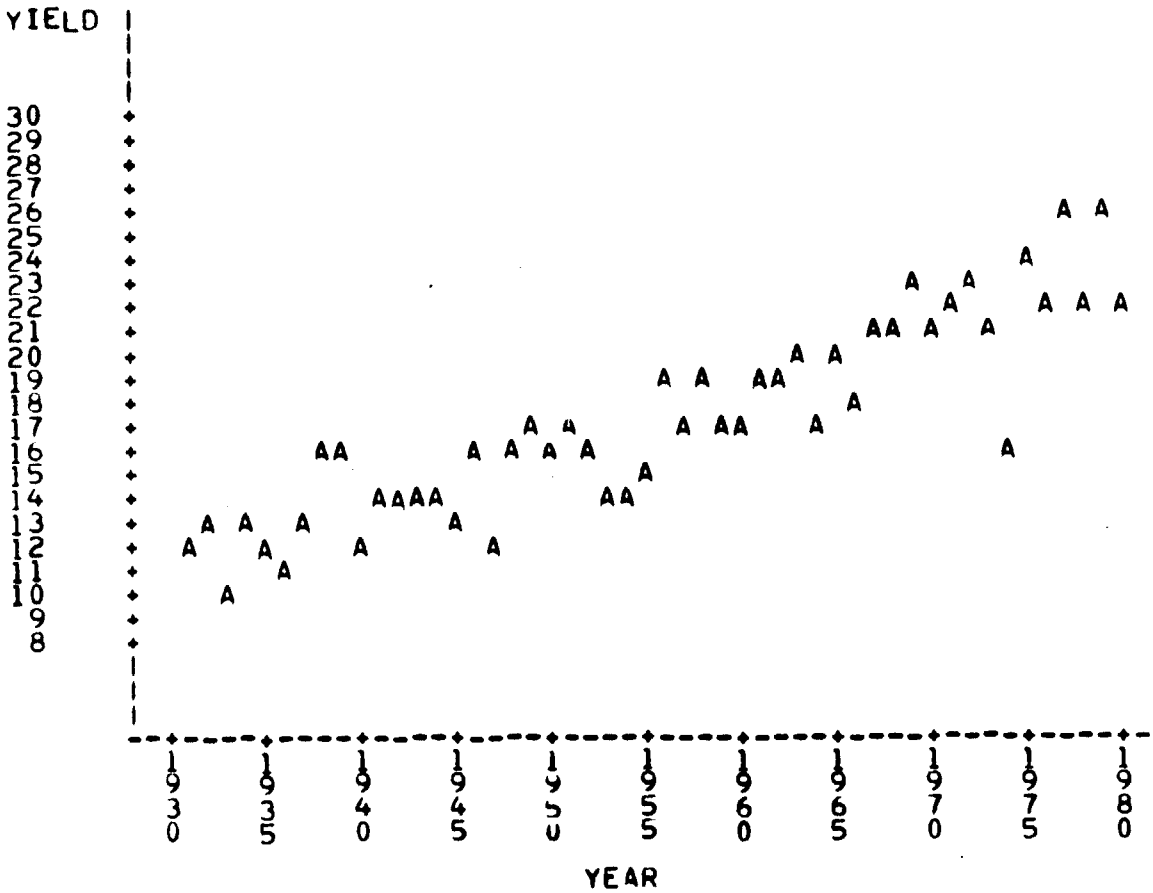


Figure 3

U.S.D.A. Reported State Soybean Yields for Indiana
1936-1979 (Quintals/Hectare)

A = Reported Yield

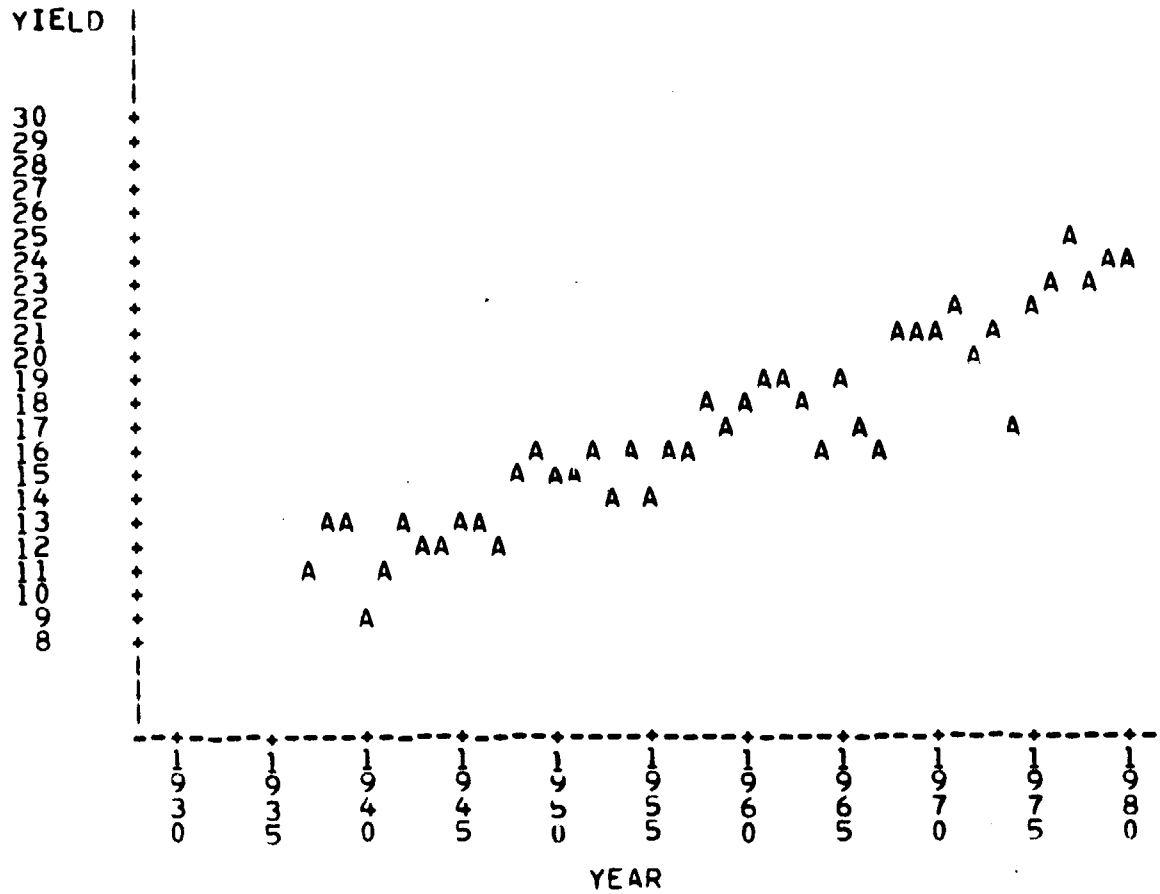
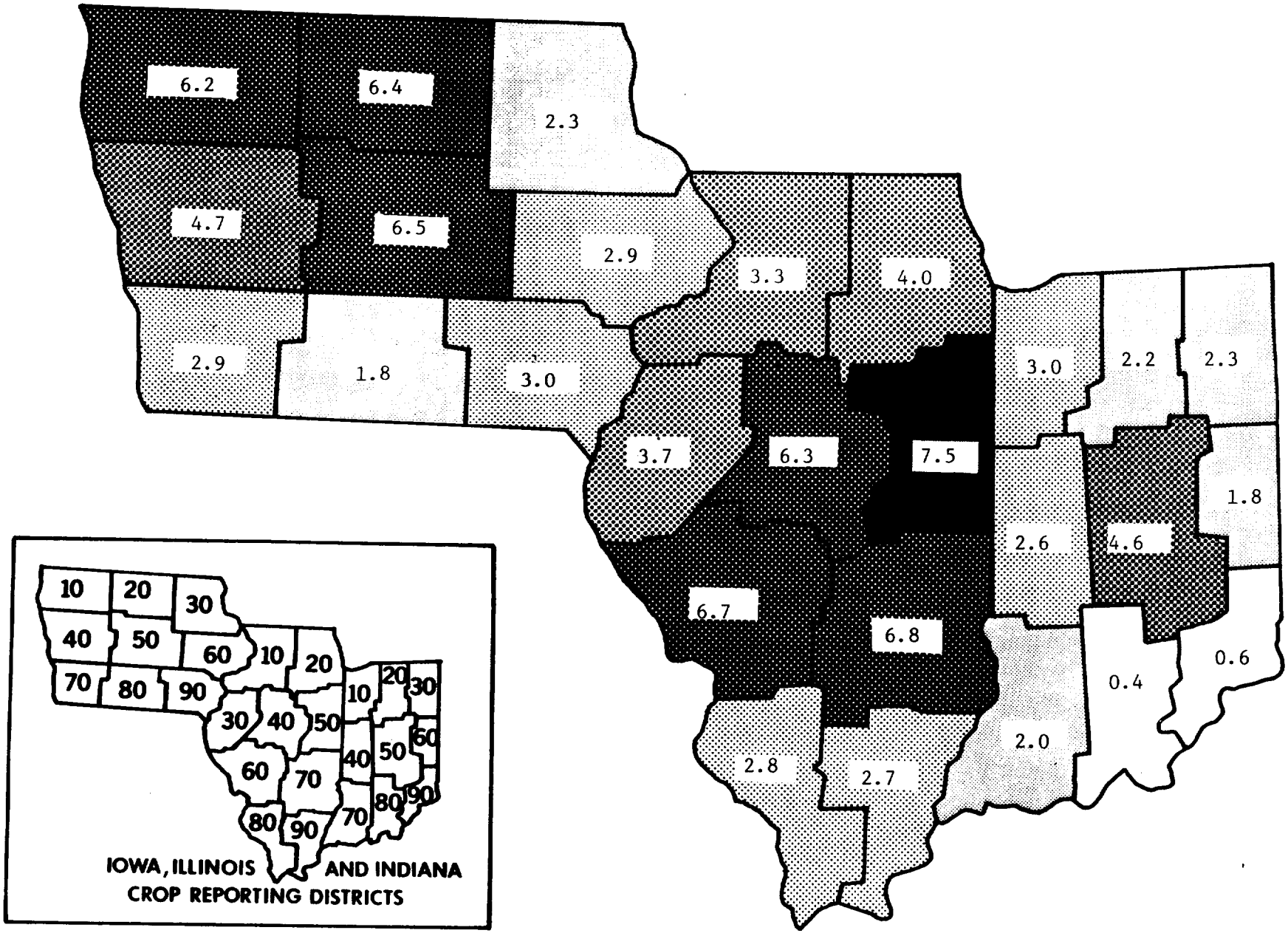


TABLE 1
AVERAGE PRODUCTION AND YIELD
FOR TEST YEARS 1970-79

SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	PRODUCTION (1,000) QUINTALS	BUSHELS	PERCENT OF STATE	REGION	YIELD QNTL/HA	BU/ACRE
IOWA	10	10,677	39,229	16.9	6.2	23.3	34.6
	20	10,954	40,250	17.4	6.4	22.7	33.7
	30	3,901	14,335	6.2	2.3	21.6	32.1
	40	8,171	30,024	13.0	4.7	22.2	33.0
	50	11,107	40,810	17.6	6.5	23.7	35.2
	60	4,993	18,344	7.9	2.9	24.3	36.1
	70	5,002	18,377	7.9	2.9	22.0	32.7
	80	3,104	11,407	4.9	1.8	20.2	30.1
	90	5,131	18,854	8.1	3.0	22.9	34.1
STATE		63,040	231,630		36.6	22.8	33.8
ILLINOIS	10	5,664	20,811	7.5	3.3	24.0	35.7
	20	6,959	25,568	9.2	4.0	22.2	33.1
	30	6,329	23,253	8.4	3.7	23.6	35.0
	40	10,899	40,045	14.4	6.3	25.0	37.2
	50	12,878	47,318	17.1	7.5	24.3	36.1
	60	11,502	42,261	15.2	6.7	23.2	34.6
	70	11,715	43,043	15.5	6.8	20.8	31.0
	80	4,881	17,935	6.5	2.8	19.3	28.7
	90	4,685	17,213	6.2	2.7	17.4	25.9
STATE		75,510	277,448		43.9	22.5	33.4
INDIANA	10	5,206	19,129	15.5	3.0	22.1	32.9
	20	3,714	13,647	11.1	2.2	21.8	32.4
	30	3,933	14,453	11.7	2.3	20.9	31.1
	40	4,422	16,246	13.2	2.6	22.6	33.6
	50	8,001	29,398	23.8	4.6	23.6	35.1
	60	3,173	11,659	9.4	1.8	21.1	31.4
	70	3,366	12,369	10.0	2.0	20.6	30.7
	80	738	2,711	2.2	0.4	18.5	27.5
	90	1,058	3,889	3.1	0.6	18.9	28.1
STATE		33,612	123,500		19.5	21.9	32.5
REGION		172,162	632,578			22.4	33.4

Figure 4. Production of soybeans by CRD (1970–79 average) as a percent of the regional total. Darker shades indicate CRDs with higher production.



region and the percent production each state contributes to the region. The percentage of regional production for each CRD is shown graphically in Figure 4. Darker shades indicate higher productivity.

Model predicted yields are derived for each CRD in Iowa, Illinois and Indiana and for each of the three states. Predicted yields at the state level are also obtained by using an aggregated weighted average of that state's CRD predicted yields. Predicted yields for the region are obtained both by aggregating the CRD predicted yields and the state level predicted yields. In all cases, the weighting factor used is soybean harvested acreage. Results obtained by aggregating from the CRD predicted yields are identified as "CRDs aggr." Results obtained by aggregating from the state level predicted yields are identified as "states aggr."

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. The indicators are also discussed in Wilson and Sebaugh (1981). Formulas are given in an Appendix (p. 54).

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 values of d for a future year will be less than one RMSE and 95% probable that it will be less than twice the RMSE. So, accurate prediction capability is indicated by a small RMSE. A non-zero bias means the model is, on the average, overestimating the yield (positive bias) or underestimating the yield (negative bias). The SD is smaller than the RMSE when there is non-zero bias and indicates what the RMSE would be if there were no bias. If the bias is near zero, the SD and the RMSE will be close in value. A model whose bias is 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 actual yield is not predicted accurately. This is because years with small observed actual yields and large differences often have the largest rd values.

Several indicators are derived using relative differences. In order to calculate the proportion of years beyond a critical error limit, we count the number of years in which the absolute value of the relative difference exceeds

the critical limit of 10 percent. Values between 5 and 25 percent were investigated and a critical limit of 10 percent was found most useful in describing model performance. The worst and next to worst performance during the test period are defined as the largest and next to largest absolute value of the relative difference. The range of yield indication accuracy is defined by the largest and smallest absolute values of the relative difference.

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

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

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

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

Models Are Ranked According to Performance

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

(1) the bias,

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

(3) the standard deviation (SD),

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

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

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

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

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

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

For most of the indicators (1-6), the model with the smallest numeric value exhibits the best performance in terms of yield reliability and is given a rank of 1. For the remaining quantities, the model with the largest value exhibits the most desirable performance. If models are tied for the same level of performance, they are all assigned the lowest rank for which they are tied. For example, if two models are tied for best performance, they are both assigned a rank of 1, the lower of ranks 1 and 2.

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

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

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

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

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

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

A test may be constructed by considering that one model is considered more reliable than another model if its predicted yields, $\hat{Y}$'s, are closer to the actual yields, Y's. No difference in the reliability of two models for a particular year means that the absolute value of the difference between their

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

Two types of paired-sample statistical tests are used: a parametric test using the student "t" test statistic and a nonparametric test using the Wilcoxon signed rank test statistic. One reason for applying both tests is that they require different assumptions. The parametric t-test assumes the D values are normally distributed while the nonparametric test does not. The d values may be considered to be approximately normally distributed. The $|d|$ values would then be folded normals rather than normally distributed. Although both models are folded at $|d| = 0$, their means may be different and the distribution of D has a possibility of not being normally distributed. The t-test is robust with respect to the normality assumption; however, this possible violation of the assumption is one reason for also running the nonparametric test. Formulas for these tests are given in an Appendix (p. 54).

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

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

The hypothesis of equal model performance will only be rejected by the nonparametric test if one model has more years with smaller $|d|$ values than the other model. The model with more smaller $|d|$ values is considered the more

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

Model Performance Is Compared in Above Average, Below Average, and Average Yielding Years

In yield modeling work, there is particular interest in the performance of models in unusual, particularly low yielding, years. Therefore, it is desirable to be able to identify unusually high and low yielding years and to compare the performance of the models in those years.

In order to identify different types of yielding years for each state, the following analysis was performed. The intercept, trend and weather coefficients were estimated using all data through 1979 for each of the three CEAS state models and for the Thompson-type pooled regional model which is used to make predictions at the state level. Predicted yields for each model were then calculated at the state level for all years through 1979 using trend with normal (average) values for the weather variables. Each year, the average of these predicted values for the CEAS and Thompson-type models was calculated. The five years whose actual yields exceeded these predicted values the most were identified as above average yielding years and the five years whose actual yields were the furthest below these normal yields were identified as below average yielding years. The remaining years were identified as average yielding years. Since the data base in Iowa begins in 1950, years from 1950 through 1979 in all three states are identified in terms of their yield level. An appendix shows the years identified as below average and above average for each state (p. 63).

The performance of the CEAS and Thompson-type models can then be compared for each type of yielding year. The predicted values calculated for each model from 1950 to 1979 are obtained using the same coefficients estimated above but with the actual, observed weather for each year. The average of the absolute value of the residual, and the lowest and highest residual are reported for below average, above average, and average years using the CEAS and the Thompson-type models in each state.

MODEL COMPARISON

Indicators of Yield Reliability Based on $d=\hat{Y}-Y$ Show All Models Have Small Bias But the CEAS Model Has the Smallest Root Mean Square Error and Standard Deviation

The model values and comparative ranks for the bias, the root mean square error (RMSE), and the standard deviation (SD) are given in Tables 2, 3, and 4. The CEAS model has the smallest bias more often at the CRD level (13 out of 27 times). It is ranked 1 at the state level in Iowa, at the state level aggregated by CRDs in Indiana and at the regional level aggregated by CRDs. The Thompson model was the poorest of the three in this respect, in that its average error was largest.

The CEAS model is generally the most accurate model. It has the smallest root mean square error in 20 of the 27 CRDs (74%), at the state level in all states (regardless of the method of aggregation), and at the regional level. The CEAS model also has the smallest standard deviation at both state and region levels. Figure 5 shows the best performing model in each CRD based on the root mean square error. The CEAS model generally performs better in the higher producing CRDs. The Thompson model is second at all levels and the straw man model has the worst performance.

Indicators of Yield Reliability Based on $rd = 100d/Y$ Show the CEAS Model Performs Best

The model values and comparative ranks for the indicators of yield reliability based on the relative difference, rd, are shown in Tables 5, 6 and 7. These indicators are valuable for demonstrating the worst performance of a model. Therefore, the best performing model will have the smallest values for the percent of years the absolute value of the relative difference exceeds ten percent and for the largest and the next largest absolute value of the relative difference.

In 20 of 27 CRDs (74%), the CEAS model has the smallest (or is tied for the smallest) percent of years in which the absolute value of rd exceeds 10% (Figure 6). The CEAS model also performs somewhat better at the state level. All models are tied at the regional level. The Thompson-type model performs slightly better at the state and CRD level than the straw man model.

When considering the smallest values of the largest absolute relative difference (Figure 7), the Thompson model performs the best in Illinois, the CEAS model performs best in Iowa, and both perform better than the straw man model in Indiana. Across the region, the Thompson model performs the best in the higher production areas. The straw man model demonstrates the worst performance.

Considering the CEAS and Thompson models at the state level, the largest $|rd|$ for the Thompson model occurs in 1974 for all three states. The same situation occurs for the CEAS model with the exception of Iowa, where 1975 was the year

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

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN BIAS	STRAW MAN RANK	THOMPSON BIAS	THOMPSON RANK	CEAS BIAS	CEAS RANK
IOWA	10	-0.69	(2)	-0.93	(3)	0.26	(1)
	20	0.23	(3)	-0.11	(1)	0.15	(2)
	30	-0.60	(3)	-0.57	(2)	-0.49	(1)
	40	0.12	(2)	0.10	(1)	-0.31	(3)
	50	0.41	(2)	0.41	(2)	0.16	(1)
	60	0.65	(2)	0.61	(1)	1.43	(3)
	70	1.16	(2)	1.42	(3)	0.47	(1)
	80	0.31	(2)	0.02	(1)	0.93	(3)
	90	-0.19	(2)	-0.28	(3)	0.10	(1)
STATE MODEL		0.09	(2)	-0.31	(3)	-0.08	(1)
CRDS AGGR.		0.10	(2)	0.00	(1)	0.23	(3)
ILLINOIS	10	-0.30	(1)	-0.55	(3)	0.39	(2)
	20	-0.77	(3)	-0.34	(1)	-0.62	(2)
	30	-0.25	(1)	-0.72	(3)	-0.27	(2)
	40	0.02	(1)	-0.37	(2)	0.45	(3)
	50	-0.41	(1)	-0.45	(2)	0.72	(3)
	60	0.36	(2)	-0.75	(3)	0.17	(1)
	70	-0.19	(1)	-0.80	(3)	0.40	(2)
	80	-0.00	(1)	0.02	(2)	0.02	(2)
	90	-0.03	(1)	0.38	(3)	-0.16	(2)
STATE MODEL		-0.08	(1)	-0.28	(2)	0.49	(3)
CRDS AGGR.		-0.15	(1)	-0.48	(3)	0.19	(2)
INDIANA	10	-0.53	(1)	-0.73	(3)	-0.68	(2)
	20	-1.06	(2)	-1.18	(3)	-0.51	(1)
	30	-1.16	(2)	-1.69	(3)	-0.72	(1)
	40	-0.18	(1)	-0.88	(3)	-0.58	(2)
	50	-0.88	(3)	-0.47	(2)	-0.32	(1)
	60	-0.78	(2)	-1.61	(3)	-0.27	(1)
	70	0.93	(3)	0.07	(2)	0.01	(1)
	80	1.60	(3)	1.07	(2)	-0.43	(1)
	90	1.57	(3)	1.22	(2)	-0.43	(1)
STATE MODEL		-0.41	(3)	-0.03	(1)	-0.22	(2)
CRDS AGGR.		-0.44	(1)	-0.74	(3)	-0.44	(1)
REGION CRDS AGGR.		-0.11	(2)	-0.33	(3)	0.09	(1)
STATES AGGR.		-0.08	(1)	-0.23	(3)	0.16	(2)

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

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN RMSE	RANK	THOMPSON RMSE	RANK	CEAS RMSE	RANK
IOWA	10	2.59	(3)	2.20	(2)	2.06	(1)
	20	1.50	(3)	1.43	(2)	1.25	(1)
	30	2.05	(3)	1.73	(2)	1.44	(1)
	40	2.51	(3)	1.81	(2)	0.83	(1)
	50	2.56	(3)	1.63	(2)	1.57	(1)
	60	2.15	(2)	1.30	(1)	2.28	(3)
	70	2.18	(3)	2.17	(2)	1.41	(1)
	80	2.80	(3)	2.30	(2)	2.21	(1)
	90	2.55	(3)	2.09	(2)	1.79	(1)
STATE MODEL		1.87	(3)	1.58	(2)	1.49	(1)
CRDS AGGR.		1.88	(3)	1.46	(2)	1.02	(1)
ILLINOIS	10	2.96	(3)	2.14	(1)	2.25	(2)
	20	2.75	(3)	2.30	(1)	2.35	(2)
	30	2.83	(3)	2.52	(1)	2.64	(2)
	40	3.24	(3)	2.33	(2)	2.28	(1)
	50	2.76	(3)	2.11	(2)	1.72	(1)
	60	2.55	(3)	2.21	(2)	2.13	(1)
	70	2.52	(3)	2.10	(1)	2.25	(2)
	80	2.38	(3)	1.78	(1)	2.11	(2)
	90	2.49	(3)	1.83	(2)	1.82	(1)
STATE MODEL		2.55	(3)	1.63	(2)	1.57	(1)
CRDS AGGR.		2.56	(3)	1.92	(2)	1.86	(1)
INDIANA	10	2.15	(3)	1.82	(2)	1.44	(1)
	20	2.66	(3)	2.55	(2)	1.30	(1)
	30	2.47	(2)	2.56	(3)	1.56	(1)
	40	2.67	(3)	2.45	(2)	2.02	(1)
	50	2.45	(3)	1.85	(2)	1.57	(1)
	60	1.89	(2)	2.36	(3)	1.74	(1)
	70	1.88	(3)	1.38	(1)	1.74	(2)
	80	2.77	(3)	1.94	(2)	1.80	(1)
	90	2.79	(3)	2.32	(2)	1.80	(1)
STATE MODEL		2.05	(3)	1.57	(2)	1.37	(1)
CRDS AGGR.		2.05	(3)	1.76	(2)	1.24	(1)
REGION CRDS AGGR.		2.00	(3)	1.50	(2)	1.33	(1)
STATES AGGR.		2.02	(3)	1.45	(2)	1.32	(1)

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

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN SD	STRAW MAN RANK	THOMPSON SD	THOMPSON RANK	CEAS SD	CEAS RANK
IOWA	10	2.50	(3)	2.00	(1)	2.04	(2)
	20	1.48	(3)	1.43	(2)	1.25	(1)
	30	1.96	(3)	1.64	(2)	1.35	(1)
	40	2.51	(3)	1.80	(2)	0.78	(1)
	50	2.53	(3)	1.57	(2)	1.57	(1)
	60	2.05	(3)	1.15	(1)	1.77	(2)
	70	1.85	(3)	1.64	(2)	1.33	(1)
	80	2.79	(3)	2.30	(2)	2.00	(1)
	90	2.55	(3)	2.07	(2)	1.79	(1)
STATE MODEL		1.87	(3)	1.55	(2)	1.48	(1)
CRDS AGGR.		1.88	(3)	1.46	(2)	0.99	(1)
ILLINOIS	10	2.94	(3)	2.07	(1)	2.22	(2)
	20	2.64	(3)	2.28	(2)	2.27	(1)
	30	2.82	(3)	2.41	(1)	2.62	(2)
	40	3.24	(3)	2.30	(2)	2.23	(1)
	50	2.73	(3)	2.06	(2)	1.56	(1)
	60	2.53	(3)	2.08	(1)	2.12	(2)
	70	2.51	(3)	1.94	(1)	2.21	(2)
	80	2.38	(3)	1.78	(1)	2.11	(2)
	90	2.49	(3)	1.79	(1)	1.81	(2)
STATE MODEL		2.54	(3)	1.61	(2)	1.49	(1)
CRDS AGGR.		2.55	(3)	1.86	(2)	1.85	(1)
INDIANA	10	2.09	(3)	1.66	(2)	1.26	(1)
	20	2.44	(3)	2.26	(2)	1.19	(1)
	30	2.19	(3)	1.92	(2)	1.38	(1)
	40	2.66	(3)	2.29	(2)	1.93	(1)
	50	2.29	(3)	1.79	(2)	1.54	(1)
	60	1.72	(2)	1.73	(3)	1.72	(1)
	70	1.63	(2)	1.38	(1)	1.74	(3)
	80	2.26	(3)	1.61	(1)	1.75	(2)
	90	2.30	(3)	1.97	(2)	1.74	(1)
STATE MODEL		2.01	(3)	1.57	(2)	1.35	(1)
CRDS AGGR.		2.00	(3)	1.60	(2)	1.16	(1)
REGION CRDS AGGR.		1.99	(3)	1.47	(2)	1.32	(1)
STATES AGGR.		2.02	(3)	1.43	(2)	1.31	(1)

Figure 5. Letter indicates the model with smallest root mean square error for soybean yields based on test years 1970-1979. Darker shades indicate CRDs with higher production. (C = CEAS, T = Thompson).

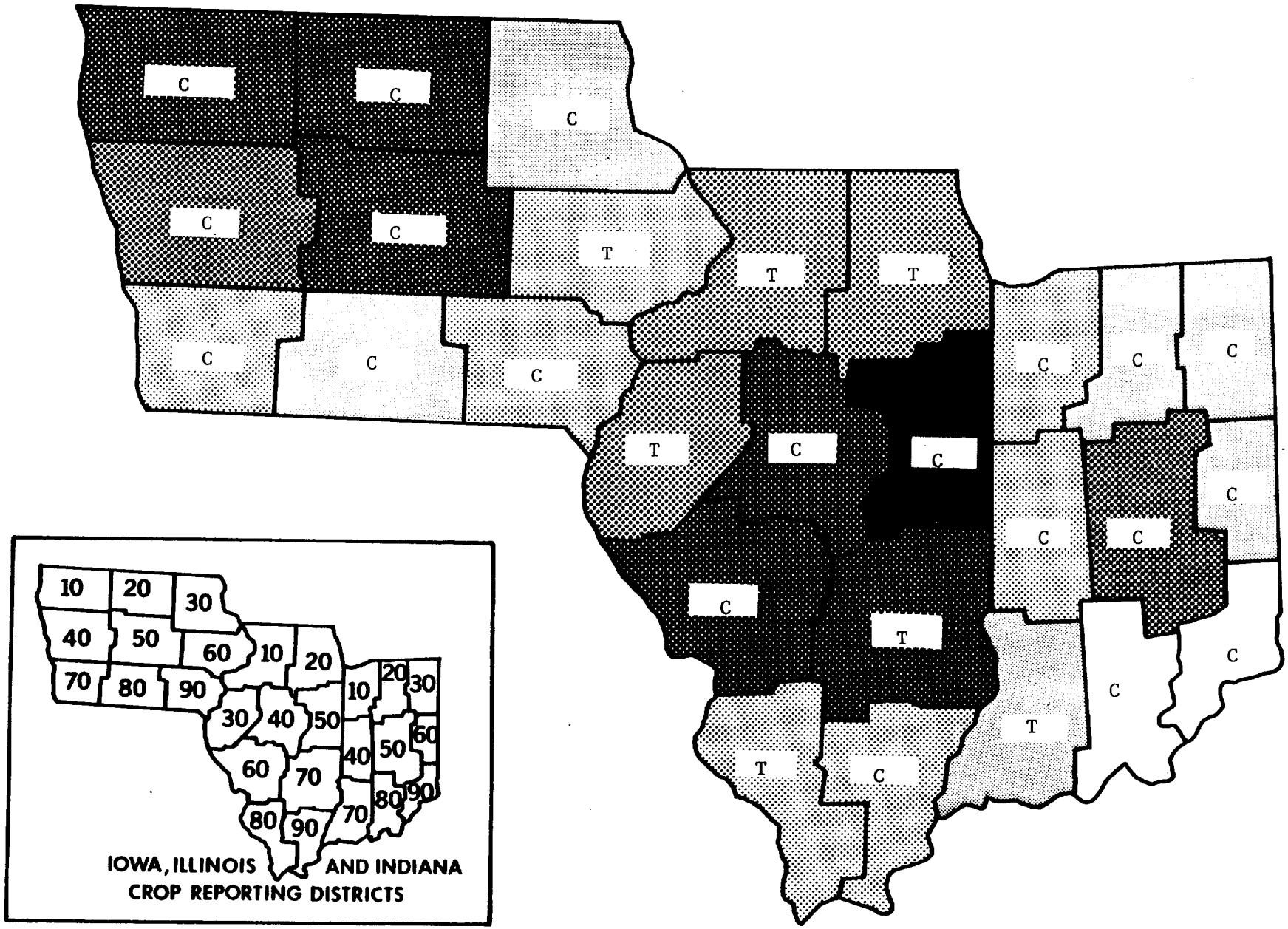


TABLE 5
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS |RELATIVE DIFFERENCE| > 10%
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN %	STRAW MAN RANK	THOMPSON %	THOMPSON RANK	CEAS $\bar{\%}$	CEAS RANK
IOWA	10	50	(3)	30	(2)	20	(1)
	20	10	(1)	10	(1)	10	(1)
	30	30	(2)	30	(2)	20	(1)
	40	40	(3)	20	(2)	0	(1)
	50	40	(3)	10	(1)	10	(1)
	60	20	(1)	20	(1)	20	(1)
	70	30	(2)	30	(2)	10	(1)
	80	20	(2)	10	(1)	30	(3)
	90	10	(1)	10	(1)	20	(3)
STATE MODEL		20	(1)	30	(3)	20	(1)
CRDS AGGR.		20	(3)	10	(1)	10	(1)
ILLINOIS	10	40	(3)	30	(2)	10	(1)
	20	40	(2)	30	(1)	40	(2)
	30	20	(1)	50	(3)	30	(2)
	40	10	(1)	10	(1)	10	(1)
	50	40	(3)	30	(2)	10	(1)
	60	20	(1)	20	(1)	20	(1)
	70	40	(1)	40	(1)	40	(1)
	80	50	(2)	30	(1)	50	(2)
	90	50	(3)	30	(1)	40	(2)
STATE MODEL		30	(3)	10	(1)	10	(1)
CRDS AGGR.		30	(3)	20	(2)	10	(1)
INDIANA	10	30	(3)	20	(1)	20	(1)
	20	40	(3)	30	(2)	10	(1)
	30	30	(2)	40	(3)	20	(1)
	40	20	(1)	40	(3)	30	(2)
	50	30	(2)	30	(2)	10	(1)
	60	20	(1)	40	(3)	20	(1)
	70	20	(1)	20	(1)	20	(1)
	80	40	(2)	40	(2)	30	(1)
	90	40	(1)	40	(1)	40	(1)
STATE MODEL		20	(3)	10	(1)	10	(1)
CRDS AGGR.		20	(2)	20	(2)	10	(1)
REGION CRDS AGGR.		10	(1)	10	(1)	10	(1)
STATES AGGR.		10	(1)	10	(1)	10	(1)

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

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS

STATE	CRD	STRAW MAN RD	STRAW MAN RANK	MODEL THOMPSON RD	MODEL THOMPSON RANK	CEAS RD	CEAS RANK
IOWA	10	-17.4	(2)	-15.4	(1)	18.2	(3)
	20	19.6	(3)	14.9	(2)	13.4	(1)
	30	15.8	(3)	-14.0	(2)	10.9	(1)
	40	25.4	(3)	18.0	(2)	-6.7	(1)
	50	28.0	(3)	19.7	(1)	20.7	(2)
	60	27.1	(2)	11.9	(1)	28.6	(3)
	70	26.5	(2)	27.0	(3)	12.7	(1)
	80	57.4	(3)	46.3	(2)	41.2	(1)
	90	38.1	(3)	29.2	(2)	16.7	(1)
STATE MODEL		23.9	(3)	16.5	(2)	-10.9	(1)
CRDS AGGR.		23.9	(3)	18.6	(2)	14.9	(1)
ILLINOIS	10	41.2	(3)	26.5	(1)	37.1	(2)
	20	26.5	(3)	20.6	(1)	22.4	(2)
	30	42.8	(3)	31.9	(1)	34.3	(2)
	40	52.7	(3)	34.1	(1)	38.3	(2)
	50	36.9	(3)	24.4	(2)	23.3	(1)
	60	34.3	(3)	21.9	(1)	23.0	(2)
	70	36.8	(3)	19.1	(1)	28.9	(2)
	80	26.6	(3)	14.9	(1)	20.8	(2)
	90	26.6	(3)	25.8	(2)	19.2	(1)
STATE MODEL		37.6	(3)	21.8	(1)	22.4	(2)
CRDS AGGR.		37.0	(3)	23.6	(1)	27.3	(2)
INDIANA	10	26.2	(3)	-15.2	(2)	-11.6	(1)
	20	30.2	(3)	-21.0	(2)	-12.6	(1)
	30	24.5	(3)	-21.6	(2)	13.2	(1)
	40	47.1	(3)	24.5	(1)	25.8	(2)
	50	27.5	(3)	16.3	(1)	17.4	(2)
	60	20.7	(2)	-18.5	(1)	23.1	(3)
	70	24.7	(3)	12.0	(1)	17.2	(2)
	80	33.8	(3)	22.5	(2)	-18.8	(1)
	90	33.1	(3)	24.8	(2)	13.7	(1)
STATE MODEL		28.0	(3)	14.9	(1)	16.1	(2)
CRDS AGGR.		28.0	(3)	-14.9	(2)	11.9	(1)
REGION CRDS AGGR.		29.9	(3)	19.5	(1)	19.5	(1)
STATES AGGR.		30.5	(3)	18.4	(2)	14.4	(1)

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

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN RD	RANK	THOMPSON RD	RANK	CEAS RD	RANK
IOWA	10	17.0	(3)	14.1	(2)	-13.0	(1)
	20	7.4	(2)	-6.8	(1)	7.9	(3)
	30	-14.4	(3)	-10.6	(2)	-10.0	(1)
	40	16.5	(3)	16.2	(2)	6.0	(1)
	50	16.2	(3)	10.0	(2)	-7.8	(1)
	60	11.9	(3)	10.6	(1)	11.5	(2)
	70	13.1	(2)	14.6	(3)	8.1	(1)
	80	-12.7	(3)	-10.0	(1)	11.5	(2)
	90	-9.5	(2)	-9.3	(1)	-11.7	(3)
STATE MODEL		12.5	(3)	-10.9	(2)	10.7	(1)
CRDS AGGR.		12.5	(3)	8.7	(2)	-3.7	(1)
ILLINOIS	10	-12.8	(2)	-12.8	(2)	6.3	(1)
	20	-16.6	(2)	-18.1	(3)	-14.0	(1)
	30	-10.3	(1)	-11.5	(2)	-16.6	(3)
	40	-9.6	(3)	-9.3	(2)	6.6	(1)
	50	-12.5	(3)	-11.7	(2)	9.7	(1)
	60	-11.6	(1)	-12.8	(3)	-12.0	(2)
	70	-12.7	(1)	-14.5	(3)	12.9	(2)
	80	-14.2	(2)	-12.1	(1)	-15.6	(3)
	90	-20.5	(2)	20.9	(3)	18.7	(1)
STATE MODEL		-10.9	(3)	-8.1	(2)	8.0	(1)
CRDS AGGR.		-11.7	(2)	-12.1	(3)	-7.6	(1)
INDIANA	10	-12.0	(2)	14.0	(3)	11.0	(1)
	20	-15.5	(2)	-19.5	(3)	-7.0	(1)
	30	-20.4	(3)	-16.9	(2)	-12.2	(1)
	40	-12.9	(1)	-16.0	(3)	-14.0	(2)
	50	-12.7	(2)	-13.1	(3)	-9.0	(1)
	60	-10.8	(1)	-17.9	(3)	-11.6	(2)
	70	16.7	(3)	10.8	(2)	-10.6	(1)
	80	27.6	(3)	21.5	(2)	17.9	(1)
	90	30.4	(3)	19.3	(2)	-13.3	(1)
STATE MODEL		-12.0	(3)	9.1	(2)	-7.2	(1)
CRDS AGGR.		-12.0	(3)	10.1	(2)	-8.8	(1)
REGION CRDS AGGR.		-8.5	(2)	-9.3	(3)	-5.2	(1)
STATES AGGR.		-8.1	(2)	-8.6	(3)	8.1	(1)

Figure 6. Letter indicates the model(s) with smallest percent of test years (1970-1979) having absolute value of the relative difference greater than ten percent. Darker shades indicate CRDs with greater production (S = Straw man, T = Thompson, C = CEAS).

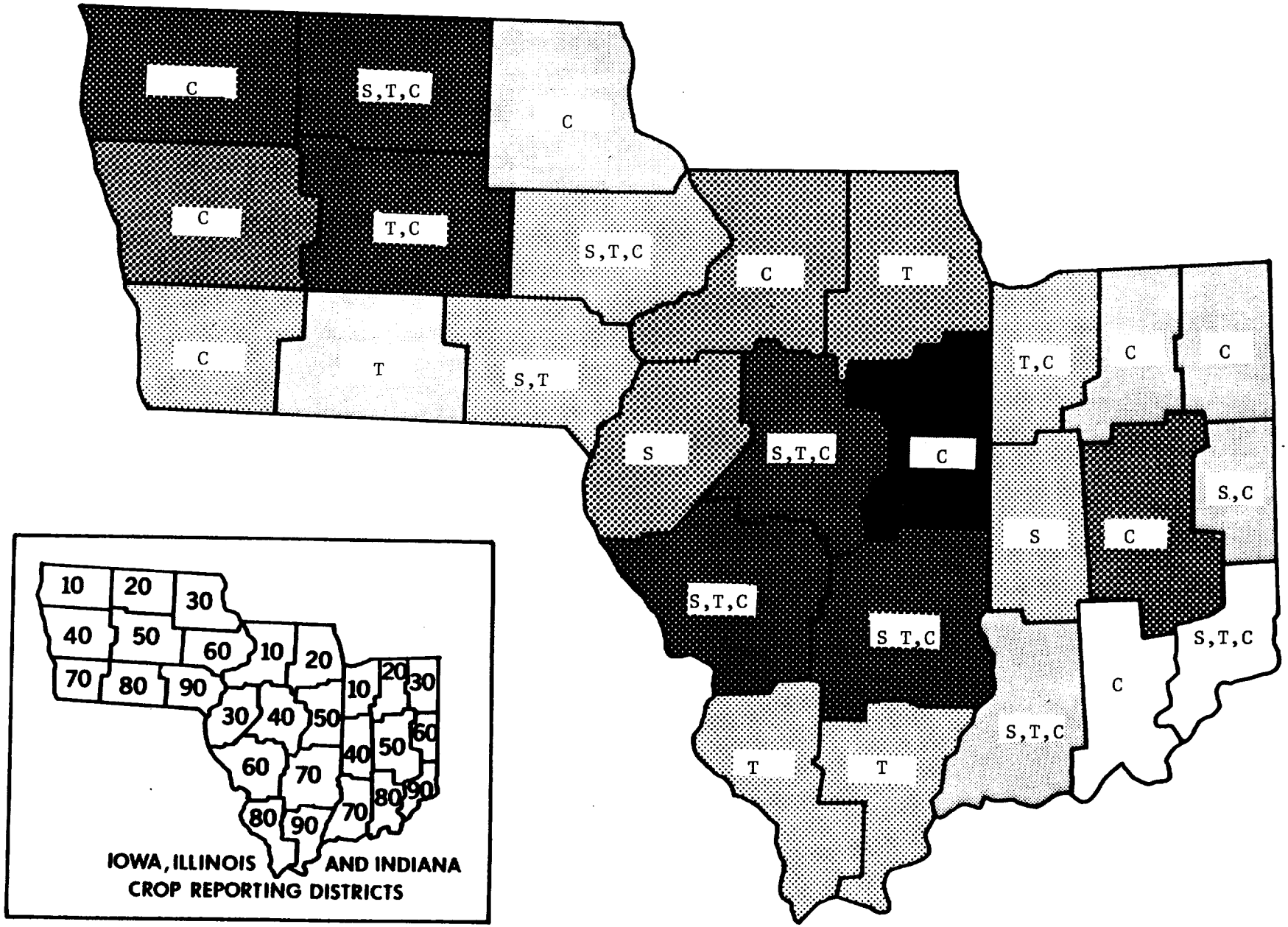
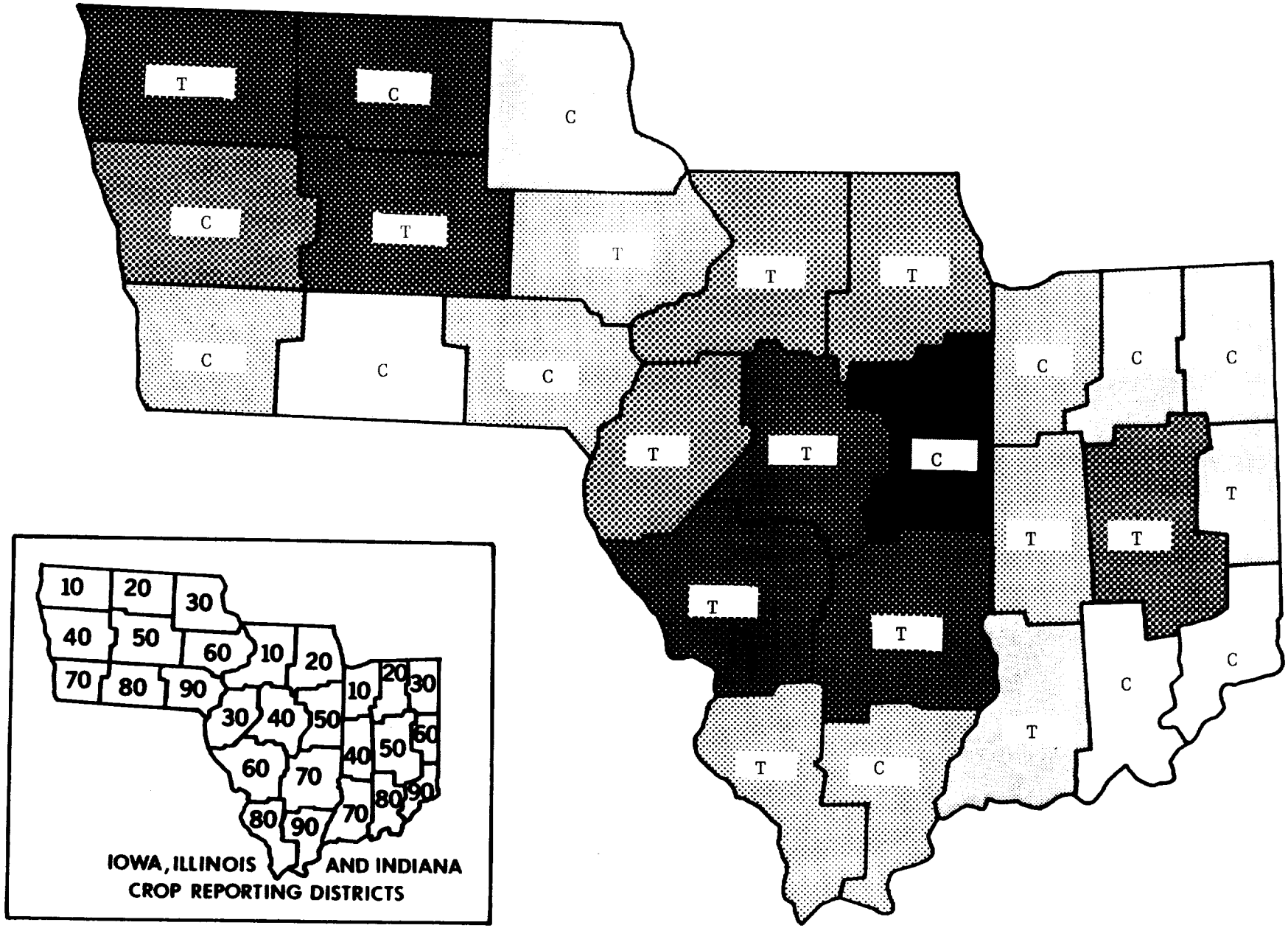


Figure 7. Letter indicates the soybean model with smallest value of the largest absolute relative difference during the test years 1970-1979. Darker shades indicate CRDs with higher production (S = Straw man, T = Thompson, C = CEAS).



of its largest |rd|. All three states had low yields in 1974. The section of the Appendix, Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years, provides information on individual test years.

In 17 of 27 CRDs (63%), the CEAS model has the smallest value of the next largest relative difference (Figure 8) and performs better in some of the higher production areas. The CEAS model also performs the best at the state and regional levels. There is very little difference at the CRD level between the Thompson and straw man models. The Thompson model performs better than the straw man model at the state level, but the situation is reversed at the regional level.

Indicators of Yield Reliability Based on Y and $\hat{Y}$ Show the CEAS Model Performing Better

Plots of the actual and predicted yields over the ten year test period for each state model are displayed in Figures 9-11. The model values and the comparative ranks of the indicators of yield reliability based on Y and $\hat{Y}$ are given in Tables 8, 9, and 10. These indicators demonstrate the correspondence between actual and predicted yields.

The best performing model will have the largest value for the percent of years in which the direction of change from the previous year and from the average of the previous three years in the $\hat{Y}$'s agrees with the Y's and for the correlation coefficient between the actual and predicted yields.

Based on correctness of direction of change from the previous year, the CEAS model performs somewhat better at the CRD level in Iowa and Indiana and at the state level in Iowa, while the Thompson-type model performs better at the CRD level in Illinois and at the regional level. Results at the state level in Illinois and Indiana are mixed. Figure 12 shows the highest ranking model(s) for each CRD.

Rankings based on correctness of direction of change from the average of the three previous years show the straw man model performs the worst with very little difference between the Thompson and CEAS models (Figure 13).

The Pearson correlation coefficient is closest to +1 for the CEAS model in 17 of 27 CRDs (63%) (Figure 14). The CEAS model also ranks first at the state and regional levels. The straw man model performs worst at all levels.

Statistical Tests Based on $d=\hat{Y}-Y$ Favor the CEAS Model

The results of the parametric and nonparametric paired-sample statistical tests are given in Tables 11, 12, and 13. The results for the compairson of the straw man model with the Thompson-type model are shown in Table 11.

The parametric test results show significant differences at the CRD level between the straw man and Thompson model five times, with the Thompson model performing better in each of those instances. No significant differences were found at state or regional levels, but state model results are close in Iowa and Indiana with somewhat more difference in Illinois.

Figure 8. Letter indicates the model with smallest value of the next largest absolute relative difference during the test years 1970-1979. Darker shades indicate CRDs with higher production (S = Straw man, T = Thompson, C = CEAS).

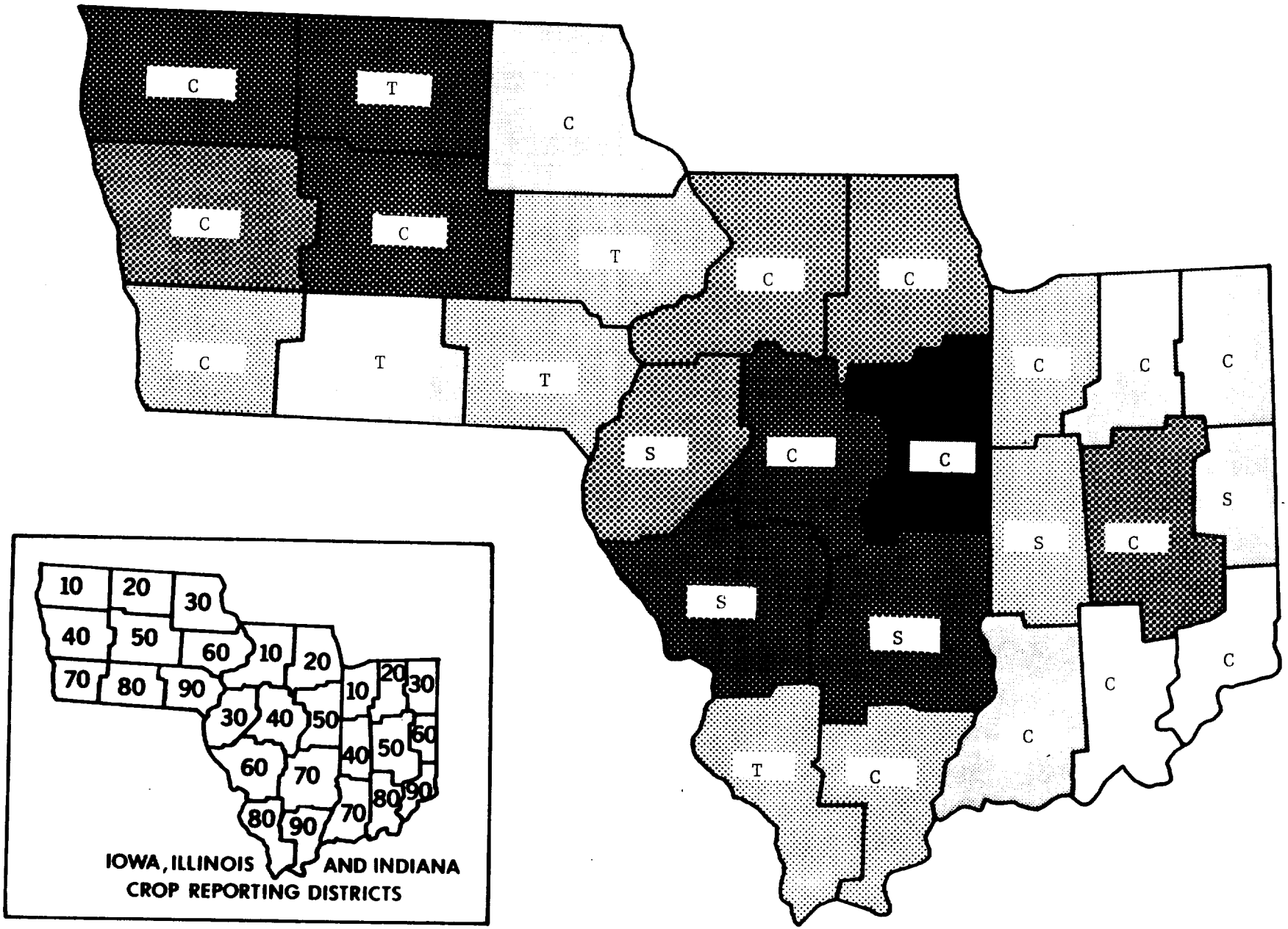


Figure 9

Iowa State Model, Reported and Predicted Soybean Yields
for the Test Years 1970-1979 (Quintals/Hectare)

A = Reported Yield
S = Straw Man, C = CEAS, T = Thompson-type

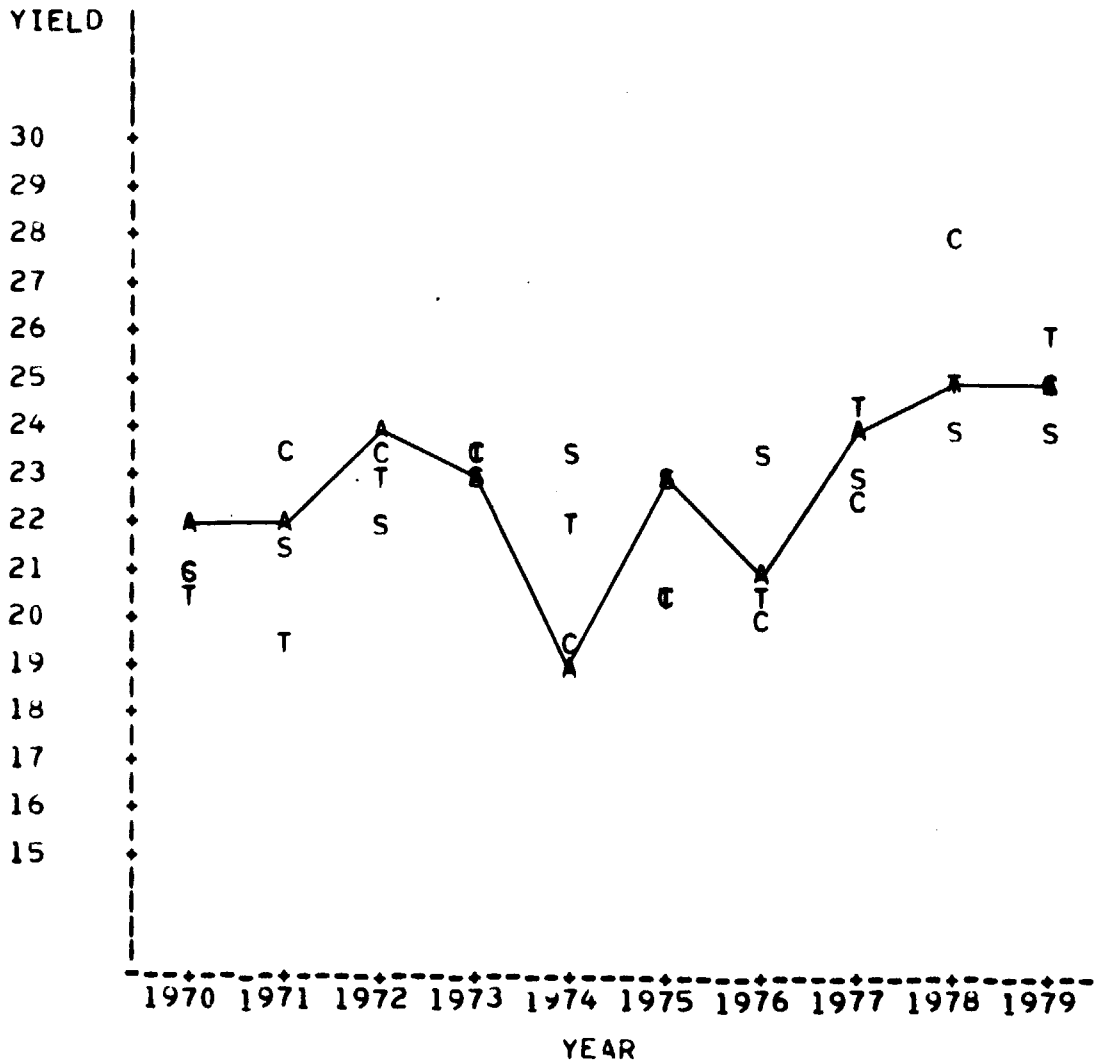


Figure 10

Illinois State Model, Reported and Predicted Soybean Yields
for the Test Years 1970-1979 (Quintals/Hectare)

A = Reported Yield
S = Straw Man, C = CEAS, T = Thompson-type

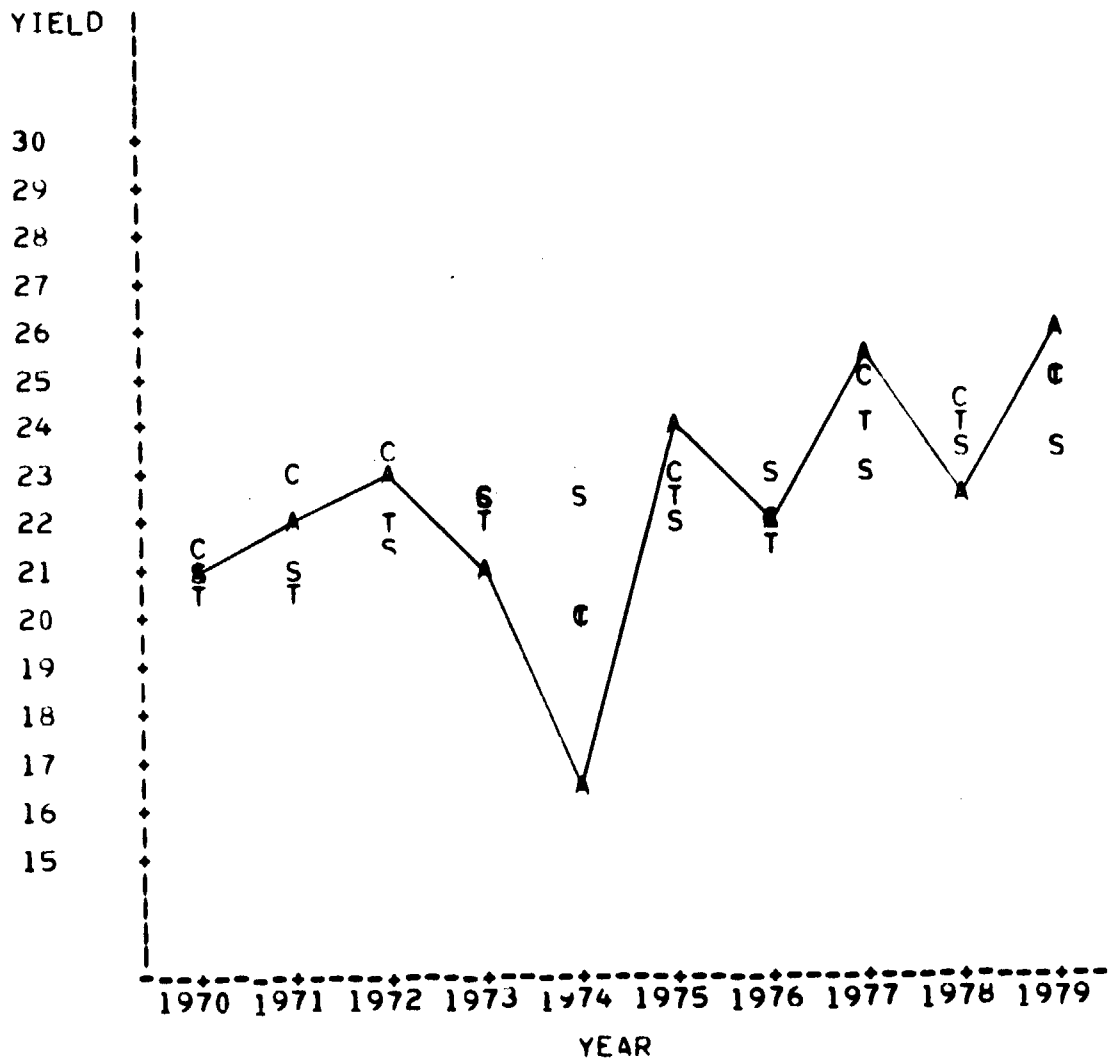


Figure 11

Indiana State Model, Reported and Predicted Soybean Yields for the Test Years 1970-1979 (Quintals/Hectare)

A = Reported Yield
S = Straw Man, C = CEAS, T = Thompson-type

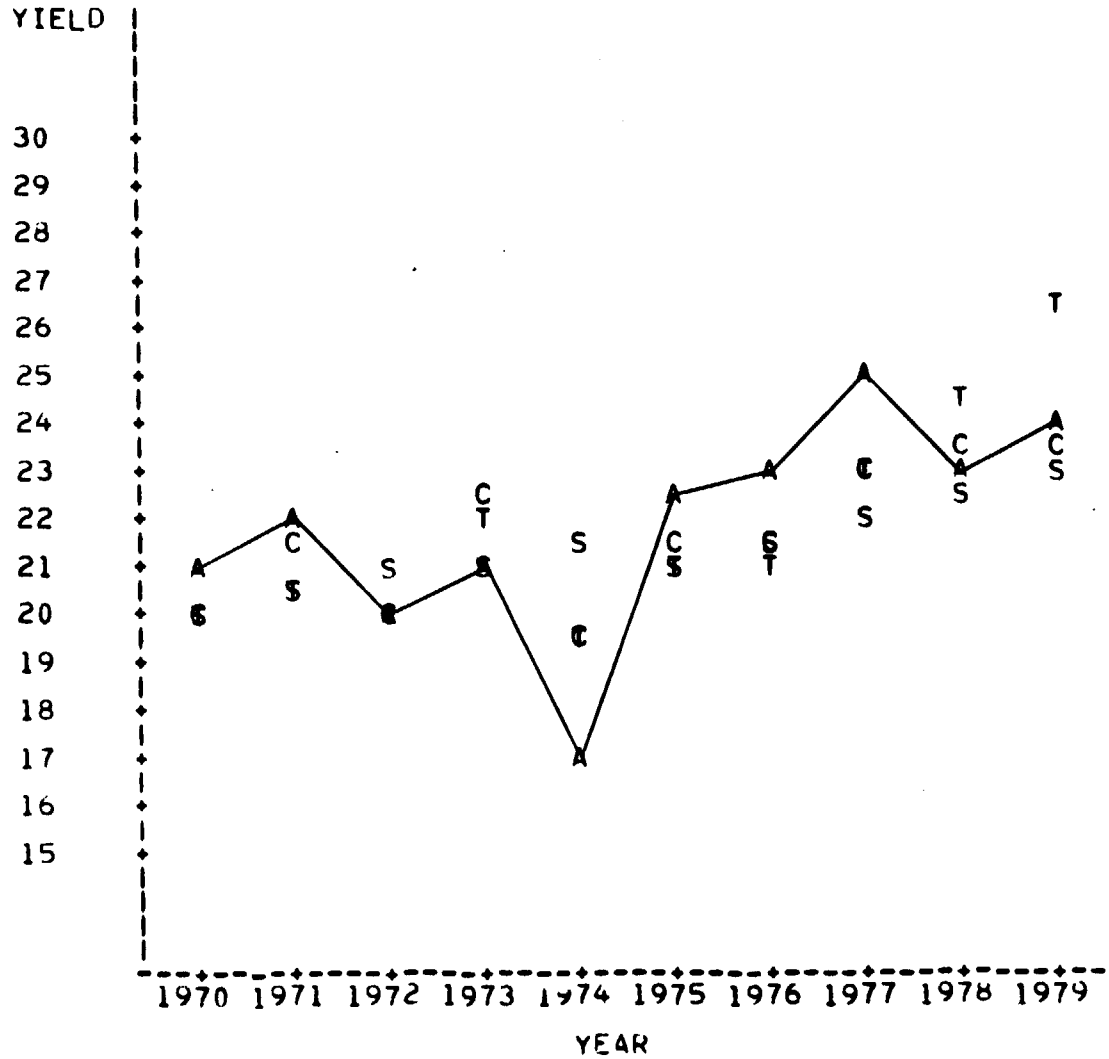


TABLE 8
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS THE DIRECTION OF CHANGE
FROM THE PREVIOUS YEAR IS CORRECT
DURING INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN %	STRAW MAN RANK	THOMPSON %	THOMPSON RANK	CEAS %	CEAS RANK
IOWA	10	22	(3)	67	(1)	67	(1)
	20	22	(3)	78	(1)	33	(2)
	30	22	(3)	67	(1)	44	(2)
	40	22	(3)	67	(2)	89	(1)
	50	22	(3)	78	(2)	89	(1)
	60	22	(3)	78	(2)	89	(1)
	70	11	(3)	22	(2)	78	(1)
	80	44	(3)	56	(2)	67	(1)
	90	44	(3)	67	(1)	56	(2)
STATE MODEL		22	(3)	44	(2)	56	(1)
CRDS AGGR.		22	(3)	67	(2)	78	(1)
ILLINOIS	10	22	(3)	89	(1)	89	(1)
	20	22	(3)	78	(1)	44	(2)
	30	33	(3)	56	(1)	56	(1)
	40	22	(3)	67	(2)	89	(1)
	50	33	(3)	67	(2)	78	(1)
	60	11	(3)	67	(1)	67	(1)
	70	44	(2)	67	(1)	44	(2)
	80	11	(3)	67	(1)	44	(2)
	90	22	(3)	89	(1)	56	(2)
STATE MODEL		11	(3)	89	(2)	100	(1)
CRDS AGGR.		11	(3)	89	(1)	78	(2)
INDIANA	10	44	(3)	67	(2)	78	(1)
	20	44	(2)	44	(2)	78	(1)
	30	56	(3)	67	(2)	89	(1)
	40	44	(3)	56	(2)	67	(1)
	50	44	(3)	56	(2)	89	(1)
	60	44	(2)	44	(2)	100	(1)
	70	33	(3)	56	(2)	67	(1)
	80	11	(3)	56	(1)	22	(2)
	90	33	(3)	56	(1)	44	(2)
STATE MODEL		56	(3)	78	(1)	67	(2)
CRDS AGGR.		56	(2)	56	(2)	89	(1)
REGION CRDS AGGR.		33	(3)	89	(1)	67	(2)
STATES AGGR.		33	(3)	67	(1)	56	(2)

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

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN %	RANK	THOMPSON %	RANK	CEAS %	RANK
IOWA	10	71	(3)	86	(1)	86	(1)
	20	71	(1)	57	(3)	71	(1)
	30	57	(1)	43	(3)	57	(1)
	40	57	(3)	71	(2)	100	(1)
	50	43	(3)	86	(1)	86	(1)
	60	43	(3)	100	(1)	57	(2)
	70	29	(3)	71	(1)	71	(1)
	80	29	(3)	57	(1)	43	(2)
	90	57	(3)	86	(1)	86	(1)
STATE MODEL		71	(3)	86	(1)	86	(1)
CRDS AGGR.		71	(2)	57	(3)	100	(1)
ILLINOIS	10	29	(3)	71	(1)	57	(2)
	20	43	(3)	57	(2)	71	(1)
	30	43	(2)	57	(1)	29	(3)
	40	43	(3)	57	(1)	57	(1)
	50	43	(3)	57	(1)	57	(1)
	60	43	(3)	57	(1)	57	(1)
	70	43	(3)	57	(1)	57	(1)
	80	29	(3)	71	(1)	71	(1)
	90	29	(3)	86	(1)	86	(1)
STATE MODEL		43	(3)	57	(2)	71	(1)
CRDS AGGR.		43	(3)	57	(1)	57	(1)
INDIANA	10	43	(3)	71	(1)	71	(1)
	20	57	(3)	71	(2)	100	(1)
	30	57	(3)	71	(2)	100	(1)
	40	57	(2)	57	(2)	71	(1)
	50	57	(3)	86	(2)	100	(1)
	60	71	(1)	71	(1)	71	(1)
	70	29	(3)	71	(1)	57	(2)
	80	29	(3)	86	(1)	71	(2)
	90	14	(3)	43	(2)	71	(1)
STATE MODEL		57	(3)	86	(1)	86	(1)
CRDS AGGR.		57	(3)	86	(1)	86	(1)
REGION CRDS AGGR.		57	(3)	86	(1)	71	(2)
STATES AGGR.		57	(1)	57	(1)	57	(1)

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

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

STATE	CRD	MODEL STRAW MAN R	RANK	THOMPSON R	RANK	CEAS R	RANK
IOWA	10	0.43	(3)	0.70	(2)	0.75	(1)
	20	0.33	(3)	0.52	(2)	0.56	(1)
	30	0.47	(3)	0.69	(2)	0.79	(1)
	40	0.36	(3)	0.77	(2)	0.96	(1)
	50	-0.16	(3)	0.78	(1)	0.76	(2)
	60	0.13	(3)	0.83	(1)	0.49	(2)
	70	-0.56	(3)	0.39	(2)	0.68	(1)
	80	-0.59	(3)	0.32	(2)	0.56	(1)
	90	0.03	(3)	0.53	(2)	0.67	(1)
STATE MODEL		0.27	(3)	0.69	(2)	0.79	(1)
CRDS AGGR.		0.26	(3)	0.65	(2)	0.86	(1)
ILLINOIS	10	0.15	(3)	0.77	(1)	0.73	(2)
	20	0.32	(3)	0.58	(2)	0.61	(1)
	30	0.04	(3)	0.48	(1)	0.24	(2)
	40	0.04	(3)	0.76	(2)	0.83	(1)
	50	0.11	(3)	0.64	(2)	0.82	(1)
	60	0.24	(3)	0.63	(1)	0.61	(2)
	70	0.50	(3)	0.73	(1)	0.62	(2)
	80	0.33	(3)	0.73	(1)	0.58	(2)
	90	0.08	(3)	0.73	(2)	0.74	(1)
STATE MODEL		0.22	(3)	0.81	(2)	0.89	(1)
CRDS AGGR.		0.20	(3)	0.75	(2)	0.81	(1)
INDIANA	10	0.33	(3)	0.67	(2)	0.90	(1)
	20	0.40	(3)	0.53	(2)	0.91	(1)
	30	0.49	(3)	0.64	(2)	0.89	(1)
	40	0.21	(3)	0.54	(2)	0.69	(1)
	50	0.46	(3)	0.72	(2)	0.83	(1)
	60	0.50	(2)	0.61	(1)	0.49	(3)
	70	0.38	(3)	0.72	(1)	0.67	(2)
	80	-0.77	(3)	0.57	(1)	0.54	(2)
	90	-0.70	(3)	0.48	(2)	0.54	(1)
STATE MODEL		0.44	(3)	0.74	(2)	0.82	(1)
CRDS AGGR.		0.44	(3)	0.70	(2)	0.91	(1)
REGION CRDS AGGR.		0.35	(3)	0.73	(2)	0.82	(1)
STATES AGGR.		0.32	(3)	0.75	(2)	0.79	(1)

Figure 12. Letter indicates the model(s) with largest percent of test years (1970-1979) having agreement in direction of change from the previous year between predicted and actual yields. Darker shades indicate CRDs with higher production (T = Thompson, C = CEAS).

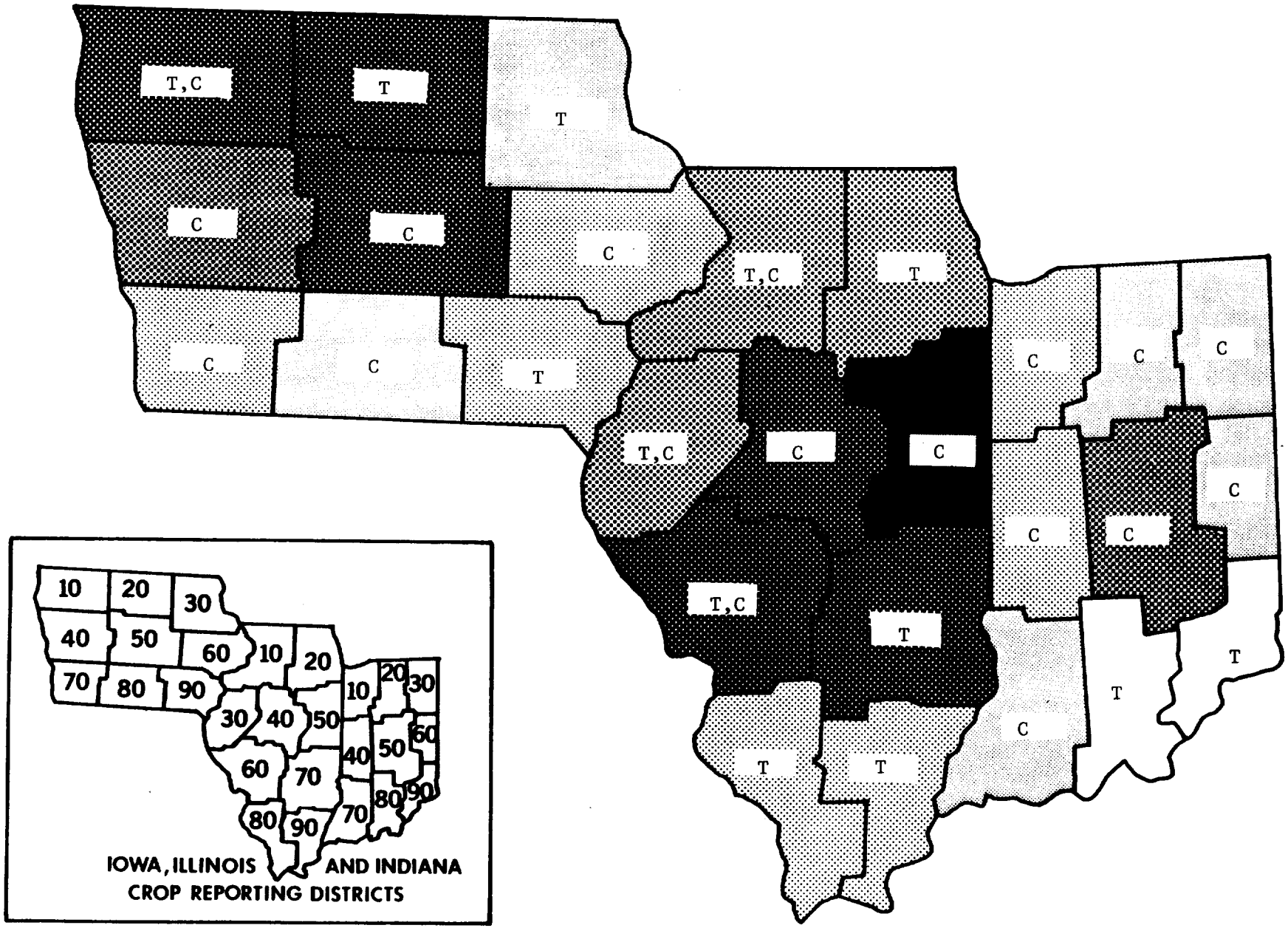


Figure 13. Letter indicates the model(s) with largest percent of test years (1970-1979) having agreement in the direction of change from the previous three year average between predicted and actual yields. Darker shades indicate CRDs with higher production (S = Straw man, T = Thompson, C = CEAS).

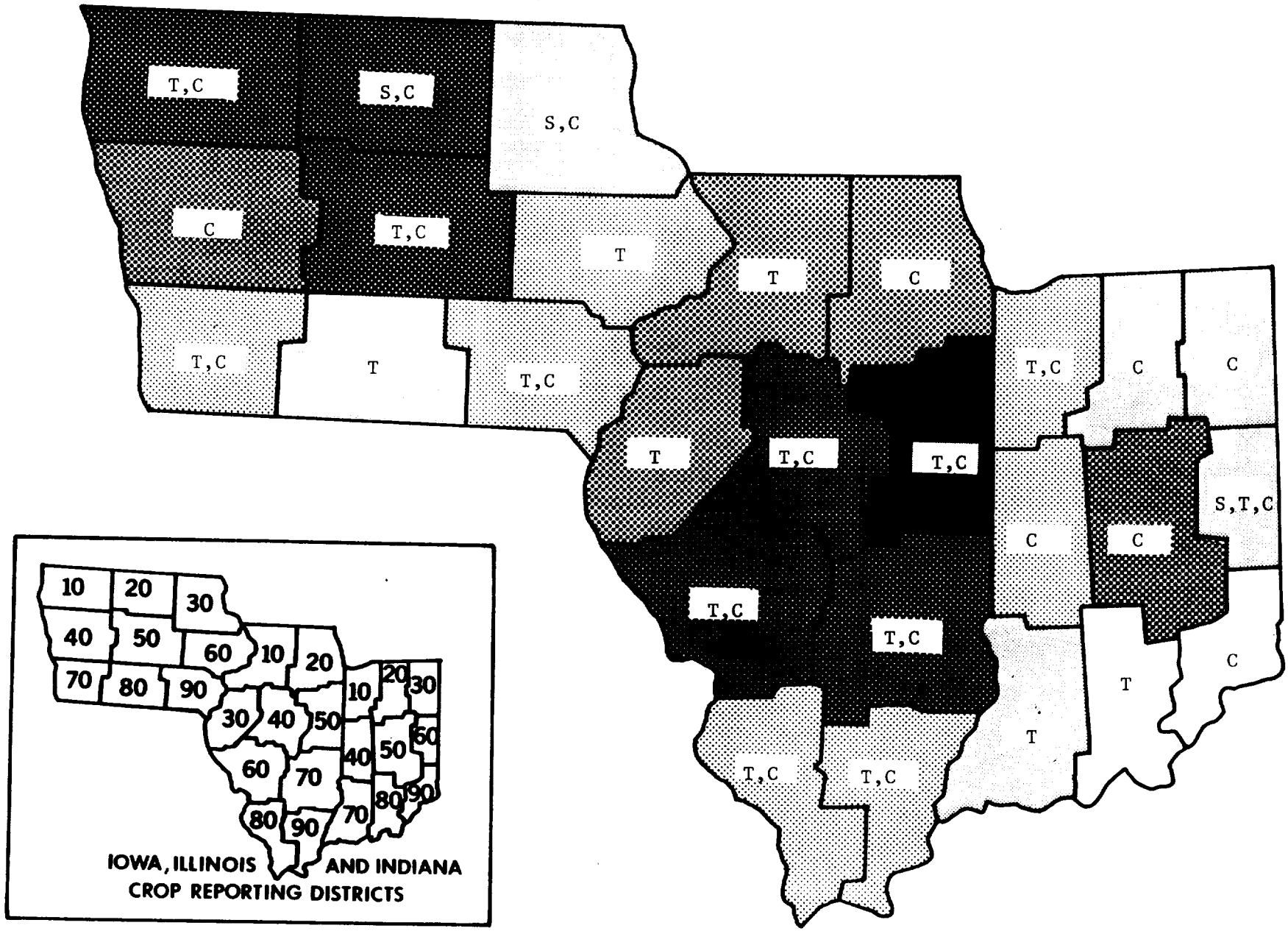


Figure 14. Letter indicates the model with the largest correlation coefficient between actual and predicted yields over the test years (1970-1979). Darker shades indicate CRDs with higher production (T = Thompson, C = CEAS).

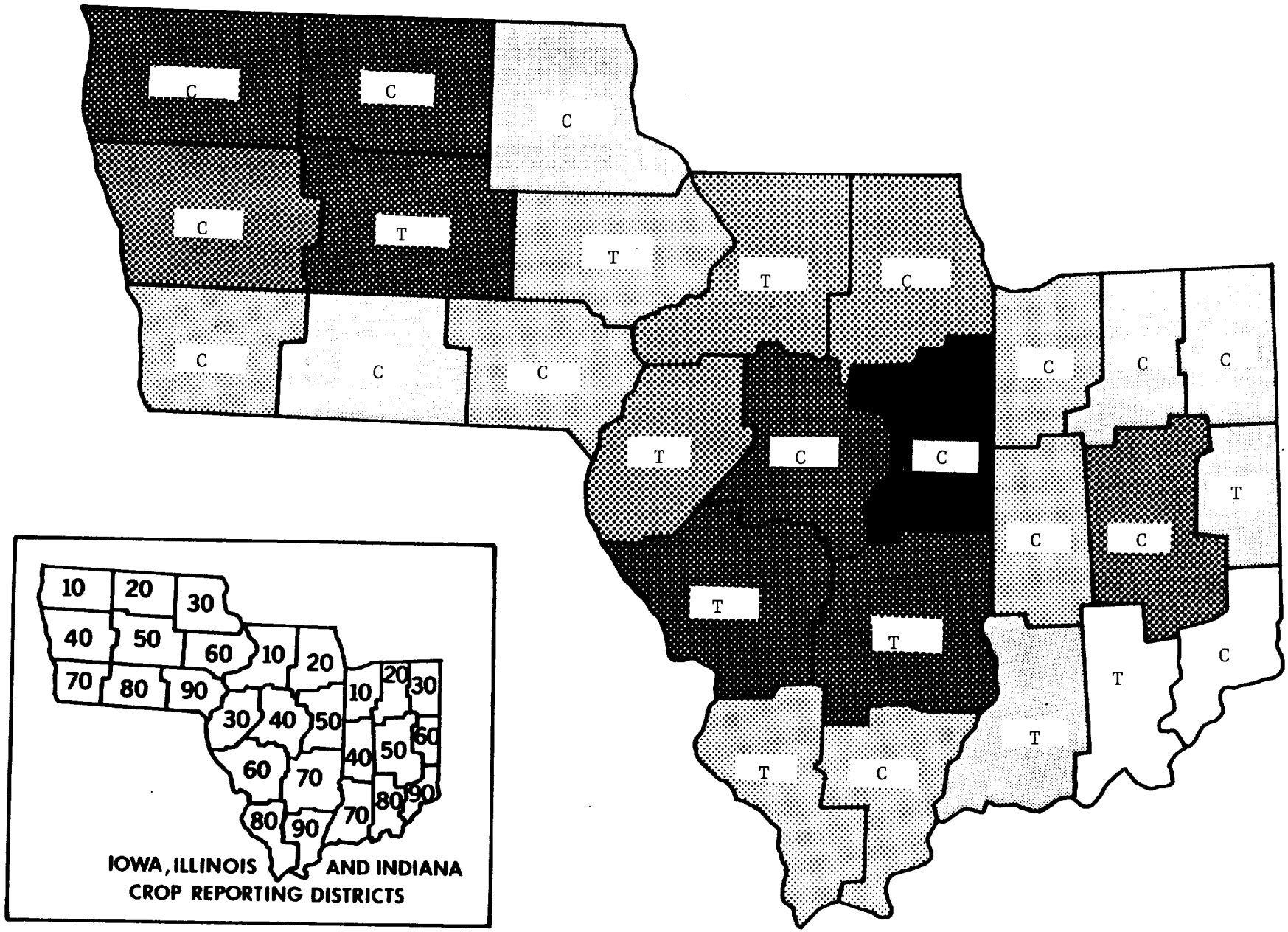


TABLE 11
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
STRAW MAN MODEL WITH THOMPSON-TYPE MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

		PARAMETRIC T-TEST				NONPARAMETRIC RANK TEST			
		AVERAGE |D| MODEL		DIFFERENCE OF AVERAGES		% SMALLER |D| MODEL		DIFFERENCE OF PERCENTAGE	
STATE	CRD	STRMAN	THOMPS			STRMAN	THOMPS		
IOWA	10	2.3	1.9	0.4		40	60	20	
	20	1.1	1.2	0.1		50	50	0	
	30	1.7	1.5	0.3		20	80	60	
	40	2.0	1.4	0.6	**	30	70	40	**
	50	2.1	1.3	0.8	**	20	80	60	**
	60	1.5	1.0	0.5		40	50	10	
	70	1.7	1.5	0.2		40	60	20	
	80	1.8	1.6	0.2		50	50	0	
	90	1.9	1.7	0.2		50	40	10	
STATE MODEL		1.3	1.3	0.1		40	60	20	
CRDS AGGR.		1.3	1.1	0.2		50	50	0	
ILLINOIS	10	2.1	1.5	0.6	*	30	60	30	*
	20	2.0	1.8	0.3		40	60	20	
	30	2.2	2.0	0.2		60	40	20	
	40	2.2	1.8	0.5		20	50	30	*
	50	2.1	1.7	0.4		20	70	50	*
	60	2.0	1.9	0.1		50	50	0	
	70	2.0	1.8	0.2		50	50	0	
	80	2.1	1.6	0.5		30	70	40	
	90	2.1	1.4	0.7	**	30	70	40	**
STATE MODEL		2.0	1.4	0.6		30	70	40	*
CRDS AGGR.		2.0	1.6	0.4		40	60	20	
INDIANA	10	1.7	1.5	0.2		40	40	0	
	20	2.2	2.0	0.2		30	60	30	
	30	2.0	2.0	0.0		50	40	10	
	40	1.7	2.0	0.3		80	20	60	*
	50	2.1	1.4	0.8	***	20	80	60	***
	60	1.7	1.9	0.2		50	50	0	
	70	1.4	1.1	0.3		40	60	20	
	80	2.1	1.5	0.5		40	60	20	
	90	2.3	1.9	0.4		40	60	20	
STATE MODEL		1.6	1.4	0.2		40	60	20	
CRDS AGGR.		1.6	1.5	0.1		60	40	20	
REGION CRDS AGGR.		1.4	1.1	0.3		40	50	10	
STATES AGGR.		1.4	1.2	0.3		50	50	0	

The more reliable model in each CRD according to the average value of $|d|$ is presented in Figure 15. The Thompson model performs better in 23 of 27 CRDs (85%), in 2 of 3 state level models, and at the regional level.

The nonparametric test results show more significant differences at the CRD level (8 of 27) and at the state level in Illinois, all but one favoring the Thompson model.

The better model in each CRD according to the percent of years with smaller $|d|$ is presented in Figure 16. The Thompson model performs better in 17 of 27 CRDs (63%), including many higher production CRDs, the straw man model performs better in 4 of 27 CRDs (15%) and the models are tied in 6 CRDs.

In summary, the results of the statistical tests for yield reliability indicate that the Thompson model performs better than the straw man model at the CRD level. The Thompson model performs somewhat better at the state level in Illinois with the results being close in Iowa, Indiana, and at the regional level.

The results of the comparison of the straw man model with the CEAS model are given in Table 12. Here there is more evidence of statistically significant differences between the two models.

The parametric test results show significant differences in 9 of 27 CRDs (33%), all favoring the CEAS model. The statistically significant differences at the state level favor the CEAS model. The CEAS model performs significantly better at the regional level aggregated from CRDs.

The better model in each CRD according to the average value of $|d|$ is displayed in Figure 17. The CEAS model performs better than the straw man model in 24 of 27 CRDs (93%).

The nonparametric test results show eleven CRDs (41%) with significant differences, all in favor of the CEAS model. Significant differences were found when aggregating CRD results to the state and regional levels.

The better model in each CRD based on the percent of years with smaller $|d|$ is presented in Figure 18. The CEAS model performs better than the straw man model in 20 of 27 CRDs (74%), the straw man model performs better in 4 of 27 CRDs (15%), and there were 3 ties.

To summarize, the CEAS model performs better than the straw man model at the CRD, state, and regional levels. Significant differences were found at all levels.

The results for the comparison of the Thompson model with the CEAS model are given in Table 13. There appears to be very little significant difference between the two models.

The parametric test results show a significant difference in only three Indiana CRDs, all favoring the CEAS model. The better model in each CRD according to the average value of $|d|$ is shown in Figure 19. The CEAS model performs better than the Thompson model in 17 of 27 CRDs (63%), although the results are quite

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

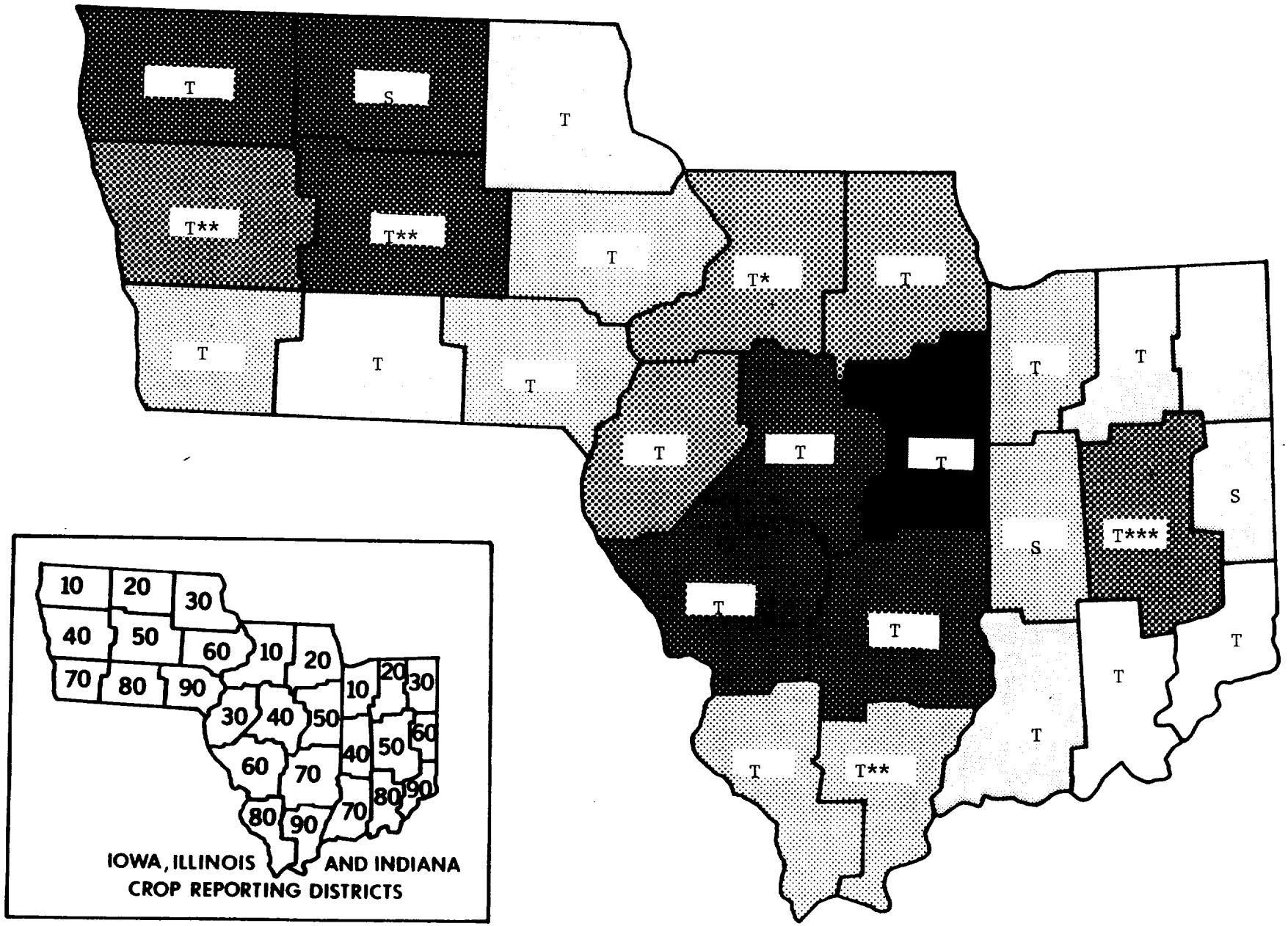


Figure 16. Comparison of Straw man and Thompson models to predict soybean yields based on the percent of test years (1970-1979) with smaller $|d| = |\hat{Y}-Y|$. Letter indicates model with larger percent. Blank denotes tie. Stars indicate the level of significance, none ($P > 0.10$), * ($0.05 < P < 0.10$), ** ($0.01 < P < 0.05$), *** ($P < 0.01$). Darker shades indicate CRDs with higher production (S = Straw man, T = Thompson).

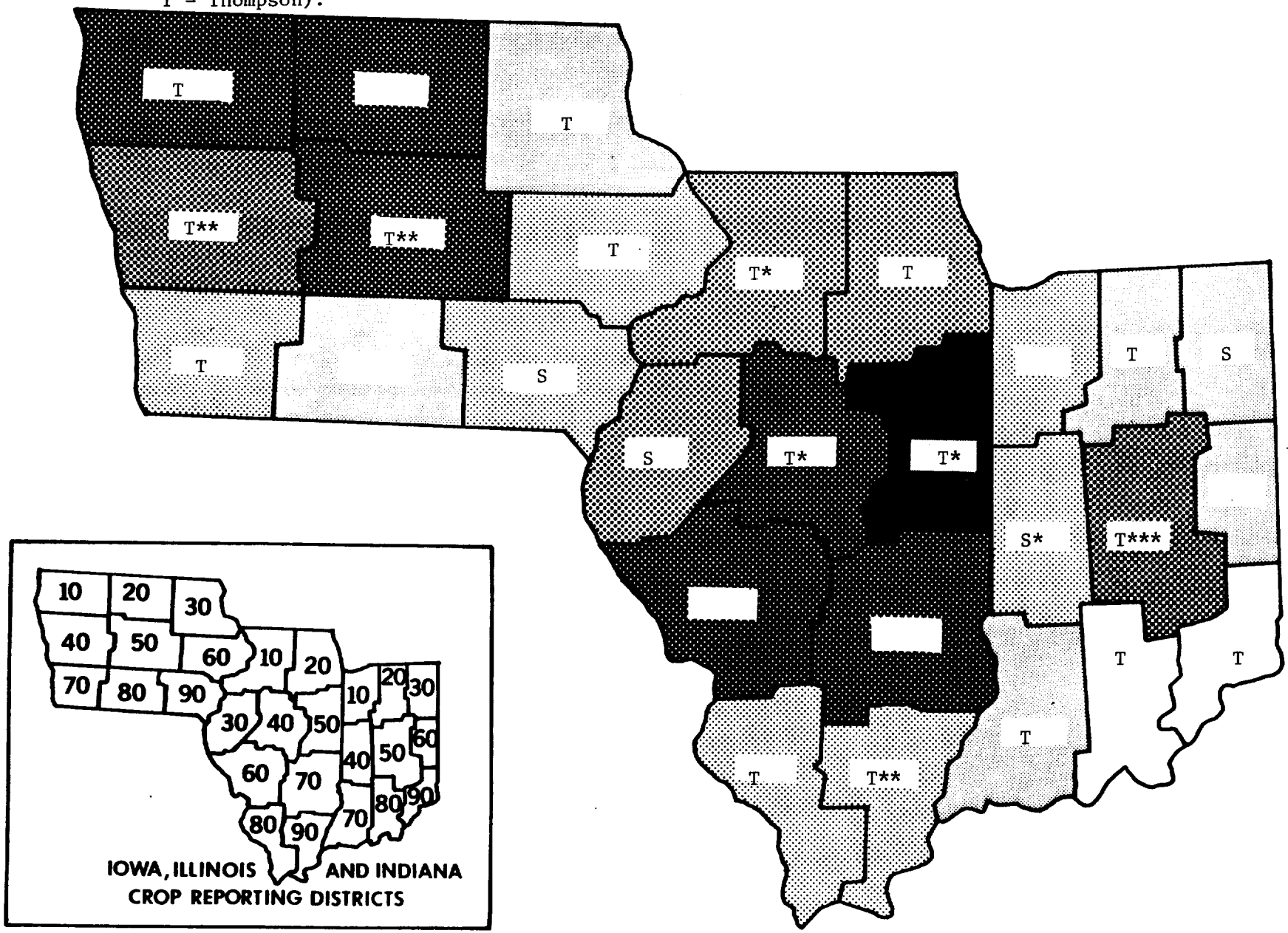


TABLE 12
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
STRAW MAN MODEL WITH CEAS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

		PARAMETRIC T-TEST			NONPARAMETRIC RANK TEST		
		AVERAGE |D| MODEL		DIFFERENCE OF AVERAGES	% SMALLER |D| MODEL		DIFFERENCE OF PERCENTAGE
STATE	CRD	STRMAN	CEAS		STRMAN	CEAS	
IOWA	10	2.3	1.7	0.6	40	60	20
	20	1.1	0.9	0.1	60	40	20
	30	1.7	1.2	0.5	30	70	40
	40	2.0	0.8	1.3 **	30	70	40 **
	50	2.1	1.2	0.9 **	40	60	20 **
	60	1.5	1.7	0.2	50	50	0
	70	1.7	1.2	0.5	30	70	40
	80	1.8	1.6	0.2	50	40	10
	90	1.9	1.5	0.4	40	60	20
STATE MODEL		1.3	1.3	0.1	60	40	20
CRDS AGGR.		1.3	0.7	0.7 **	20	60	40 **
ILLINOIS	10	2.1	1.5	0.7 **	20	70	50 **
	20	2.0	1.9	0.1	40	60	20
	30	2.2	2.1	0.2	20	70	50
	40	2.2	1.6	0.7 *	40	60	20 *
	50	2.1	1.4	0.7	30	60	30 *
	60	2.0	1.9	0.1	60	30	30
	70	2.0	2.0	0.0	40	60	20
	80	2.1	1.9	0.2	40	50	10
	90	2.1	1.5	0.6 **	20	70	50 **
STATE MODEL		2.0	1.2	0.7 *	30	70	40 **
CRDS AGGR.		2.0	1.4	0.5 **	30	70	40 **
INDIANA	10	1.7	1.2	0.5 *	20	80	60 **
	20	2.2	1.0	1.2 **	10	90	80 ***
	30	2.0	1.2	0.8 ***	0	90	90 ***
	40	1.7	1.6	0.1	60	40	20
	50	2.1	1.3	0.9 **	10	90	80 **
	60	1.7	1.3	0.3	20	70	50 *
	70	1.4	1.4	0.0	50	50	0
	80	2.1	1.4	0.7	50	50	0
	90	2.3	1.6	0.7	40	60	20
STATE MODEL		1.6	1.2	0.4	20	80	60 *
CRDS AGGR.		1.6	1.1	0.5 *	10	80	70 **
REGION CRDS AGGR.		1.4	1.0	0.5 *	20	80	60 **
STATES AGGR.		1.4	1.1	0.3	30	60	30

Figure 17. Comparison of Straw man and CEAS models to predict soybean yields based on the average of $|d| = |\hat{Y}-Y|$ for 1970-1979. Number indicates model with smaller average $|d|$. Blank denotes tie. Stars indicate the level of significance, none ($P > 0.10$), * ($0.05 < P < 0.10$), ** ($0.01 < P < 0.05$), *** ($P < 0.01$). Darker shades indicate CRDs with higher production (C = CEAS).

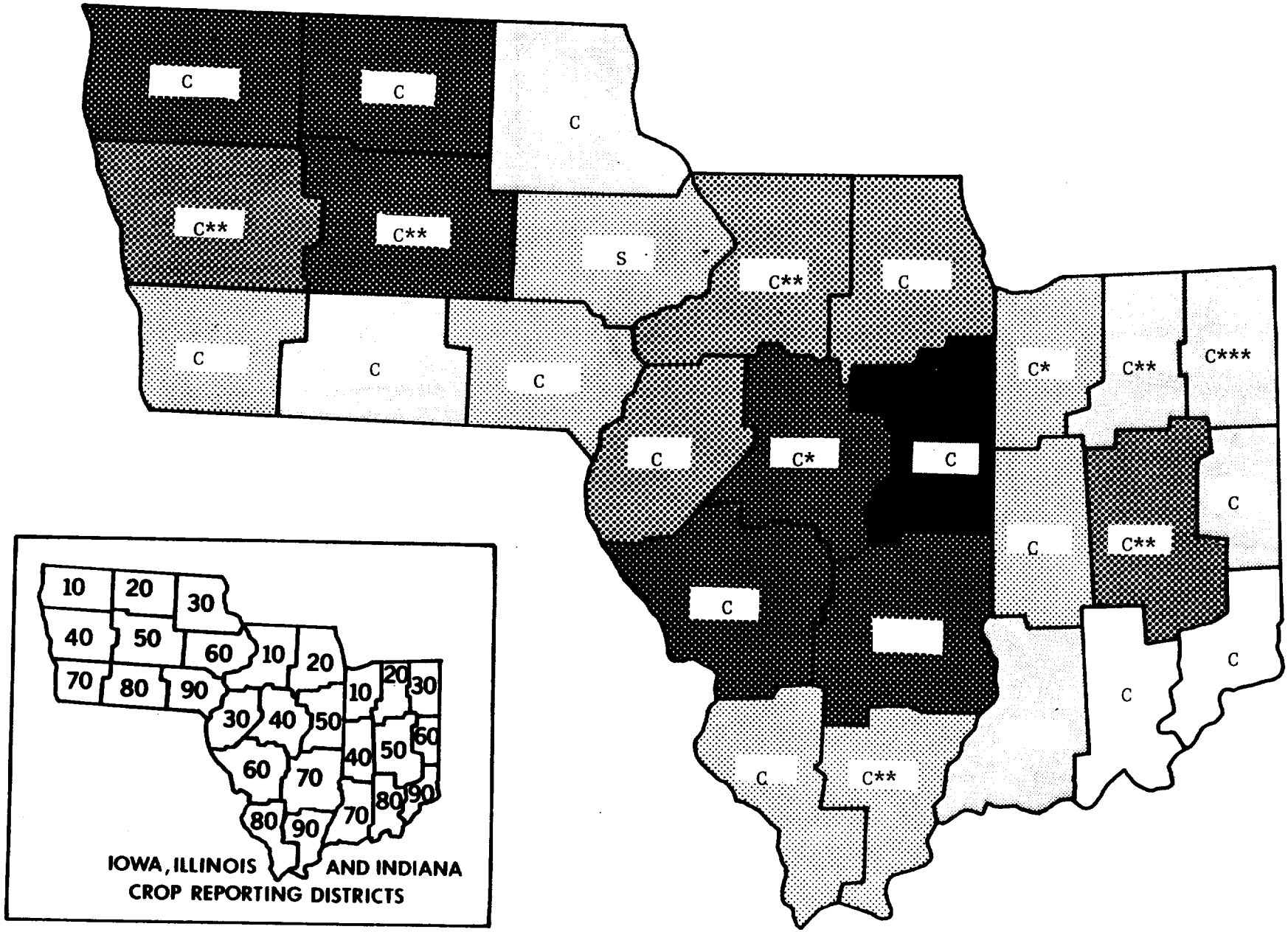


Figure 18. Comparison of Straw man and CEAS models to predict soybean yields based on the percent of test years (1970-1979) with smaller $|d| = |\hat{Y}-Y|$. Letter indicates model with larger percent. Blank denotes tie. Stars indicate the level of significance, none ($P > 0.10$), * ($0.05 < P < 0.10$), ** ($0.01 < P < 0.05$), *** ($P < 0.01$). Darker shades indicate CRDs with higher production (S = Straw man, C = CEAS).

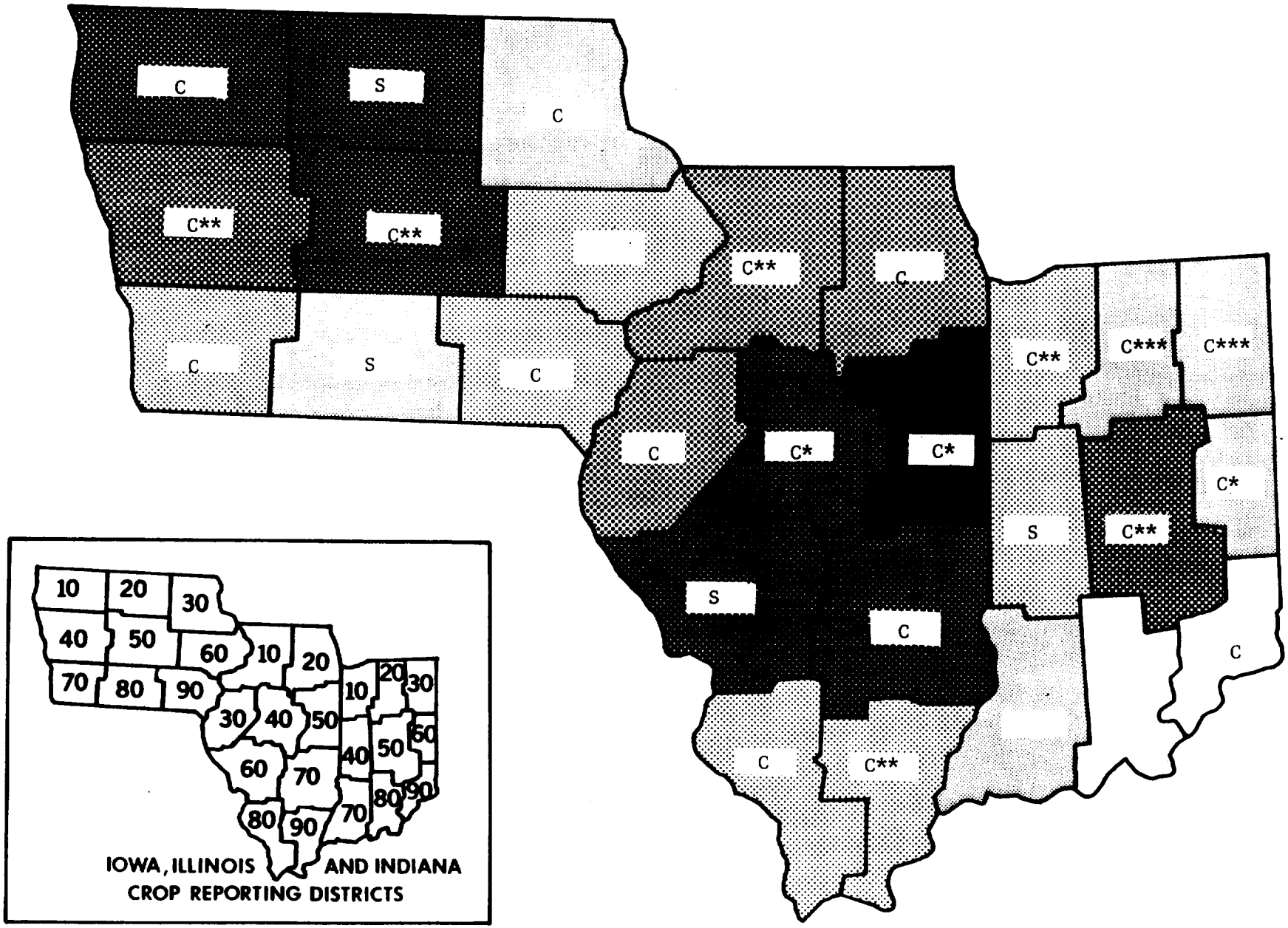
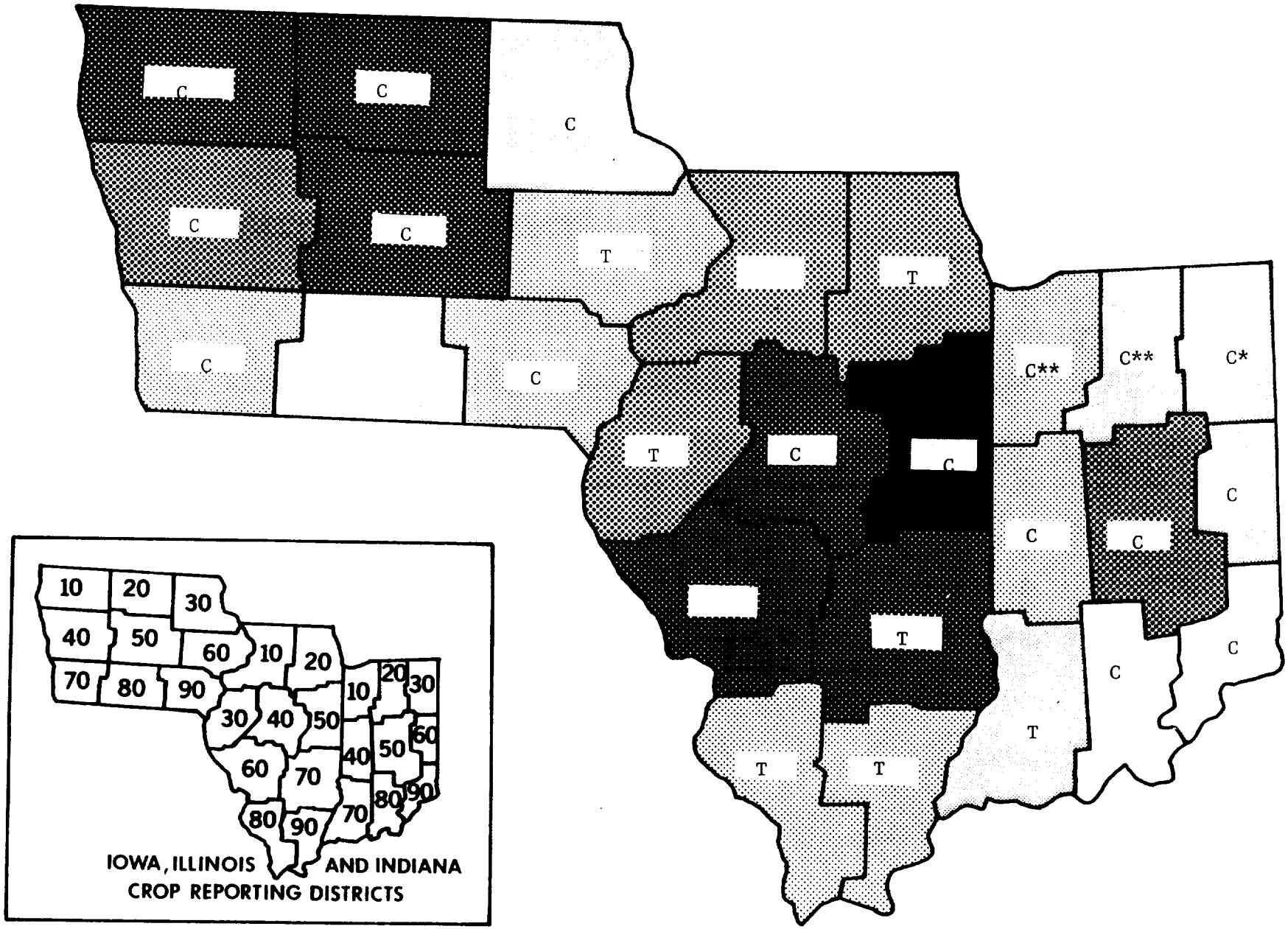


TABLE 13
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
THOMPSON-TYPE MODEL WITH CEAS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
SOYBEANS
IOWA, ILLINOIS, INDIANA

		PARAMETRIC T-TEST			NONPARAMETRIC RANK TEST		
		AVERAGE |D| MODEL		DIFFERENCE OF AVERAGES	% SMALLER |D| MODEL		DIFFERENCE OF PERCENTAGE
STATE	CRD	THOMPS	CEAS		THOMPS	CEAS	
IOWA	10	1.9	1.7	0.2	40	60	20
	20	1.2	0.9	0.3	40	60	20
	30	1.5	1.2	0.3	30	70	40
	40	1.4	0.8	0.7	30	70	40 *
	50	1.3	1.2	0.1	50	40	10
	60	1.0	1.7	0.7	60	40	20 *
	70	1.5	1.2	0.3	60	40	20
	80	1.6	1.6	0.1	60	40	20
	90	1.7	1.5	0.2	50	50	0
STATE MODEL		1.3	1.3	0.0	40	50	10
CRDS AGGR.		1.1	0.7	0.4 *	20	80	60 **
ILLINOIS	10	1.5	1.5	0.1	30	70	40
	20	1.8	1.9	0.1	60	40	20
	30	2.0	2.1	0.0	50	50	0
	40	1.8	1.6	0.2	50	50	0
	50	1.7	1.4	0.3	40	60	20
	60	1.9	1.9	0.0	50	50	0
	70	1.8	2.0	0.2	60	40	20
	80	1.6	1.9	0.3	70	20	50 *
	90	1.4	1.5	0.2	40	40	0
STATE MODEL		1.4	1.2	0.1	50	50	0
CRDS AGGR.		1.6	1.4	0.1	50	50	0
INDIANA	10	1.5	1.2	0.3 **	20	80	60 **
	20	2.0	1.0	1.0 **	0	80	80 ***
	30	2.0	1.2	0.8 *	10	70	60 **
	40	2.0	1.6	0.4	30	60	30 *
	50	1.4	1.3	0.1	40	50	10
	60	1.9	1.3	0.5	40	60	20
	70	1.1	1.4	0.3	50	40	10
	80	1.5	1.4	0.1	20	80	60
	90	1.9	1.6	0.3	50	50	0
STATE MODEL		1.4	1.2	0.2	30	50	20
CRDS AGGR.		1.5	1.1	0.4 *	20	60	40 **
REGION							
CRDS AGGR.		1.1	1.0	0.2	40	50	10
STATES AGGR.		1.2	1.1	0.1	40	60	20

Figure 19. Comparison of Thompson and CEAS models to predict soybean yields based on the average of $|d| = |\hat{Y}-Y|$ for 1970-1979. Number indicates model with smaller average $|d|$. Blank denotes tie. Stars indicate the level of significance, none ($P > 0.10$), * ($0.05 < P < 0.10$), ** ($0.01 < P < 0.05$), *** ($P < 0.01$). Darker shades indicate CRDs with higher production (T = Thompson, C = CEAS).



close in Illinois. The CEAS model generally performs better than the Thompson model in the higher producing CRDs. State level results aggregated from CRDs are significantly better for the CEAS model in Iowa and Indiana.

The nonparametric test results show seven CRDs with significant differences, five of which favor the CEAS model. Results at the state level indicate that the CEAS model performs slightly better in Iowa and Indiana with no difference shown in Illinois.

The better model in each CRD, according to the percent of years with smaller $|d|$, is presented in Figure 20. The CEAS model performs better in 12 of 27 CRDs (44%), the Thompson model performs better in 9 of 27 CRDs (33%) and the models are tied in 6 CRDs. The CEAS model tends to do better in the Iowa and Indiana CRDs with higher production.

In summary, the CEAS model performs somewhat better at the CRD level in Iowa and Indiana. State level, non-aggregated results are not significantly different in any state. The CEAS model performs only slightly better at the regional level with no significant differences resulting.

Both Models Perform Worse in Below Average Yielding Years

Results of the comparison between the CEAS and Thompson-type state level model performance in below-average, above-average, and average yielding years are presented in Table 14. Referring to the table column of the average of the absolute values of the base period residuals (AAVR), both models demonstrate larger AAVRs in the below average years as compared to the above average years, and larger AAVRs in the above average years as compared to the average years. This pattern is consistent for all three states. It is disappointing that the performance of these models is worse in the unusual years, the years for which assistance in estimating yield levels is most desired. From examining the lowest and highest residual values, it can be seen that the below average yields are usually overestimated and that the above average yields are usually underestimated. There are, however, exceptions (see Indiana above average years, Thompson-type model) which make it difficult to adequately adjust for this pattern of bias.

In confirmation of previous findings, the CEAS models consistently show at least somewhat smaller AAVRs than the Thompson-type models for all types of years in all states. More information on the below and above average years may be found in a section of the Appendix entitled "Below Average and Above Average Yielding Years for Each State and Associated Model Performance Data."

Neither Model Provides a Current Measure of Modeled Yield Reliability

This criterion for model evaluation asks whether the model can provide any indication of its accuracy in the current year. For example, one might speculate that the accuracy of a model's prediction is related to how unusual the weather is in a given year, as compared to an average year. A measure of the distance from a model's independent variable values for a given year to the average values is provided by the standard error of prediction for the given year.

Figure 20. Comparison of Thompson and CEAS models to predict soybean yields based on the percent of test years (1970-1979) with smaller $|d| = |\hat{Y}-Y|$. Letter indicates model with larger percent. Blank denotes tie. Stars indicate level of significance, none ($P > 0.10$), * ($0.05 < P < 0.10$), ** ($0.01 < P < 0.05$), *** ($P < 0.01$). Darker shades indicate CRDs with higher production (T = Thompson, C = CEAS).

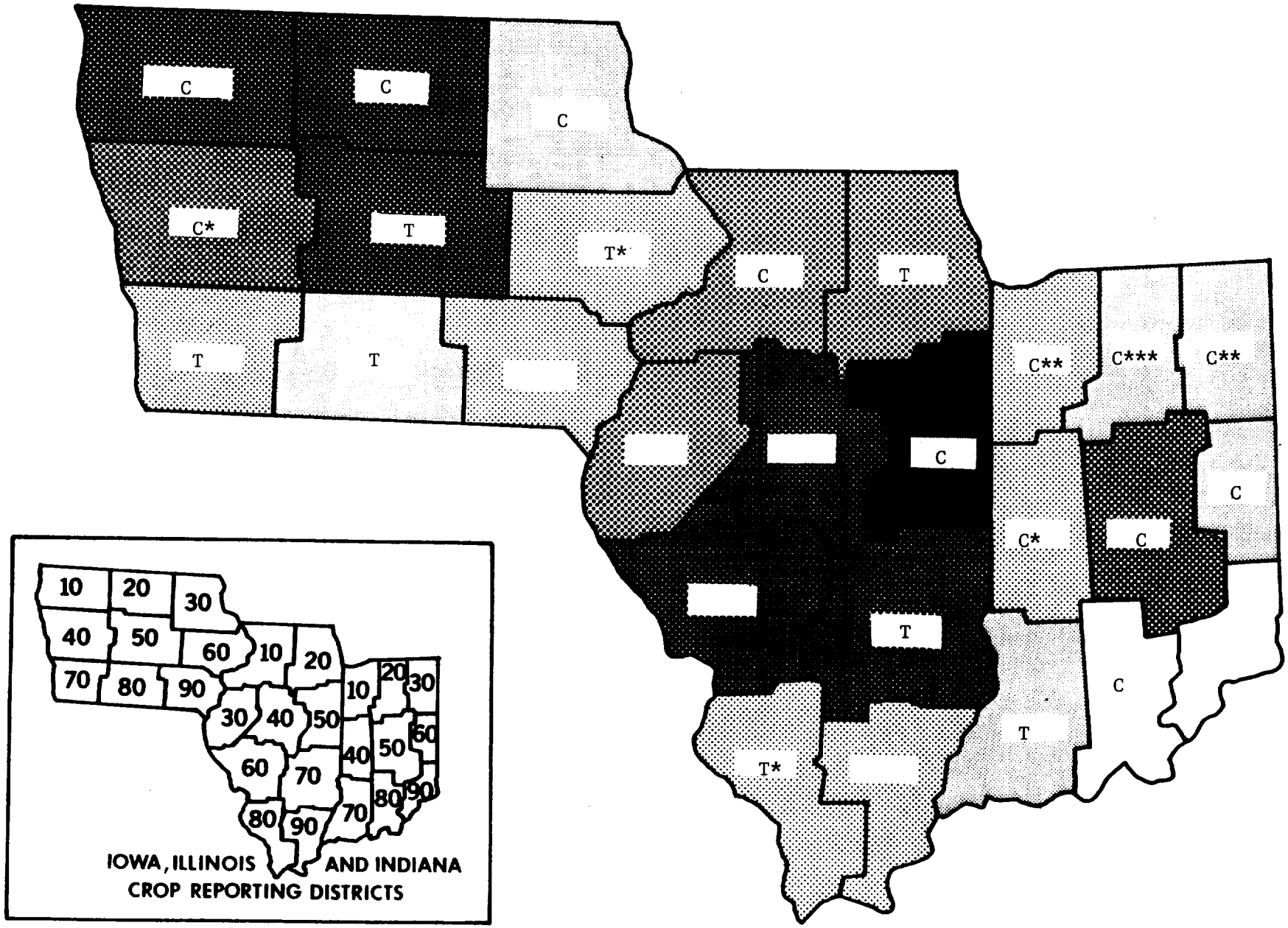


Table 14. Comparison of CEAS and Thompson-type state level performance in below average, above average, and average yielding years.

State	Type of year	Model	Base period residuals ($\hat{Y}$-Y) Average of absolute value	Lowest value	Highest value
Iowa	Below average	CEAS	1.0	-0.4	1.4
		Th-type	1.4	-0.1	2.9
	Above average	CEAS	0.7	-1.4	-0.1
		Th-type	1.3	-1.8	-0.9
	Average	CEAS	0.6	-1.6	1.6
		Th-type	0.9	-1.9	2.1
Illinois	Below average	CEAS	1.3	0.3	2.4
		Th-type	1.9	1.3	2.6
	Above average	CEAS	0.9	-1.4	-0.6
		Th-type	1.1	-1.4	-0.3
	Average	CEAS	0.6	-1.6	1.5
		Th-type	0.6	-1.3	0.9
Indiana	Below average	CEAS	0.9	0.0	2.1
		Th-type	1.7	1.1	2.2
	Above average	CEAS	0.8	-1.3	-0.4
		Th-type	1.3	-1.6	1.7
	Average	CEAS	0.7	-1.4	1.3
		Th-type	0.8	-2.0	1.4

However, previous work (French, 1982; Kestle, 1982) has shown that this distance is not related to the model's accuracy. Also, inspection of the Appendix on below-average and above-average yielding years shows that the relative size of the standard error of prediction for the CEAS and Thompson-type models in a given year does not indicate the relative accuracy of their predictions.

One does note from that appendix that both models tend to overestimate in a below-average yielding year and underestimate in an above-average yielding year. However, the accuracy of the predictions in some of these years is good, particularly for the CEAS model.

Models Are Equally Timely

It takes about three months after the end of a month to obtain that month's average temperature and total precipitation for the climatic divisions in Iowa, Illinois, and Indiana from the National Climatic Data Center (NCDC) in Asheville, North Carolina. Estimates of these climatic division values could be prepared earlier based on first-order weather station values available on the NOAA computer system on a real-time basis or based on arrangements made with a sample of the cooperative stations which submit their data to NCDC. These weather data approximations could be calculated during the first week of the month following the month for which the weather data pertains. The accuracy of such estimates would need to be monitored.

Although not discussed here, truncated CEAS models have been developed for use at the end of March through the end of September. Since Thompson did not develop his model for the purpose of yield prediction, he did not develop forecasting models. However, his models could be truncated or estimates of weather values for future months could be made so that his model could be run in a forecast mode. His model provides the end-of-season estimate at the end of August. Some of the CEAS models, particularly in Iowa, require September data values for the end-of-season estimate.

Models Are About Equally Inexpensive to Operate

The largest cost involved in operating these models is acquisition and maintenance of the required input data, i.e., the monthly climatic division weather values. In the past, the climatic division weather values have been telephoned to NOAA's Assessment and Information Services Center in Columbia, Missouri from the USDA World Agricultural Outlook Board and NOAA's Climatic Assessment Branch in Washington, D.C. Recently, only the latter source has been used and the timeliness of the reporting has been quite variable (during March through September 1982, from six to thirty-four days after the end of month for which the data pertained). For domestic use by USDA, some additional cost might be required to insure the data's availability on a timely basis from one of these sources or to develop and implement an independent system.

The maintenance of the historic agricultural and meteorological data bases requires the part-time efforts of persons familiar with meteorological data, agricultural data, and the computer system being used. This maintenance is currently being performed on a routine basis for Iowa, Illinois, and Indiana, among other states, at the Modeling Center in Columbia, Missouri.

All that is required to obtain the yield estimates is to have someone responsible for acquiring the real-time climatic division weather data estimates 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. Using the Thompson-type approach, each state has one model (set of regression coefficients) for all CRDs within the state, whereas the CEAS approach requires a separate model for each CRD. So the CEAS approach requires keeping track of more models, but the number of observations per model and the number of variables per model are less. Thus, the Thompson-type approach requires the estimation of fewer sets of coefficients, but the amount of computer time and, particularly, memory (because of pooling) and the number of variables required for any given model is greater than for any of the CEAS models. In either case, the cost of obtaining the yield estimates, once the climatic division weather values are obtained, is not significant.

As the yield/weather data base grows, the variables included in the CEAS models would need to be re-examined. Redevelopment of the CEAS models would require the skills of a person familiar with statistical regression methodology and agronomic modeling using meteorologically derived variables.

The Thompson-type Models Are Somewhat Easier to Understand and Use

The Thompson-type models are very simple, both to understand and use. The weather variables are simple transformations of the basic monthly temperature and precipitation values and the form of the model is fixed. The agronomic variables in the CEAS model are somewhat more difficult to calculate and interpret. The contents of the soil moisture budget would need to be saved from the previous year unless it could be assumed that the budget was filled to capacity over the winter months. It may be confusing for users to have two different kinds of similarly defined stress variables, DEF and RATIO, which are functions of monthly precipitation, as well as separate precipitation terms, DFNP and SDFNP.

Both models are straightforward applications of ordinary least squares regression models. Once the normal weather values to be used each month are determined and the algorithms for computing the derived weather variables are programmed, the use of the models is not complicated.

Both Models Are Based on Historic, Statistical Relationships Between Monthly Weather Values and Yield

The evaluation reports for each model (French, 1982; Kestle, 1982) provide detailed discussion of the model's consistency with scientific knowledge. Both the CEAS and Thompson-type models are derived based on the historical, statistical relationships between crop yields and weather. The weather values used by both models are averaged over calendar months and large areas (CRDs or states), so both would be subject to the limitations implied by such averaging.

A single linear trend term is used in Indiana by both models. The Thompson-type models for Iowa and Illinois also use a single linear trend term. The CEAS models in those states use two intersecting linear trend terms, one for the time period up to and including 1960 and the other for 1961 to 1978. No explanation is given for the change in trend after 1960.

The major difference in the use of the weather data by the models is the CEAS model developer's use of agroclimatic variables. These variables are constructed based on algorithms for estimating potential evapotranspiration (PET) and actual evapotranspiration (ET). Stress variables are then constructed, such as monthly precipitation minus monthly PET, which contrast the supply of moisture with its demand. The use of such variables may be partially responsible for the somewhat better performance of the CEAS models.

Another major difference between the CEAS and Thompson-type models involves the method of model construction, pooled versus unpooled. The CEAS model developer used the unpooled approach, resulting in individual CEAS models for each CRD and state. The variables were chosen independently for each of the thirty models using stepwise techniques. This may result in a variable appearing in the model for a CRD and not in the models for any of the surrounding CRDs. Also, the same variables may appear with different coefficients, implying different responses to weather in adjacent CRDs.

Kestle (1982) compared the performance of Thompson-type models using the unpooled and pooled approaches and determined that somewhat better performance was obtained using the pooled models. The inherent assumption with pooled models is that the response to weather, e.g., increase in yield per inch of rainfall, is uniform over the area in which pooling occurs. Adjustments are still made for differences in fertility levels within the region. One advantage of pooling is the increase in the size of the data base since data are pooled over regions as well as over years.

In general, a disadvantage of using historical data to statistically estimate the relationship between weather and yield is that the variety of extreme weather conditions may not be sufficiently represented in the data base. Pooling over regions as well as years may help expand the data base so that a greater variety of weather conditions is represented. The pooling could have been more easily accomplished through the use of indicator variables than through the use of the cumbersome two-step process Thompson describes (1970).

Since CEAS models were not developed using the pooled approach, in this analysis one cannot separate the effects of pooling from the effects of using different types of weather variables. However, since both models use the same monthly weather data base, neither can reflect the impact of weather conditions of a short term nature.

Models Are About Equally Objective

As presently defined, both models are equally objective in their application to the current year. The trend variable(s) is simply extrapolated and the weather variables in both models are unambiguously defined. The CEAS model also requires

the specification of two soil moisture budget values for each location. These values relate to the available water capacity, (1) in the surface layer and (2) in the underlying layer. The CEAS model developers have specified values to use in each state and CRD which, presumably, would not change.

As the yield/weather data base grows, one would expect the additional years to be included in the estimation of the regression coefficients. However, for both models an examination of the trend specification would eventually be required. Any required trend respecification may involve subjective decisions. The weather variables included in the Thompson-type model are fixed, whereas the weather variables included in the CEAS models are chosen by variable selection procedures. At some future point, consideration would need to be given to a reinspection of the variables included in the model. Since the methodology used in the original variable selection process is not well defined, this analysis would involve some subjectivity.

Model Redevelopment Would Be Required to Use the CEAS Models in Other Areas

Because of the number of variables in the Thompson-type model (twelve weather variables plus trend) and the stepwise procedures used to select variables to be included in CEAS models, both require a rather lengthy time series of yield and weather data (at least twenty-five years) for application in a new area. A CEAS model would require a complete model development effort, including specification of the available water capacities in the surface and underlying layers. The models have the same requirements in terms of trend specification.

CONCLUSION

The CEAS and Thompson-type models for soybean yields in Iowa, Illinois, and Indiana are quite similar in terms of the eight model characteristics by which they were compared. The CEAS models' yield predictions are somewhat more accurate in Iowa and Indiana. Both models tend to overestimate in below-average yielding years and underestimate in above-average yielding years. The use of the agroclimatic variables in the CEAS models and the method of pooling observations over geographic areas in the Thompson-type models both appear to be advantageous and merit further investigation.

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APPENDIX - STATISTICAL FORMULAS

Measures of Model Performance

Definition of Terms:

Y_i = Yield as reported by U.S.D.A. for year i ("true" or "actual" yield).

$\hat{Y}_i$ = Yield as predicted by a model for year i.

$d_i = \hat{Y}_i - Y_i$ = difference between predicted and actual yield for year i.

$rd_i = 100\ d_i/Y_i$ = relative difference for year i.

s_{Y_i} = Standard error of regression = (Residual or Error Mean Square from Model Development Base Period $)^{\frac{1}{2}}$ for year i.

$s_{\hat{Y}_i}$ = Standard error of a predicted value for year i = $s_{Y_i}(1 + \underline{x}_0'(\underline{X}'\underline{X})^{-1}\underline{x}_0)^{\frac{1}{2}}$, where $\underline{X}$ is the regression design matrix of independent variable values and $\underline{x}_0$ is the vector of independent variable values for the year the prediction is being made.

$i = 1, \ldots, n$ = number of test years and $\Sigma = \sum_{i=1}^{n}$ = summation over the test years.

$\bar{Y} = 1/n \sum_{i=1}^{n} Y_i$ = average actual yield.

Measures:

Bias = $B = 1/n\ \Sigma\ d_i = \bar{d}$.

Relative Bias = $RB = 100\ B/\bar{Y}$.

Mean Square Error = $MSE = 1/n\ \Sigma\ d_i^2$.

Root Mean Square Error = $RMSE = (MSE)^{\frac{1}{2}}$.

Relative Root Mean Square Error = $RRMSE = 100\ RMSE/\bar{Y}$.

Variance = $Var = 1/n\ \Sigma\ (d_i - \bar{d})^2$.

Standard Deviation = $SD = (Var)^{\frac{1}{2}}$.

Relative Standard Deviation = $RSD = 100\ SD/(\bar{Y} + \bar{d})$.

Mean Square Error = Variance + $(\text{Bias})^2$,

or

Accuracy = Precision + $(\text{Bias})^2$.

Pearson r between $\hat{Y}_i$ and Y_i:

$$r = \left[\Sigma\hat{Y}_i Y_i - \frac{(\Sigma\hat{Y}_i)\ (\Sigma Y_i)}{n}\right] \left[\left(\Sigma\hat{Y}_i^{\,2} - \frac{(\Sigma\hat{Y}_i)^2}{n}\right)\left(\Sigma Y_i^{\,2} - \frac{(\Sigma Y_i)^2}{n}\right)\right]^{-\frac{1}{2}}$$

Paired-Sample Statistical Tests Comparing the Performance of Two Crop Yield Models

Definition of Terms:

$\hat{Y}_{1_i}$ = Yield as predicted by model 1 for year i.

$\hat{Y}_{2_i}$ = Yield is predicted by model 2 for year i.

$|d_{1_i}| = |\hat{Y}_{1_i} - Y_i|$ = Absolute value of the difference between model 1 predicted and actual yield for year i.

$|d_{2_i}| = |\hat{Y}_{2_i} - Y_i|$ = Absolute value of the difference between model 2 predicted and actual yield for year i.

$D_i = |d_{1_i}| - |d_{2_i}|$.

Rank $(|D_i|)$ = Ranks of the absolute values of D_i assigned in ascending order (smallest value of $|D_i|$ = rank 1, ..., largest value of $|D_i|$ = rank n). If two or more years have the same value for $|D_i|$, assign each year the average of the ranks.

Parametric Test - Student t:

H_0: $\mu_D = 0$

H_a: $\mu_D \neq 0$

Test Statistic = $t = \frac{\bar{D}}{s_{\bar{D}}}$, where

$\bar{D} = 1/n\ \Sigma D_i$,

$s_{\bar{D}} = (s_D^2/n)^{\frac{1}{2}}$, and

$s_D^2 = [\Sigma D_i^2 - 1/n(\Sigma D_i)^2]/(n-1)$.

Reject H_0 if $|t| > t_{\alpha,\ (n-1)}$.

Nonparametric Test - Wilcoxon Signed Rank:

H_0: There is no difference in the performance of the models.

H_a: There is a difference in the performance of the models.

Procedure to compute test statistic, T:

1. Compute the D_i.
2. Assign ranks to $|D_i|$.
3. Assign signs to Rank ($|D_i|$) corresponding to the signs of D_i.
4. Let T = the absolute value of the sum of the ranks with the less frequent sign.

Reject H_0 if $T \leq T_{\alpha(1\ \text{tailed}),\ n}$.

APPENDIX

Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years

Year	State	Description
1970	Iowa	Yield same as record 1969 level. Production up 4%. Planting well ahead of average. Dry conditions in west, mid June to early August. Wet harvest conditions cause field losses. Small crop insurance claims for drought.
	Illinois	Yield down 7½%, record harvested area up 2%. Heavy April rains in north and central delayed planting. Crops in good condition most of season. September rains cause late harvest. Dominant variety is Wayne, followed by Amsoy.
	Indiana	Yield and production down 4%. Harvested area down 1%. Wet soils hindered planting. Heavy August and September rains also delayed harvest.
1971	Iowa	Yield same as record 1970 level. Production down 3%. Planting well ahead of average. Cool, dry weather during May slows crop development. June rain and warm weather help crops to make normal progress. Dry conditions during midsummer stress soybeans. Early harvest. Small crop insurance claims for hail and drought.
	Illinois	Yield up 6%, record harvested area up 5%. Record production up 12%. Planting over early. Lack of extremes in temperature bring ideal growing conditions. Harvest ahead of normal.
	Indiana	Yield up 6%, production up 9%. Harvested area up 3%; all are new state records. Dry cool spring with mild drought. Planting completed early. Harvest also ahead of schedule.

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Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years

Year	State	Description
1972	Iowa	Yield up 11%, production up 21%. Rains delay planting. Season noteworthy for hail losses and flood losses. 24 tornadoes during season. Harvest season one of worst on record. Small insurance claims for hail and excess moisture.
	Illinois	Yield up 4½%, production up 10%, harvested area up 5%; all are new state records. Planting normal. Dry June weather. Summer moisture adequate. Cool temperatures all summer. Rain slowed harvest. 41% of planted area sown in 37-38" row widths.
	Indiana	Yield down 11%, production down 3%. Record harvested area up 9%. Planting occurred on schedule. During season south was dry, north had excess moisture. Harvest far behind schedule - only 60% completed by end of year.
1973	Iowa	Yield down 6%, production up 22%. Planting slow due to rain. Wettest year since 1902. Growing season cooler than normal but longer. Harvest season delayed due to rain but one of finest. Small crop insurance losses due to excess moisture.
	Illinois	Yield down 7%. Record production up 8% and record harvested area up 19%. Heavy spring rains delay planting. Growing season temperatures normal with above normal precipitation through July. Harvest on time.
	Indiana	Yield up 7%, record production up 24%. Record harvested area up 16%. Surplus spring moisture slows planting. Harvest on normal schedule.

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Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years

Year	State	Description
1974	Iowa	Yield down 18%, production down 24%. Heavy rains in May and June. Hot, dry weather in late June and July. Unusually early frosts in September. Erosion and flooding worst in years in the eastern part of the state. Small crop insurance losses due to hail. Corsoy, Amsoy and Wayne are major varieties.
	Illinois	Yield down 24%, production down 28% (lowest since 1967). Heavy spring rains and late freeze delay planting very late. Cool temperatures most of summer, dry late summer. Early September rains and freeze delay harvest. Wayne, Williams and Amsoy dominant varieties.
	Indiana	Yield down 26%, production down 30%. Harvested area down 9%. Lowest yield and production since 1967. Heavy May rains slow planting. Hot, dry July. Extremely early fall freeze catches 40% of crop still in immature stages.
1975	Iowa	Yield up 21%, production up 19%. Frequent rains delay planting. Late June rains in the central region cause flooding. Six consecutive weeks of hot, dry weather in July and August. Ideal harvest weather. Small insurance losses due to drought. Wayne now 2nd most popular variety behind Corsoy.
	Illinois	Record yield up 50%. Record production up 46%, harvested area down 3%. Planting completed early. Growing season temperatures normal and precipitation above normal. Dry, warm fall weather allows harvest to finish well ahead of normal.

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Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years

Year	State	Description
	Indiana	Record yield up 32%, production up 25%. Harvested area down 7%. Excellent early planting weather. Growing season conditions bring abundant rainfall and optimum temperatures. Early fall weather dry and sunny, producing early harvest.
1976	Iowa	Yield down 9%, production down 16%. Dry mid-May for good planting. June and July warm and dry. Hot, dry weather later slows development. Early harvest due to weather. Small insurance loss due to drought.
	Illinois	Yield down 8%, production down 17%, harvested area down 9% (lowest since 1972). Planting ahead of normal. Growing season mostly cool and dry; precipitation 10" below normal (especially NW, NE, and west). Harvest completed early. Williams now dominant variety, Wayne drops to second. 42% of planted area sown in 27"-30" row widths.
	Indiana	Record yield up 1%, production down 8%. Harvested area down 10%. Most favorable planting conditions in several years. Spring and early summer cool and dry. Some moisture stress in late summer. Harvest underway early. Williams is dominant variety, followed by Amsoy.
1977	Iowa	Yield up 15%, production up 26%. Coldest winter in Iowa history. Herbicide damage causes some replanting. Grasshopper damage occurred. Crop stress in June and July. Cool, wet weather delays harvest. Small insurance claims due to drought.

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Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years

Year	State	Description
	Illinois	Record yield up 15%, record production up 35%. Harvested area up 17%. Planting ahead of normal. Growing season generally cool and wet. Heavy fall precipitation reduces quality and delays harvest.
	Indiana	Record yield up 8%, record production up 29%. Harvested area up 18%. Weather extremes occurred over state. Early summer had some drought. Harvest delayed by wet, cool weather. Williams still dominant variety but only by small percentage over Amsoy.
1978	Iowa	Yield up 6%, record production up 13%. Cold, wet spring delayed planting. Excellent June and July growing season conditions, with above average July moisture. Hot, dry weather in early fall promotes crop maturity. Excellent harvest weather. Corsoy, Wells and Williams are most popular varieties.
	Illinois	Yield down 12%, production down 8½%, record harvested area up 4%. Planting extremely delayed by heavy rains. Growing season generally cool and dry with temperatures 3° below normal. Harvest normal to early. Williams and Amsoy dominant varieties. 46% of planted area in 27"-30" row widths.
	Indiana	Yield down 7%, production down 1%. Harvested area up 1%. Wet fields slowed early planting. Growth slow over early summer. Excellent harvest conditions. Williams dominant variety.

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Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years

Year	State	Description
1979	Iowa	Yield same as 1978, record production up 8%. One of worst winters on record. Wet, cold soils delay planting but later progressed rapidly. Harvest ahead of schedule. Small insurance claims for hail.
	Illinois	Yield up 15%, production up 21%, harvested area up 6%; all are new state records. Planting starts late but finishes early. Weather during growing season slightly cool with normal precipitation. W, C, and SW had slightly less moisture. Normal to early harvest.
	Indiana	Yield up 4%, record production up 10%. Record harvested area up 5%. Cold wintery early spring weather slows planting. Summer rains also heavy in parts (10"-16"). Cool autumn weather allows for early maturity and harvest.

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APPENDIX

Below average and above average yielding years (1950-1979) for each state and associated model performance data*

State	Year and Type	Obs. Yield (Y)	CEAS Model: Pred. Yield ($\hat{Y}$)	CEAS Model: $\hat{Y}$-Y	CEAS Model: $s_{\hat{y}}$	Thompson-type Model: Pred. Yield ($\hat{Y}$)	Thompson-type Model: $\hat{Y}$-Y	Thompson-type Model: $s_{\hat{y}}$
		Quintals/Hectare						
Iowa	Below average							
	1974	18.8	20.2	1.4	0.54	20.6	1.8	0.50
	1956	13.5	14.5	1.0	0.59	16.4	2.9	0.58
	1955	13.5	14.3	0.8	0.65	13.9	0.5	0.52
	1976	20.8	20.4	-0.4	0.59	20.7	-0.1	0.45
	1965	17.5	18.8	1.3	0.44	19.1	1.6	0.24
	Above average							
	1972	24.2	23.3	-0.9	0.35	23.0	-1.2	0.28
	1952	17.1	16.6	-0.5	0.55	16.2	-0.9	0.36
	1954	17.8	17.0	-0.8	0.44	16.6	-1.2	0.49
	1963	20.5	20.4	-0.1	0.46	19.3	-1.2	0.41
	1957	18.2	16.8	-1.4	0.38	16.4	-1.8	0.36
Illinois	Below average							
	1974	16.5	18.9	2.4	0.54	19.1	2.6	0.51
	1953	13.8	14.9	1.1	0.45	15.7	1.9	0.54
	1954	14.5	15.9	1.4	0.40	16.5	2.0	0.39
	1964	16.8	18.0	1.2	0.34	18.6	1.8	0.25
	1955	15.5	15.8	0.3	0.26	16.8	1.3	0.44
	Above average							
	1979	26.2	25.3	-0.9	0.55	25.0	-1.2	0.31
	1977	25.6	25.0	-0.6	0.52	24.3	-1.3	0.45
	1969	22.9	21.5	-1.4	0.32	21.5	-1.4	0.32
	1975	24.2	23.3	-0.9	0.33	23.0	-1.2	0.51
	1956	19.2	18.7	-0.5	0.34	18.9	-0.3	0.26
Indiana	Below average							
	1974	16.8	18.9	2.1	0.51	18.6	1.8	0.45
	1967	16.5	17.1	0.6	0.36	18.1	1.6	0.42
	1964	16.5	17.2	0.7	0.43	18.7	2.2	0.25
	1955	14.5	15.6	1.1	0.36	16.1	1.6	0.38
	1966	17.5	17.5	0.0	0.33	18.6	1.1	0.27
	Above average							
	1977	24.9	23.6	-1.3	0.48	23.3	-1.6	0.36
	1968	21.5	20.4	-1.1	0.28	20.5	-1.0	0.24
	1971	22.2	21.5	-0.7	0.37	21.3	-0.9	0.34
	1969	21.5	20.8	-0.7	0.28	20.3	-1.2	0.29
	1979	24.2	23.8	-0.4	0.67	25.9	1.7	0.57

*Predicted yields ($\hat{Y}$) and standard errors of the predicted yield ($s_{\hat{y}}$) are computed using all data through 1979.

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
IOWA	10	1970	19.1	20.4	18.4	20.1	1.3	-0.7	1.0
		1971	21.6	20.4	19.8	20.3	-1.2	-1.8	-1.3
		1972	25.3	20.9	21.4	22.0	-4.4	-3.9	-3.3
		1973	24.7	22.0	22.4	23.1	-2.7	-2.3	-1.6
		1974	19.8	22.9	22.6	23.4	3.1	2.8	3.6
		1975	24.1	22.7	22.3	23.0	-1.4	-1.8	-1.1
		1976	20.0	23.4	21.0	20.3	3.4	1.0	0.3
		1977	26.3	23.3	23.0	26.4	-3.0	-3.3	0.1
		1978	26.9	24.6	26.5	29.4	-2.3	-0.4	2.5
		1979	24.9	25.2	26.0	27.3	0.3	1.1	2.4
	20	1970	22.2	21.1	20.7	22.2	-1.1	-1.5	0.0
		1971	21.4	21.7	20.4	23.1	0.3	-1.0	1.7
		1972	23.4	22.1	22.7	22.0	-1.3	-0.7	-1.4
		1973	22.8	22.7	21.4	23.5	-0.1	-1.4	0.7
		1974	19.4	23.2	22.3	22.0	3.8	2.9	2.6
		1975	23.2	22.7	23.0	21.7	-0.5	-0.2	-1.5
		1976	21.7	23.3	22.9	21.8	1.6	1.2	0.1
		1977	24.6	23.4	23.0	24.6	-1.2	-1.6	0.0
		1978	24.3	24.2	25.8	24.7	-0.1	1.5	0.4
		1979	23.6	24.5	23.3	22.5	0.9	-0.3	-1.1
	30	1970	21.8	18.9	19.5	20.1	-2.9	-2.3	-1.7
		1971	19.1	19.8	18.5	20.8	0.7	-0.6	1.7
		1972	22.0	20.1	21.5	19.8	-1.9	-0.5	-2.2
		1973	21.0	20.8	18.9	19.2	-0.2	-2.1	-1.8
		1974	18.3	21.2	20.0	20.3	2.9	1.7	2.0
		1975	20.4	21.0	21.3	20.2	0.6	0.9	-0.2
		1976	19.8	21.3	21.0	19.6	1.5	1.2	-0.2
		1977	25.0	21.4	21.5	23.7	-3.6	-3.5	-1.3
		1978	24.6	22.5	23.3	23.6	-2.1	-1.3	-1.0
		1979	24.1	23.1	24.9	23.9	-1.0	0.8	-0.2
	40	1970	19.3	21.1	20.1	18.4	1.8	0.8	-0.9
		1971	20.1	21.1	20.4	21.3	1.0	0.3	1.2
		1972	24.5	21.2	22.5	23.7	-3.3	-2.0	-0.8
		1973	22.1	22.1	21.5	22.4	0.0	-0.6	0.3
		1974	19.4	22.6	22.9	18.1	3.2	3.5	-1.3
		1975	23.2	22.5	22.0	22.6	-0.7	-1.2	-0.6
		1976	18.5	23.2	21.5	18.5	4.7	3.0	0.0
		1977	22.9	22.6	22.9	22.1	-0.3	0.0	-0.8
		1978	26.7	23.2	24.6	25.8	-3.5	-2.1	-0.9
		1979	25.5	23.8	24.8	26.2	-1.7	-0.7	0.7

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STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
IOWA	50	1970	24.4	22.6	23.3	22.5	-1.8	-1.1	-1.9
		1971	23.2	23.3	22.6	22.4	0.1	-0.6	-0.8
		1972	25.1	23.7	24.8	25.6	-1.4	-0.3	0.5
		1973	24.5	24.3	23.6	25.3	-0.2	-0.9	0.8
		1974	19.3	24.7	23.1	23.3	5.4	3.8	4.0
		1975	23.5	24.2	23.9	24.6	0.7	0.4	1.1
		1976	21.9	24.6	23.9	22.1	2.7	2.0	0.2
		1977	21.0	24.4	23.1	19.6	3.4	2.1	-1.4
		1978	27.0	24.3	26.1	26.5	-2.7	-0.9	-0.5
		1979	26.9	24.8	26.5	26.5	-2.1	-0.4	-0.4
	60	1970	24.5	23.6	24.1	24.2	-0.9	-0.4	-0.3
		1971	24.3	24.2	24.0	24.1	-0.1	-0.3	-0.2
		1972	24.6	24.7	25.2	26.3	0.1	0.6	1.7
		1973	23.4	25.1	22.1	25.0	1.7	-1.3	1.6
		1974	19.9	25.3	22.0	25.6	5.4	2.1	5.7
		1975	24.3	24.8	25.1	26.6	0.5	0.8	2.3
		1976	22.6	25.3	25.3	25.2	2.7	2.7	2.6
		1977	26.0	25.1	26.1	26.7	-0.9	0.1	0.7
		1978	25.5	25.7	27.0	26.4	0.2	1.5	0.9
		1979	28.0	25.8	28.3	27.3	-2.2	0.3	-0.7
	70	1970	21.8	22.6	22.1	23.1	0.8	0.3	1.3
		1971	21.6	22.8	22.9	21.8	1.2	1.3	0.2
		1972	23.9	23.0	24.1	23.8	-0.9	0.2	-0.1
		1973	21.6	23.6	21.3	22.7	2.0	-0.3	1.1
		1974	18.9	23.9	24.0	20.0	5.0	5.1	1.1
		1975	20.9	23.2	22.3	22.6	2.3	1.4	1.7
		1976	20.6	23.3	23.6	19.7	2.7	3.0	-0.9
		1977	23.3	23.0	23.1	21.7	-0.3	-0.2	-1.6
		1978	22.8	23.3	25.6	25.7	0.5	2.8	2.9
		1979	24.7	23.0	25.3	23.7	-1.7	0.6	-1.0
	80	1970	22.1	19.3	19.9	21.5	-2.8	-2.2	-0.6
		1971	21.0	20.0	19.5	20.5	-1.0	-1.5	-0.5
		1972	22.4	20.5	21.7	22.9	-1.9	-0.7	0.5
		1973	20.0	21.1	18.5	22.2	1.1	-1.5	2.2
		1974	13.6	21.4	19.9	19.2	7.8	6.3	5.6
		1975	19.4	20.3	19.7	20.5	0.9	0.3	1.2
		1976	20.2	20.6	20.7	19.4	0.4	0.5	-0.8
		1977	20.2	20.6	19.8	21.2	0.4	-0.4	1.0
		1978	20.9	20.8	21.8	23.3	-0.1	0.9	2.4
		1979	22.4	20.7	20.9	20.7	-1.7	-1.5	-1.7

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STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
IOWA	90	1970	23.1	20.9	21.4	21.3	-2.2	-1.7	-1.8
		1971	23.7	21.6	21.5	25.2	-2.1	-2.2	1.5
		1972	24.3	22.3	22.3	22.4	-2.0	-2.0	-1.9
		1973	21.5	22.9	20.0	21.4	1.4	-1.5	-0.1
		1974	16.8	23.2	21.7	19.5	6.4	4.9	2.8
		1975	22.6	22.5	22.2	23.3	-0.1	-0.4	0.7
		1976	22.6	23.0	23.3	23.4	0.4	0.7	0.8
		1977	24.8	23.1	23.9	24.8	-1.7	-0.9	0.0
		1978	23.4	23.8	25.0	25.5	0.4	1.6	2.1
		1979	26.4	24.0	25.1	23.3	-2.4	-1.3	-3.1
STATE MODEL		1970	21.9	21.2	20.6	20.8	-0.7	-1.3	-1.1
		1971	21.9	21.7	19.7	23.5	-0.2	-2.2	1.7
		1972	24.2	22.1	23.0	23.5	-2.1	-1.2	-0.7
		1973	22.9	22.8	23.4	23.5	-0.1	0.5	0.6
		1974	18.8	23.3	21.9	19.7	4.5	3.1	0.9
		1975	22.9	22.8	20.4	20.4	-0.1	-2.5	-2.5
		1976	20.8	23.4	20.6	20.1	2.6	-0.2	-0.7
		1977	23.9	23.2	24.3	22.4	-0.7	0.4	-1.5
		1978	25.2	23.9	24.8	27.9	-1.3	-0.4	2.7
		1979	25.2	24.2	25.9	25.0	-1.0	0.7	-0.2
CRDS AGGR.		1970	21.9	21.3	21.0	21.3	-0.6	-0.9	-0.6
		1971	21.9	21.7	21.1	22.2	-0.2	-0.8	0.3
		1972	24.2	22.1	23.0	23.3	-2.1	-1.2	-0.9
		1973	22.9	22.8	21.5	23.1	-0.1	-1.4	0.2
		1974	18.8	23.3	22.3	21.6	4.5	3.5	2.8
		1975	22.9	22.9	22.7	22.9	0.0	-0.2	0.0
		1976	20.8	23.4	22.6	21.1	2.6	1.8	0.3
		1977	23.9	23.2	23.0	23.4	-0.7	-0.9	-0.5
		1978	25.2	23.8	25.4	26.1	-1.4	0.2	0.9
		1979	25.2	24.2	25.1	25.0	-1.0	-0.1	-0.2

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
ILLINOIS	10	1970	23.4	22.6	23.2	23.3	-0.8	-0.2	-0.1
		1971	23.0	22.8	22.4	22.5	-0.2	-0.6	-0.5
		1972	24.4	23.1	24.8	24.5	-1.3	0.4	0.1
		1973	23.5	23.8	22.9	23.8	0.3	-0.6	0.3
		1974	17.0	24.0	21.5	23.3	7.0	4.5	6.3
		1975	26.4	23.2	23.3	24.8	-3.2	-3.1	-1.6
		1976	22.3	24.1	21.7	23.7	1.8	-0.6	1.4
		1977	27.3	23.8	23.8	25.7	-3.5	-3.5	-1.6
		1978	24.6	24.7	24.4	25.7	0.1	-0.2	1.1
		1979	28.1	24.9	26.5	26.6	-3.2	-1.6	-1.5
	20	1970	21.0	20.7	20.9	20.1	-0.3	-0.1	-0.9
		1971	20.6	20.7	21.1	20.4	0.1	0.5	-0.2
		1972	22.0	20.8	22.7	21.6	-1.2	0.7	-0.4
		1973	21.4	21.4	20.9	20.7	0.0	-0.5	-0.7
		1974	17.0	21.5	20.5	20.8	4.5	3.5	3.8
		1975	25.0	20.9	21.9	21.5	-4.1	-3.1	-3.5
		1976	20.5	21.8	21.1	21.7	1.3	0.6	1.2
		1977	25.9	21.6	21.2	22.6	-4.3	-4.7	-3.3
		1978	22.2	22.6	24.0	23.6	0.4	1.8	1.4
		1979	26.8	22.7	24.7	23.2	-4.1	-2.1	-3.6
	30	1970	23.1	21.8	22.9	22.7	-1.3	-0.2	-0.4
		1971	24.3	21.8	21.5	22.3	-2.5	-2.8	-2.0
		1972	25.0	22.5	22.4	23.8	-2.5	-2.6	-1.2
		1973	22.0	23.4	23.0	24.3	1.4	1.0	2.3
		1974	16.6	23.7	21.9	22.3	7.1	5.3	5.7
		1975	25.0	23.0	22.4	23.2	-2.0	-2.6	-1.8
		1976	23.3	23.8	22.7	22.9	0.5	-0.6	-0.4
		1977	25.6	23.9	23.6	24.3	-1.7	-2.0	-1.3
		1978	23.6	24.5	23.8	24.5	0.9	0.2	0.9
		1979	27.1	24.7	24.2	22.6	-2.4	-2.9	-4.5
	40	1970	22.7	24.0	23.4	24.2	1.3	0.7	1.5
		1971	25.7	23.7	23.3	24.7	-2.0	-2.4	-1.0
		1972	26.4	24.3	24.3	25.2	-2.1	-2.1	-1.2
		1973	24.8	25.2	24.7	26.1	0.4	-0.1	1.3
		1974	16.7	25.5	22.4	23.1	8.8	5.7	6.4
		1975	27.1	24.5	25.6	25.7	-2.6	-1.5	-1.4
		1976	25.1	25.3	24.1	24.8	0.2	-1.0	-0.3
		1977	28.0	25.5	25.5	27.5	-2.5	-2.5	-0.5
		1978	25.6	26.2	26.2	26.5	0.6	0.6	0.9
		1979	28.1	26.2	27.0	26.9	-1.9	-1.1	-1.2

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
ILLINOIS	50	1970	23.1	22.4	22.6	23.8	-0.7	-0.5	0.7
		1971	25.7	22.5	22.7	24.4	-3.2	-3.0	-1.3
		1972	24.4	23.3	23.3	24.9	-1.1	-1.1	0.5
		1973	22.7	23.9	23.5	24.9	1.2	0.8	2.2
		1974	17.6	24.1	21.9	21.7	6.5	4.3	4.1
		1975	26.4	23.4	24.4	25.0	-3.0	-2.0	-1.4
		1976	23.7	24.2	22.4	23.1	0.5	-1.3	-0.6
		1977	27.3	24.3	24.4	27.9	-3.0	-2.9	0.6
		1978	24.9	25.1	25.4	26.0	0.2	0.5	1.1
		1979	26.8	25.3	27.5	28.1	-1.5	0.7	1.3
	60	1970	21.0	22.6	21.4	22.5	1.6	0.4	1.5
		1971	23.3	22.4	21.3	24.3	-0.9	-2.0	1.0
		1972	24.0	23.0	22.0	22.5	-1.0	-2.0	-1.5
		1973	22.0	23.7	22.7	24.2	1.7	0.7	2.2
		1974	17.8	23.9	21.7	21.9	6.1	3.9	4.1
		1975	24.3	23.5	22.7	23.1	-0.8	-1.6	-1.2
		1976	23.0	24.1	21.3	21.9	1.1	-1.7	-1.1
		1977	26.6	24.1	23.2	25.1	-2.5	-3.4	-1.5
		1978	22.9	24.4	23.8	24.4	1.5	0.9	1.5
		1979	27.5	24.3	24.8	24.2	-3.2	-2.7	-3.3
	70	1970	18.3	19.6	17.9	18.8	1.3	-0.4	0.5
		1971	19.6	19.6	18.9	21.6	0.0	-0.7	2.0
		1972	21.7	20.0	19.0	20.2	-1.7	-2.7	-1.5
		1973	18.6	20.7	19.8	21.0	2.1	1.2	2.4
		1974	15.2	20.8	18.1	19.6	5.6	2.9	4.4
		1975	21.6	20.3	20.9	22.0	-1.3	-0.7	0.4
		1976	22.3	20.8	19.4	20.5	-1.5	-2.9	-1.8
		1977	24.2	21.2	20.7	21.8	-3.0	-3.5	-2.4
		1978	21.9	21.7	22.8	24.1	-0.2	0.9	2.2
		1979	25.1	21.9	23.0	22.9	-3.2	-2.1	-2.2
	80	1970	18.0	17.8	16.8	17.1	-0.2	-1.2	-0.9
		1971	17.2	18.0	18.6	19.0	0.8	1.4	1.8
		1972	20.0	18.4	19.7	19.7	-1.6	-0.3	-0.3
		1973	17.2	19.3	17.8	18.5	2.1	0.6	1.3
		1974	15.4	19.5	17.7	18.6	4.1	2.3	3.2
		1975	21.6	19.5	20.0	19.5	-2.1	-1.6	-2.1
		1976	17.9	20.3	19.6	19.7	2.4	1.7	1.8
		1977	23.1	19.9	20.3	19.5	-3.2	-2.8	-3.6
		1978	19.2	20.2	21.4	20.6	1.0	2.2	1.4
		1979	23.3	20.0	21.2	20.9	-3.3	-2.1	-2.4

APPENDIX
BOOTSTRAP TEST RESULTS
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IOWA, ILLINOIS, AND INDIANA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
ILLINOIS	90	1970	15.6	16.5	15.8	15.4	0.9	0.2	-0.2
		1971	16.2	16.6	17.2	16.7	0.4	1.0	0.5
		1972	18.7	17.0	18.5	17.3	-1.7	-0.2	-1.4
		1973	15.2	17.6	16.0	16.1	2.4	0.8	0.9
		1974	13.9	17.6	16.8	16.5	3.7	2.9	2.6
		1975	19.0	17.4	18.2	17.5	-1.6	-0.8	-1.5
		1976	18.1	17.8	17.7	17.7	-0.3	-0.4	-0.4
		1977	20.3	17.7	19.1	17.7	-2.6	-1.2	-2.6
		1978	15.1	18.1	19.0	18.0	3.0	3.9	2.9
		1979	22.0	17.5	19.6	19.5	-4.5	-2.4	-2.4
STATE MODEL		1970	20.8	21.2	20.6	21.5	0.4	-0.2	0.7
		1971	22.2	21.2	20.4	22.9	-1.0	-1.8	0.7
		1972	23.2	21.7	22.0	23.4	-1.5	-1.2	0.2
		1973	21.2	22.5	21.8	22.7	1.3	0.6	1.5
		1974	16.5	22.7	20.1	20.2	6.2	3.6	3.7
		1975	24.2	22.1	22.5	22.9	-2.1	-1.7	-1.3
		1976	22.2	22.8	21.3	22.0	0.6	-0.9	-0.2
		1977	25.6	22.8	24.2	24.8	-2.8	-1.4	-0.8
		1978	22.5	23.4	23.8	24.3	0.9	1.3	1.8
		1979	26.2	23.4	25.1	24.8	-2.8	-1.1	-1.4
CRDS AGGR.		1970	20.8	21.2	20.7	21.3	0.4	-0.1	0.5
		1971	22.2	21.2	20.9	22.3	-1.0	-1.3	0.1
		1972	23.2	21.7	21.9	22.4	-1.5	-1.3	-0.8
		1973	21.2	22.5	21.7	22.7	1.3	0.5	1.5
		1974	16.5	22.6	20.4	21.0	6.1	3.9	4.5
		1975	24.2	22.0	22.4	22.8	-2.2	-1.8	-1.4
		1976	22.2	22.7	21.2	21.9	0.5	-1.0	-0.3
		1977	25.6	22.6	22.5	23.9	-3.0	-3.1	-1.7
		1978	22.5	23.3	23.6	24.0	0.8	1.1	1.5
		1979	26.2	23.3	24.5	24.2	-2.9	-1.7	-2.0

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STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
INDIANA	10	1970	21.7	20.3	20.3	20.6	-1.4	-1.4	-1.1
		1971	22.8	20.5	21.5	22.2	-2.3	-1.3	-0.6
		1972	20.2	21.2	21.1	20.7	1.0	0.9	0.5
		1973	21.1	21.4	21.4	21.2	0.3	0.3	0.1
		1974	17.2	21.7	19.6	19.1	4.5	2.4	1.9
		1975	23.1	21.2	20.8	21.3	-1.9	-2.3	-1.8
		1976	22.3	21.8	21.2	21.4	-0.5	-1.1	-0.9
		1977	25.0	22.0	21.2	22.1	-3.0	-3.8	-2.9
		1978	22.7	22.9	23.0	22.3	0.2	0.3	-0.4
		1979	25.2	23.0	23.9	23.6	-2.2	-1.3	-1.6
	20	1970	20.7	19.4	20.2	20.3	-1.3	-0.5	-0.4
		1971	21.5	19.5	20.0	20.5	-2.0	-1.5	-1.0
		1972	19.6	20.0	20.8	20.8	0.4	1.2	1.2
		1973	21.3	20.3	21.8	21.8	-1.0	0.5	0.5
		1974	15.9	20.7	17.6	16.7	4.8	1.7	0.8
		1975	23.8	20.1	18.8	20.8	-3.7	-5.0	-3.0
		1976	22.5	20.9	21.0	22.4	-1.6	-1.5	-0.1
		1977	25.1	21.3	20.2	24.1	-3.8	-4.9	-1.0
		1978	21.6	22.3	22.3	21.3	0.7	0.7	-0.3
		1979	25.6	22.5	23.1	23.8	-3.1	-2.5	-1.8
	30	1970	19.9	18.4	18.3	18.5	-1.5	-1.6	-1.4
		1971	20.5	18.5	17.8	18.8	-2.0	-2.7	-1.7
		1972	19.2	18.9	19.1	19.1	-0.3	-0.1	-0.1
		1973	20.5	19.3	21.1	21.0	-1.2	0.6	0.5
		1974	15.9	19.8	16.9	18.0	3.9	1.0	2.1
		1975	20.7	19.3	17.2	20.4	-1.4	-3.5	-0.3
		1976	21.6	19.9	19.2	20.8	-1.7	-2.4	-0.8
		1977	25.5	20.3	20.0	22.4	-5.2	-5.5	-3.1
		1978	21.2	21.5	20.9	20.9	0.3	-0.3	-0.3
		1979	24.3	21.8	21.9	22.2	-2.5	-2.4	-2.1
	40	1970	21.2	20.6	20.2	20.0	-0.6	-1.0	-1.2
		1971	24.0	20.9	20.8	21.6	-3.1	-3.2	-2.4
		1972	21.6	21.8	21.0	20.4	0.2	-0.6	-1.2
		1973	22.4	22.3	23.1	22.8	-0.1	0.7	0.4
		1974	15.5	22.8	19.3	19.5	7.3	3.8	4.0
		1975	23.4	22.0	21.1	21.9	-1.4	-2.3	-1.5
		1976	24.2	22.7	20.8	20.8	-1.5	-3.4	-3.4
		1977	25.0	23.2	21.0	23.7	-1.8	-4.0	-1.3
		1978	24.5	23.9	25.0	24.8	-0.6	0.5	0.3
		1979	24.4	24.2	25.1	24.9	-0.2	0.7	0.5

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STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
INDIANA	50	1970	22.1	21.2	22.3	21.9	-0.9	0.2	-0.2
		1971	24.1	21.4	21.1	23.1	-2.7	-3.0	-1.0
		1972	20.7	22.1	21.3	21.2	1.4	0.6	0.5
		1973	23.6	22.2	24.1	24.8	-1.4	0.5	1.2
		1974	17.8	22.7	20.7	20.9	4.9	2.9	3.1
		1975	24.4	22.2	22.8	22.7	-2.2	-1.6	-1.7
		1976	24.5	22.9	23.3	23.6	-1.6	-1.2	-0.9
		1977	26.7	23.3	23.2	24.3	-3.4	-3.5	-2.4
		1978	26.3	24.2	26.6	26.2	-2.1	0.3	-0.1
		1979	25.5	24.7	25.6	23.8	-0.8	0.1	-1.7
	60	1970	20.1	18.6	19.1	19.9	-1.5	-1.0	-0.2
		1971	21.2	18.9	17.4	20.1	-2.3	-3.8	-1.1
		1972	18.5	19.4	17.8	19.2	0.9	-0.7	0.7
		1973	21.3	19.7	20.6	22.0	-1.6	-0.7	0.7
		1974	16.9	20.4	17.6	20.8	3.5	0.7	3.9
		1975	22.2	20.1	18.5	21.5	-2.1	-3.7	-0.6
		1976	21.5	20.8	19.1	21.4	-0.7	-2.4	-0.1
		1977	23.2	21.0	18.9	21.5	-2.2	-4.3	-1.7
		1978	23.5	21.8	22.7	21.8	-1.7	-0.8	-1.7
		1979	22.5	22.4	23.1	19.9	-0.1	0.6	-2.6
	70	1970	19.4	20.6	19.5	18.9	1.2	0.1	-0.5
		1971	20.4	20.9	20.5	20.1	0.5	0.1	-0.3
		1972	19.8	21.4	20.9	20.4	1.6	1.1	0.6
		1973	18.6	21.7	20.6	20.0	3.1	2.0	1.4
		1974	17.4	21.7	16.3	16.3	4.3	-1.1	-1.1
		1975	21.3	21.4	20.9	21.0	0.1	-0.4	-0.3
		1976	22.7	21.7	20.6	20.3	-1.0	-2.1	-2.4
		1977	23.1	21.9	22.5	20.9	-1.2	-0.6	-2.2
		1978	21.6	22.3	24.2	22.7	0.7	2.6	1.1
		1979	22.1	22.1	21.1	25.9	0.0	-1.0	3.8
	80	1970	19.3	19.8	18.6	18.7	0.5	-0.7	-0.6
		1971	19.2	20.3	20.0	18.9	1.1	0.8	-0.3
		1972	17.6	20.8	19.9	18.9	3.2	2.3	1.3
		1973	16.3	20.8	19.8	16.9	4.5	3.5	0.6
		1974	16.5	20.5	16.4	13.4	4.0	-0.1	-3.1
		1975	15.1	20.2	18.5	17.8	5.1	3.4	2.7
		1976	19.7	19.6	19.1	19.9	-0.1	-0.6	0.2
		1977	21.1	19.5	20.2	17.7	-1.6	-0.9	-3.4
		1978	20.3	19.7	22.7	19.2	-0.6	2.4	-1.1
		1979	19.8	19.7	20.4	19.2	-0.1	0.6	-0.6

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STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
INDIANA	90	1970	18.9	20.1	19.1	18.5	1.2	0.2	-0.1
		1971	19.7	20.5	20.8	18.3	0.8	1.1	-1.4
		1972	16.1	21.0	19.2	18.3	4.9	3.1	2.2
		1973	15.7	20.9	19.6	17.7	5.2	3.9	2.0
		1974	17.3	20.5	17.4	16.0	3.2	0.1	-1.3
		1975	17.6	20.2	18.1	18.7	2.6	0.5	1.1
		1976	21.8	19.9	19.8	18.9	-1.9	-2.0	-2.9
		1977	22.0	20.3	20.7	20.1	-1.7	-1.3	-1.9
		1978	19.7	20.6	23.2	20.2	0.9	3.5	0.5
		1979	19.9	20.4	23.0	17.4	0.5	3.1	-2.5
STATE MODEL		1970	20.8	20.1	20.2	20.2	-0.7	-0.6	-0.6
		1971	22.2	20.4	20.5	21.3	-1.8	-1.7	-0.9
		1972	19.8	21.0	20.0	20.1	1.2	0.2	0.3
		1973	21.2	21.2	22.1	22.6	0.0	0.9	1.4
		1974	16.8	21.5	19.3	19.5	4.7	2.5	2.7
		1975	22.5	21.0	21.2	21.3	-1.5	-1.3	-1.2
		1976	22.9	21.6	21.1	21.3	-1.3	-1.8	-1.6
		1977	24.9	21.9	23.1	23.1	-3.0	-1.8	-1.8
		1978	23.2	22.7	24.3	23.6	-0.5	1.1	0.4
		1979	24.2	23.0	26.4	23.3	-1.2	2.2	-0.9
CRDS AGGR.		1970	20.8	20.1	20.2	20.2	-0.7	-0.6	-0.6
		1971	22.2	20.3	20.2	21.1	-1.9	-2.0	-1.1
		1972	19.8	20.9	20.4	20.3	1.1	0.6	0.5
		1973	21.2	21.1	21.9	21.9	-0.1	0.7	0.7
		1974	16.8	21.5	18.5	18.8	4.7	1.7	2.0
		1975	22.5	21.0	20.3	21.3	-1.5	-2.2	-1.2
		1976	22.9	21.6	21.0	21.5	-1.3	-1.9	-1.3
		1977	24.9	21.9	21.2	22.7	-3.0	-3.7	-2.2
		1978	23.2	22.7	23.8	23.0	-0.5	0.6	-0.2
		1979	24.2	23.0	23.6	23.2	-1.2	-0.6	-1.0

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAW MAN THOMP=THOMPSON-TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	THOMP	CEAS	D= PREDICTED-ACTUAL STMAN	THOMP	CEAS
REGION									
	CRDS AGGR.	1970	21.2	21.0	20.7	21.1	-0.2	-0.5	-0.1
		1971	22.1	21.2	20.8	22.0	-0.9	-1.3	-0.1
		1972	22.8	21.7	21.9	22.2	-1.1	-0.9	-0.6
		1973	21.8	22.3	21.7	22.7	0.5	-0.1	0.9
		1974	17.4	22.6	20.8	20.9	5.2	3.4	3.4
		1975	23.4	22.1	22.1	22.6	-1.3	-1.3	-0.8
		1976	21.8	22.7	21.7	21.5	0.9	-0.1	-0.3
		1977	24.8	22.7	22.5	23.5	-2.1	-2.3	-1.3
		1978	23.6	23.4	24.3	24.6	-0.2	0.7	1.0
		1979	25.5	23.6	24.6	24.3	-1.9	-0.9	-1.2
STATES	AGGR.	1970	21.2	21.0	20.5	21.0	-0.2	-0.7	-0.2
		1971	22.1	21.2	20.2	22.8	-0.9	-1.9	0.7
		1972	22.8	21.7	21.9	22.7	-1.1	-0.9	-0.1
		1973	21.8	22.3	22.4	23.0	0.5	0.6	1.2
		1974	17.4	22.7	20.6	19.9	5.3	3.2	2.5
		1975	23.4	22.1	21.5	21.7	-1.3	-1.9	-1.7
		1976	21.8	22.8	21.0	21.2	1.0	-0.8	-0.6
		1977	24.8	22.8	24.0	23.6	-2.0	-0.8	-1.2
		1978	23.6	23.4	24.3	25.5	-0.2	0.7	1.9
		1979	25.5	23.6	25.7	24.6	-1.9	0.2	-0.9