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Evaluation of the Thompson-type Yield Models for Soybeans in Iowa, Illinois, and Indiana

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EVALUATION OF THE THOMPSON-TYPE YIELD MODELS FOR SOYBEANS IN IOWA, ILLINOIS, AND INDIANA. By Richard A. Kestle; Research Division, Statistical Reporting Service, U. S. Department of Agriculture, Columbia, Missouri 65201, July, 1982. SRS Staff Report No. AGES820715

ABSTRACT

The Thompson-type models evaluated use the basic input variables of year and monthly average temperature and total precipitation to predict soybean yields in Iowa, Illinois, and Indiana. Both pooled and unpooled models predicting crop reporting district and state level yields were compared; pooled models outperformed the unpooled models. Evaluation of yield reliability at the state level indicated bias of pooled models less than one quintal/hectare and standard deviation between one and two quintals/hectare. The models are objective. Some input variables were not statistically significant. Timely yield estimates can be made with approximate (or assumed normal) climatic division weather data. The models are not costly to use and are easy to understand.

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

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

AgRISTARS
Yield Model Development
Project

YMD-1-4-1(82-07.2)

FOREWORD

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

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

The previously published reports in these series are listed below:

- "Evaluation of the CEAS Trend and Monthly Weather Data Models for Spring Wheat Yields in North Dakota and Minnesota," by Jeanne L. Sebaugh (USDA).

- "Evaluation of the Williams-Type Spring Wheat Model in North Dakota and Minnesota," by Sharon K. LeDuc (NOAA).

- "Comparison of CEAS and Williams-Type Models for Spring Wheat Yields in North Dakota and Minnesota," by Tom L. Barnett (NASA).

- "Evaluation of the CEAS Model for Barley Yields in North Dakota and Minnesota," by Tom L. Barnett (NASA).

- "Evaluation of the Williams-Type Model for Barley Yields in North Dakota and Minnesota," by Tom L. Barnett (NASA).

- "Comparison of CEAS and Williams-Type Barley Yield Models for North Dakota and Minnesota," by Sharon K. LeDuc (NOAA).

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

WENDELL W. WILSON, Head
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Yield Research Branch
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U. S. Department of Agriculture

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Average Production and Yield
For Years 1970-1979

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

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

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

MODEL COMPARISON

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

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

A statistical test has been constructed by considering that one model performs better than another if its predicted yields, $\hat{Y}$'s, are closer to the reported yields, Y's, than the other model. The reliability of each model is related to the absolute value of the discrepancy between reported and predicted yields. Thus, where $|d_1| = |\hat{Y}_1 - Y|$ and $|d_2| = |\hat{Y}_2 - Y|$, for models 1 (pooled) and 2 (unpooled), the statistic of interest is $D = |d_1| - |d_2|$. The null hypothesis to be tested is that there is no difference in the reliability of the two models over the ten test years. This hypothesis is rejected if D is not close to zero.

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

Indicators of Yield Reliability and Statistical Tests Show the Pooled Model is Preferred

The model values and comparative ranks for the bias, root mean square error (RMSE), and standard deviation (SD) are given in the Appendix (p. 38). In Iowa the pooled model RMSE and SD results rank first in an overwhelming majority of CRDs and at the state level. For Illinois and Indiana there is less distinction between model results. Generally, the pooled models do better in Indiana and the unpooled models better in Illinois. Biases are small in all models, but the pooled approach does give a smaller bias in more CRDs and at state and region levels than the unpooled approach.

Results of the parametric and non-parametric paired-sample statistical tests are given in the Appendix (p. 39). Only three CRDs and the Indiana state results show any significant difference between the pooled and unpooled models using the parametric test. The pooled models give the better performance in each case. With the nonparametric test results, more significant differences were found, and in each case the pooled models were more reliable.

In summary, the pooled model method resulted in more reliable model performances than the unpooled model method in all three states. The remainder of this report will deal with the evaluation of the Thompson-type pooled soybean yield models.

MODEL EVALUATION

Indicators of Yield Reliability Based on $d = \hat{Y}-Y$ Show Bias Usually Less Than 1 Quintal/Hectare and Standard Deviations Between 1 and 3 Quintals/Hectare

The CRD, state, and region values of indicators of yield reliability based on d are given in Table 2. The bias is negative for nearly all models in Illinois and Indiana. Generally, the absolute value of the bias is less than a quintal/hectare in all CRDs with exceptions occurring in CRD 70 in Iowa and in CRDs 20, 30, 60, 80 and 90 in Indiana. These exceptions also include the only CRD models with a relative bias greater than five percent. The root mean square error is between one and three quintals/hectare in all CRDs for all three states (Figure 2). The relative root mean square error varies from state to state; in Iowa it is below ten percent in all but CRD 80, in Indiana it ranges between six and thirteen percent, and in Illinois it ranges between eight and eleven percent. Because of the relatively small biases, standard deviations and relative standard deviations are comparable to root mean square error values.

Only CRDs 20 and 60 in Iowa and CRD 70 in Indiana produced smaller standard deviations and root mean square errors than the state models. Biases at the state level were small and relative root mean square errors at the state level were all less than nine percent. The state model did somewhat better than the aggregated CRD results in Illinois and Indiana, but did slightly worse than the aggregated CRD results in Iowa. At the regional level, aggregating from states produced slightly more favorable results than aggregating from CRDs.

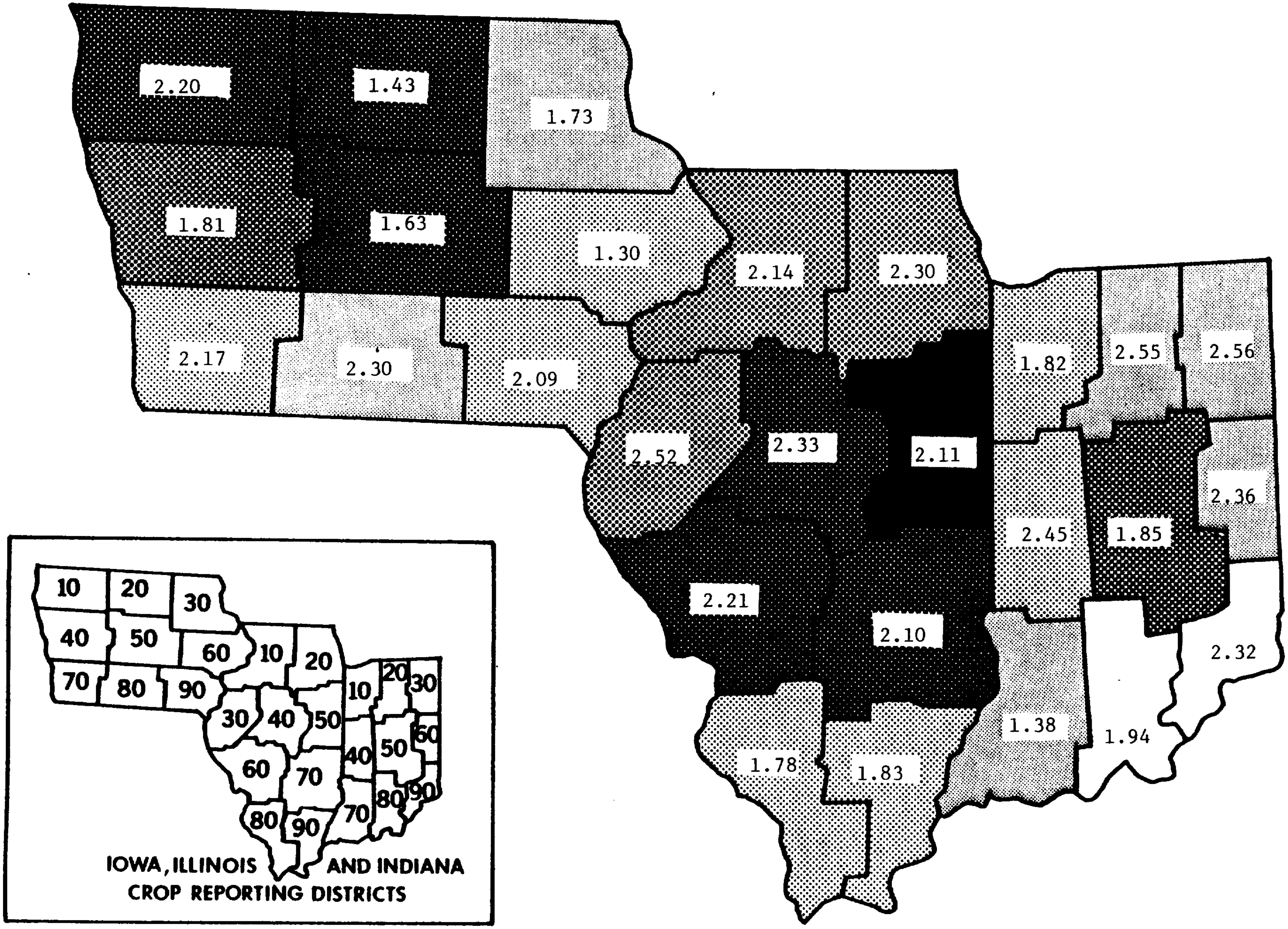
Table 2
Indicators of Yield Reliability
Based on D = Predicted - Reported Yield

Thompson Model - Soybeans
Iowa, Illinois, Indiana 1970-1979

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

STATE	CRD	MSE	RMSE	RRMSE	VAR	SD	RSD	B-SQR	BIAS	RB
IOWA	10	4.86	2.20	9.5	3.99	2.00	8.9	0.86	-0.93	-4.0
	20	2.05	1.43	6.3	2.04	1.43	6.3	0.01	-0.11	-0.5
	30	3.00	1.73	8.0	2.68	1.64	7.8	0.32	-0.57	-2.6
	40	3.27	1.81	8.1	3.26	1.80	8.1	0.01	0.10	0.5
	50	2.64	1.63	6.9	2.48	1.57	6.5	0.17	0.41	1.7
	60	1.70	1.30	5.4	1.33	1.15	4.6	0.37	0.61	2.5
	70	4.71	2.17	9.9	2.70	1.64	7.0	2.02	1.42	6.5
	80	5.31	2.30	11.4	5.31	2.30	11.4	0.00	0.02	0.1
	90	4.37	2.09	9.1	4.29	2.07	9.2	0.08	-0.28	-1.2
STATE MODEL		2.49	1.58	6.9	2.40	1.55	6.9	0.10	-0.31	-1.4
CRDS AGGR.		2.12	1.46	6.4	2.12	1.46	6.4	0.00	0.00	0.0
ILLINOIS	10	4.60	2.14	8.9	4.30	2.07	8.8	0.30	-0.55	-2.3
	20	5.30	2.30	10.3	5.18	2.28	10.4	0.12	-0.34	-1.5
	30	6.33	2.52	10.7	5.81	2.41	10.6	0.52	-0.72	-3.1
	40	5.42	2.33	9.3	5.29	2.30	9.3	0.14	-0.37	-1.5
	50	4.44	2.11	8.7	4.24	2.06	8.6	0.20	-0.45	-1.9
	60	4.90	2.21	9.5	4.33	2.08	9.3	0.56	-0.75	-3.2
	70	4.42	2.10	10.1	3.78	1.94	9.7	0.64	-0.80	-3.8
	80	3.17	1.78	9.2	3.17	1.78	9.2	0.00	0.02	0.1
	90	3.33	1.83	10.5	3.19	1.79	10.0	0.14	0.38	2.2
STATE MODEL		2.66	1.63	7.3	2.58	1.61	7.2	0.08	-0.28	-1.2
CRDS AGGR.		3.68	1.92	8.5	3.45	1.86	8.4	0.23	-0.48	-2.1
INDIANA	10	3.30	1.82	8.2	2.77	1.66	7.8	0.53	-0.73	-3.3
	20	6.51	2.55	11.7	5.12	2.26	11.0	1.39	-1.18	-5.4
	30	6.53	2.56	12.2	3.68	1.92	10.0	2.86	-1.69	-8.1
	40	6.01	2.45	10.8	5.24	2.29	10.5	0.77	-0.88	-3.9
	50	3.44	1.85	7.9	3.22	1.79	7.8	0.22	-0.47	-2.0
	60	5.59	2.36	11.2	2.99	1.73	8.9	2.59	-1.61	-7.6
	70	1.91	1.38	6.7	1.91	1.38	6.7	0.00	0.07	0.3
	80	3.75	1.94	10.5	2.61	1.61	8.3	1.14	1.07	5.8
	90	5.39	2.32	12.3	3.90	1.97	9.8	1.49	1.22	6.5
STATE MODEL		2.46	1.57	7.2	2.46	1.57	7.2	0.00	-0.03	-0.1
CRDS AGGR.		3.10	1.76	8.1	2.55	1.60	7.6	0.55	-0.74	-3.4
REGION										
CRDS AGGR.		2.26	1.50	6.7	2.15	1.47	6.6	0.11	-0.33	-1.5
STATES AGGR.		2.09	1.45	6.4	2.04	1.43	6.4	0.05	-0.23	-1.0

Figure 2. Root mean square error (RMSE) for Thompson-type soybean yield models in quintals per hectare based on test years 1970-1979. Darker shades indicate CRDs with higher production.



Indicators of Yield Reliability Based on rd = 100d/Y Show 10 to 50 Percent of Years Have rd Greater Than 10 Percent and the Largest rd Between 11 and 47 Percent

The CRD, state, and region values for indicators of reliability based on rd are given in Table 3. CRD values are also shown in Figures 3-5. In Iowa, no CRD had more than 30 percent of its test years for which $|rd|$ was greater than 10 percent. CRD 80 had the largest $|rd|$ value of all (46.3%), but this was the only test year for that CRD in which $|rd|$ was greater than 10 percent. In Illinois, one CRD had $|rd|$ values greater than 10 percent in 50 percent of the years. The largest $|rd|$ values ranged from 15 percent to 34 percent. In Indiana, five CRDs showed 40 percent of the years with an $|rd|$ greater than 10 percent. The largest $|rd|$ values ranged from 15 to 25 percent. Over the three states, the range of the smallest $|rd|$ values was zero to three percent. The year with the largest $|rd|$ value varied, but was most commonly 1974 (see the Appendix section "Brief Description of Growing Conditions for Soybeans in the Bootstrap Test Years" for more information on yearly growing conditions and yields).

At the state level there is little difference between the state model and aggregated CRD results in any of the three states. Likewise, at the region level, the method of aggregation does not appear to matter.

Indicators of Yield Reliability Based on $\hat{Y}$ and Y Show Good Correspondence Between Direction of Change in Predicted As Compared to Reported Yields

Plots of the reported and predicted soybean yields over the ten-year test period from the state yield models are displayed in Figures 6-8. The CRD, state and regional values for indicators of yield reliability based on reported and predicted yields are given in Table 4. CRD values are also shown in Figures 9-11.

For most of the models in Iowa and Indiana, and for all models in Illinois, the change of direction in predicted yields agrees with the change in direction in reported yields (from the previous year and from the three-year base period) over fifty percent of the time. However, many of the Pearson correlation coefficients between reported and predicted yields did not prove significantly greater than zero at the 5 percent significance level. Non-significant coefficients were found in four of the Iowa CRDs (20, 70, 80, and 90), three of the Indiana CRDs (20, 40, and 90), and in Illinois CRD 30.

A review of Figures 6-8 shows that in both Indiana (1975-1977) and Illinois (1970-1972) the predicted state yields are somewhat insensitive to higher reported yields. In fact, the Illinois state model underestimates reported yields in seven of the ten bootstrap years. In most cases the movement of predicted yields (whether increasing or decreasing) does follow that of reported yields. The greatest departure was in Iowa where predicted yields decreased two quintals/hectare between 1974 and 1975 while reported soybean yields increased four quintals/hectare.

Table 3
Indicators of Yield Reliability
Based on RD = 100 * ((Predicted-Reported Yield)/Reported Yield

Thompson Model - Soybeans
Iowa, Illinois, Indiana 1970-1979

STATE	CRD	PERCENT OF YEARS |RD|>10%	LARGEST |RD| RD (YEAR)	NEXT LARGEST	SMALLEST |RD|	RANGE |RD|
IOWA	10	30	-15.4 (1972)	14.1	-1.5	13.9
	20	10	14.9 (1974)	-6.8	-0.9	14.1
	30	30	-14.0 (1977)	-10.6	-2.3	11.7
	40	20	18.0 (1974)	16.2	0.0	18.0
	50	10	19.7 (1974)	10.0	-1.2	18.5
	60	20	11.9 (1976)	10.6	0.4	11.6
	70	30	27.0 (1974)	14.6	0.8	26.1
	80	10	46.3 (1974)	-10.0	1.5	44.8
	90	10	29.2 (1974)	-9.3	-1.8	27.4
STATE MODEL		30	16.5 (1974)	-10.9	-1.0	15.5
CRDS AGGR.		10	18.6 (1974)	8.7	-0.4	18.2
ILLINOIS	10	30	26.5 (1974)	-12.8	-0.8	25.7
	20	30	20.6 (1974)	-18.1	-0.5	20.1
	30	50	31.9 (1974)	-11.5	0.8	31.1
	40	10	34.1 (1974)	-9.3	-0.4	33.7
	50	30	24.4 (1974)	-11.7	2.0	22.4
	60	20	21.9 (1974)	-12.8	1.9	20.0
	70	40	19.1 (1974)	-14.5	-2.2	16.9
	80	30	14.9 (1974)	-12.1	-1.5	13.4
	90	30	25.8 (1978)	20.9	-1.1	24.8
STATE MODEL		10	21.8 (1974)	-8.1	-1.0	20.9
CRDS AGGR.		20	23.6 (1974)	-12.1	-0.5	23.2
INDIANA	10	20	-15.2 (1977)	14.0	1.3	13.9
	20	30	-21.0 (1975)	-19.5	2.3	18.7
	30	40	-21.6 (1977)	-16.9	-0.5	21.0
	40	40	24.5 (1974)	-16.0	2.0	22.5
	50	30	16.3 (1974)	-13.1	0.4	15.9
	60	40	-18.5 (1977)	-17.9	2.7	15.9
	70	20	12.0 (1978)	10.8	0.5	11.5
	80	40	22.5 (1975)	21.5	-0.6	21.9
	90	40	24.8 (1973)	19.3	0.6	24.3
STATE MODEL		10	14.9 (1974)	9.1	1.0	13.9
CRDS AGGR.		20	-14.9 (1977)	10.1	-2.5	12.4
REGION MODEL						
CRDS AGGR.		10	19.5 (1974)	-9.3	-0.5	19.1
STATES AGGR.		10	18.4 (1974)	-8.6	0.8	17.6

Figure 3. Percent of test years (1970-1979) the absolute value of the relative difference from the Thompson-type soybean models is greater than ten percent. Darker shades indicate CRDs with higher production.

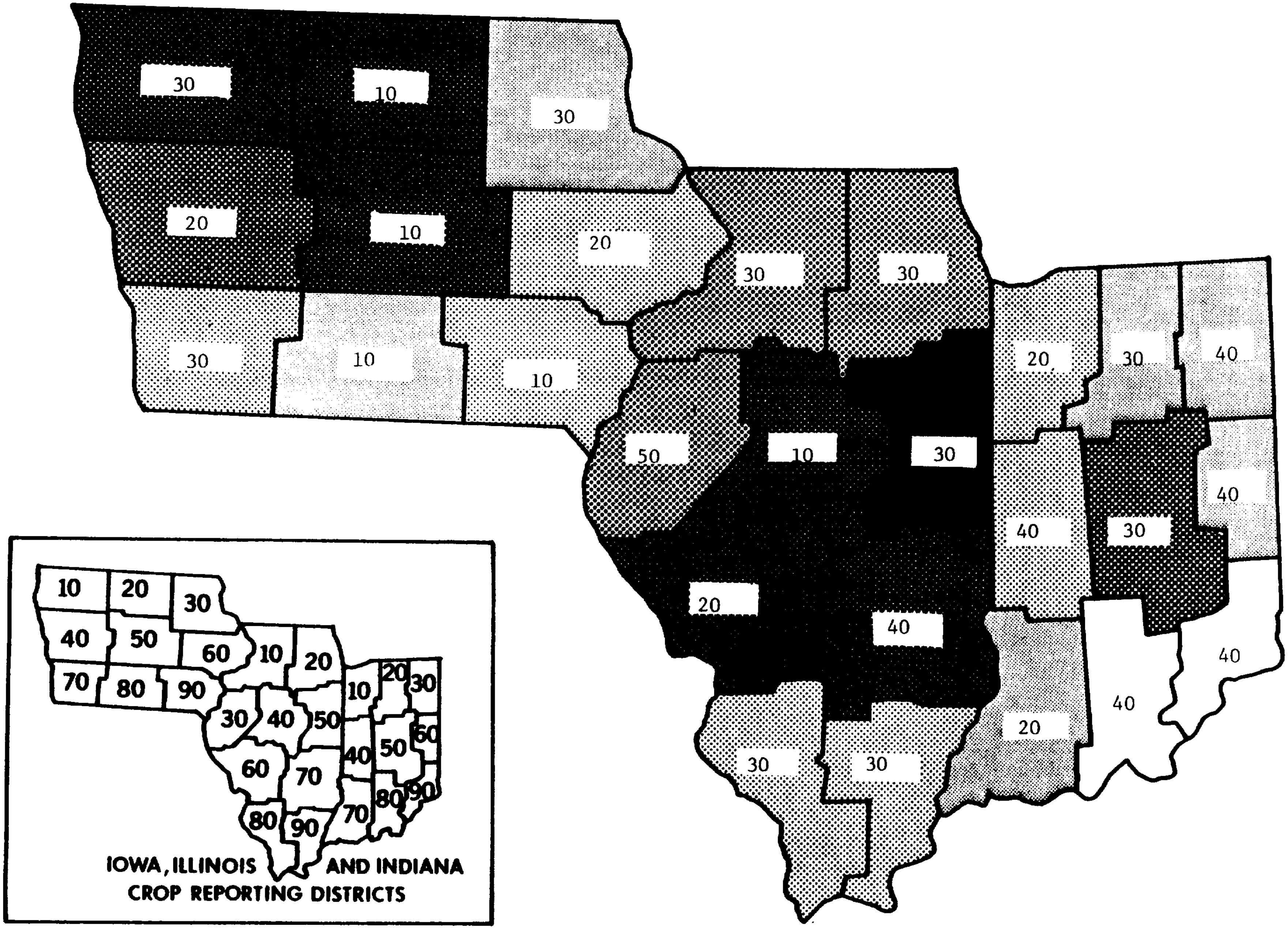


Figure 4. Largest absolute value of the relative difference from the Thompson-type soybean models during the test years 1970-1979. Darker shades indicate CRDs with higher production.

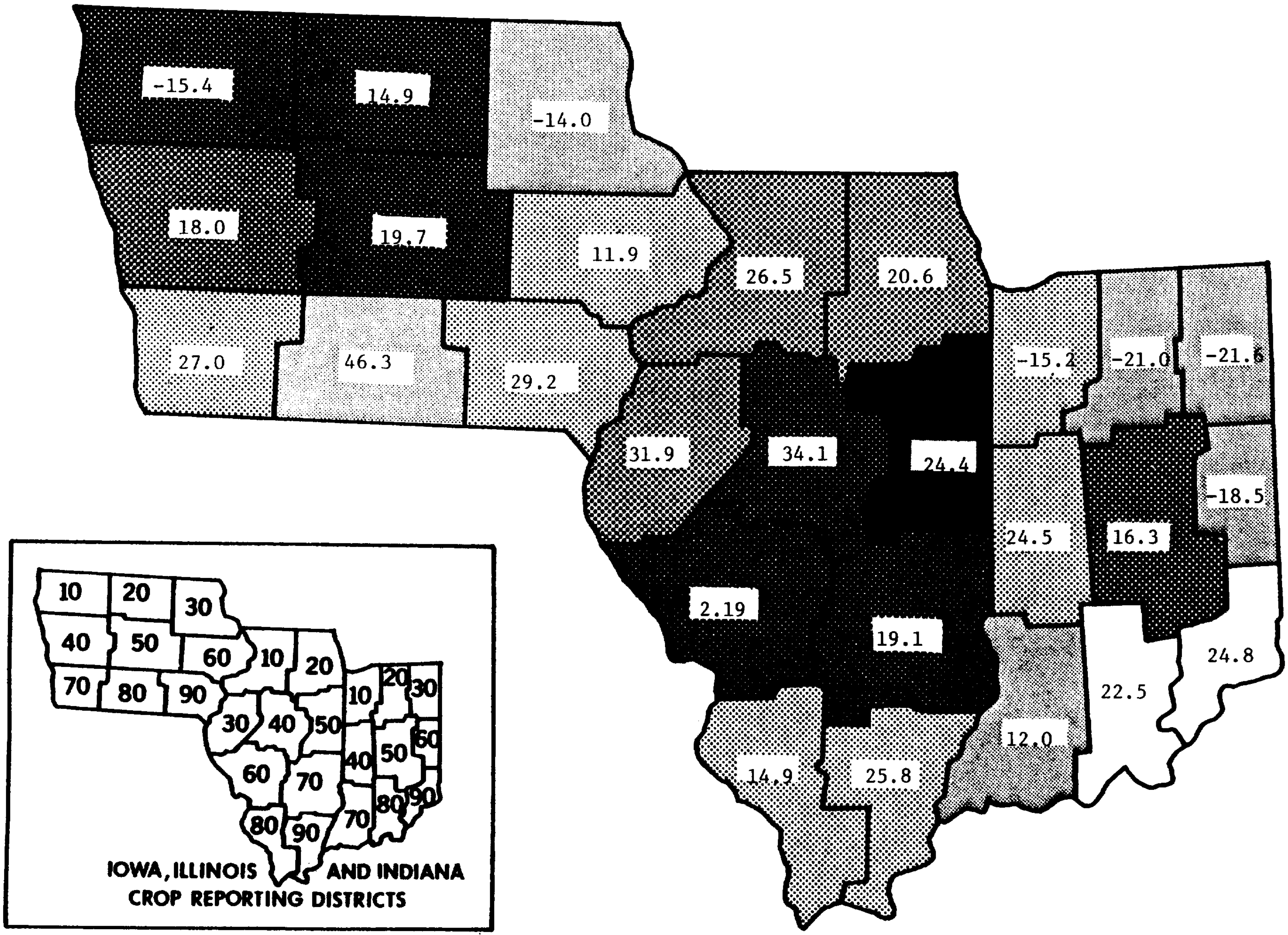


Figure 5. Next largest absolute value of the relative difference from the Thompson-type soybean models during the test years 1970-1979. Darker shades indicate CRDs with higher production.

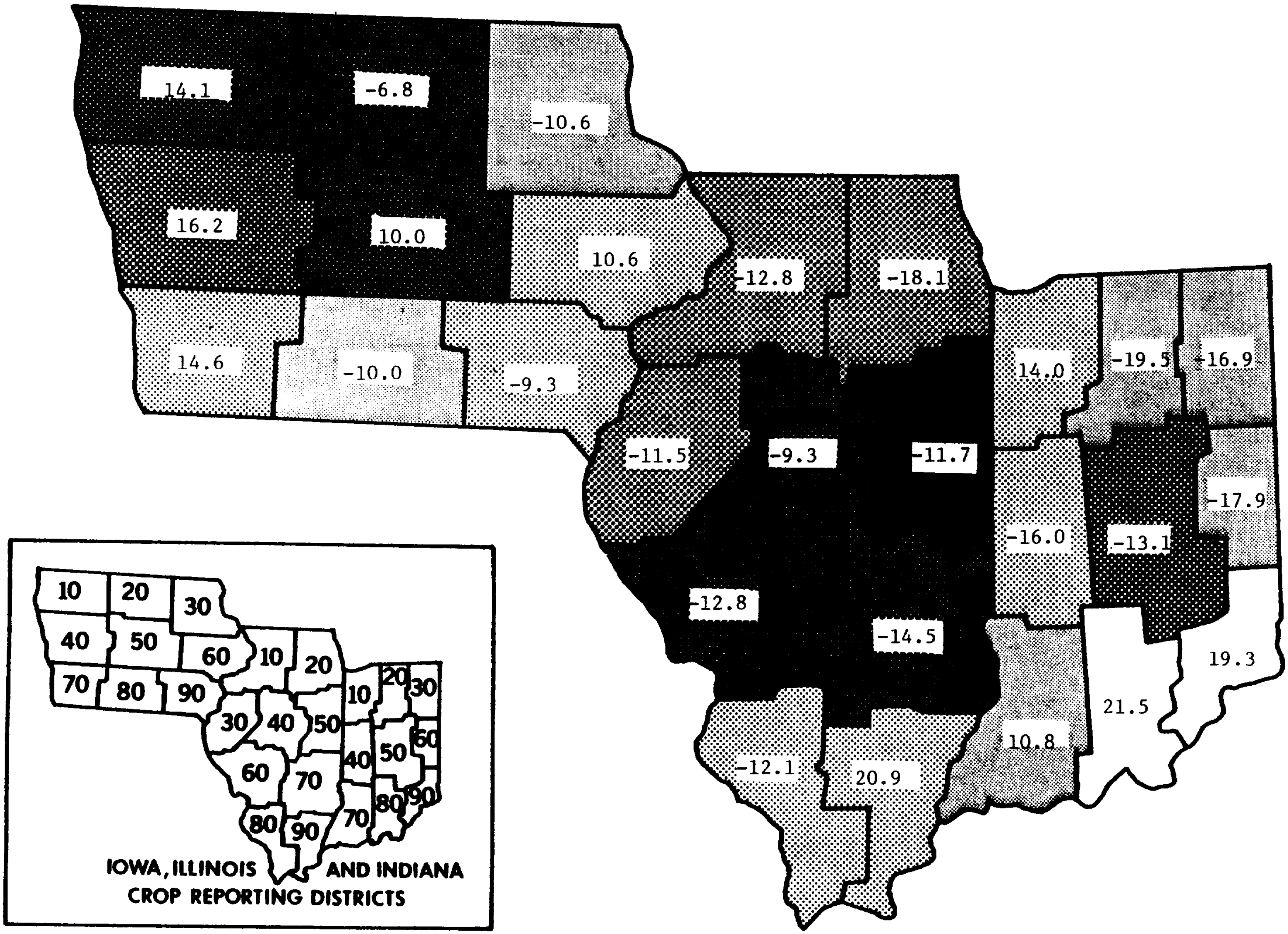


Figure 6

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

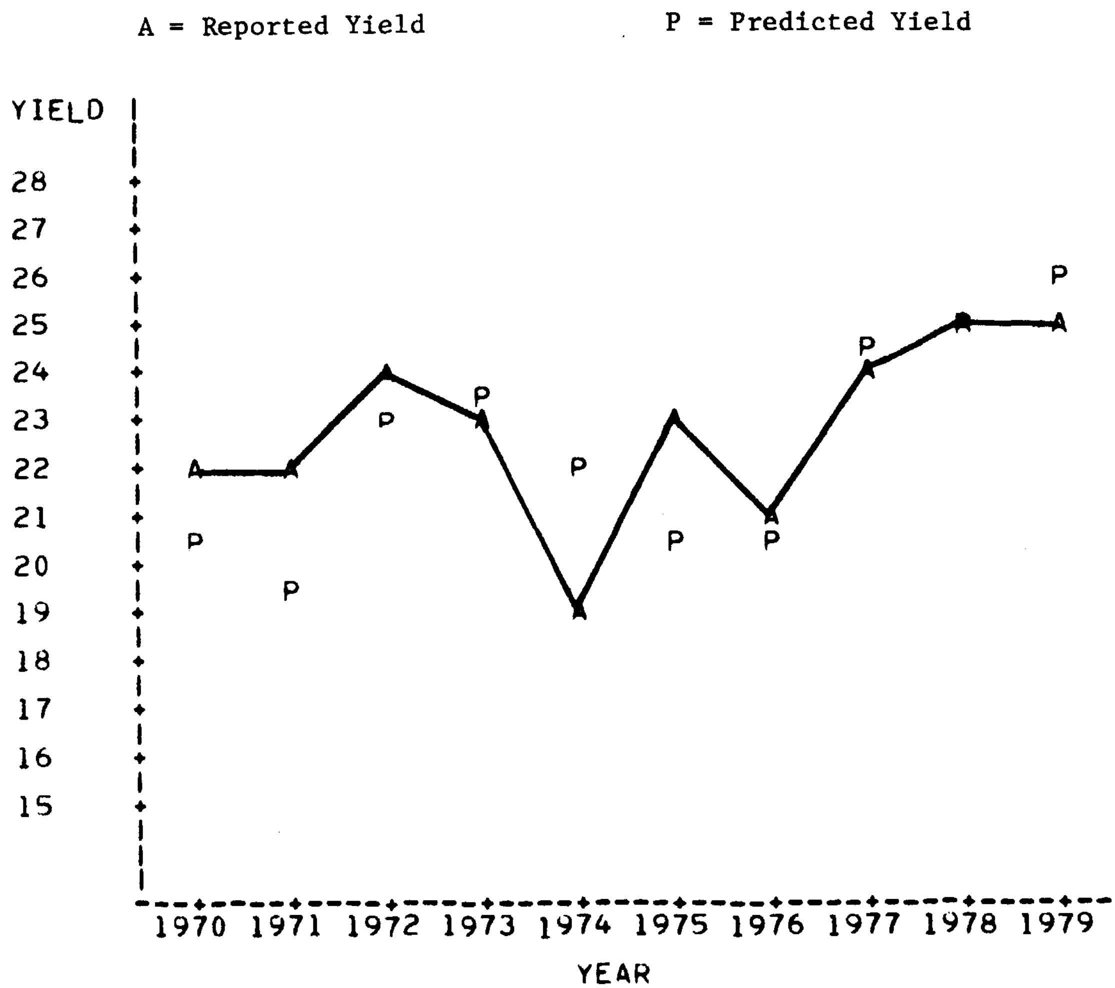


Figure 7

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

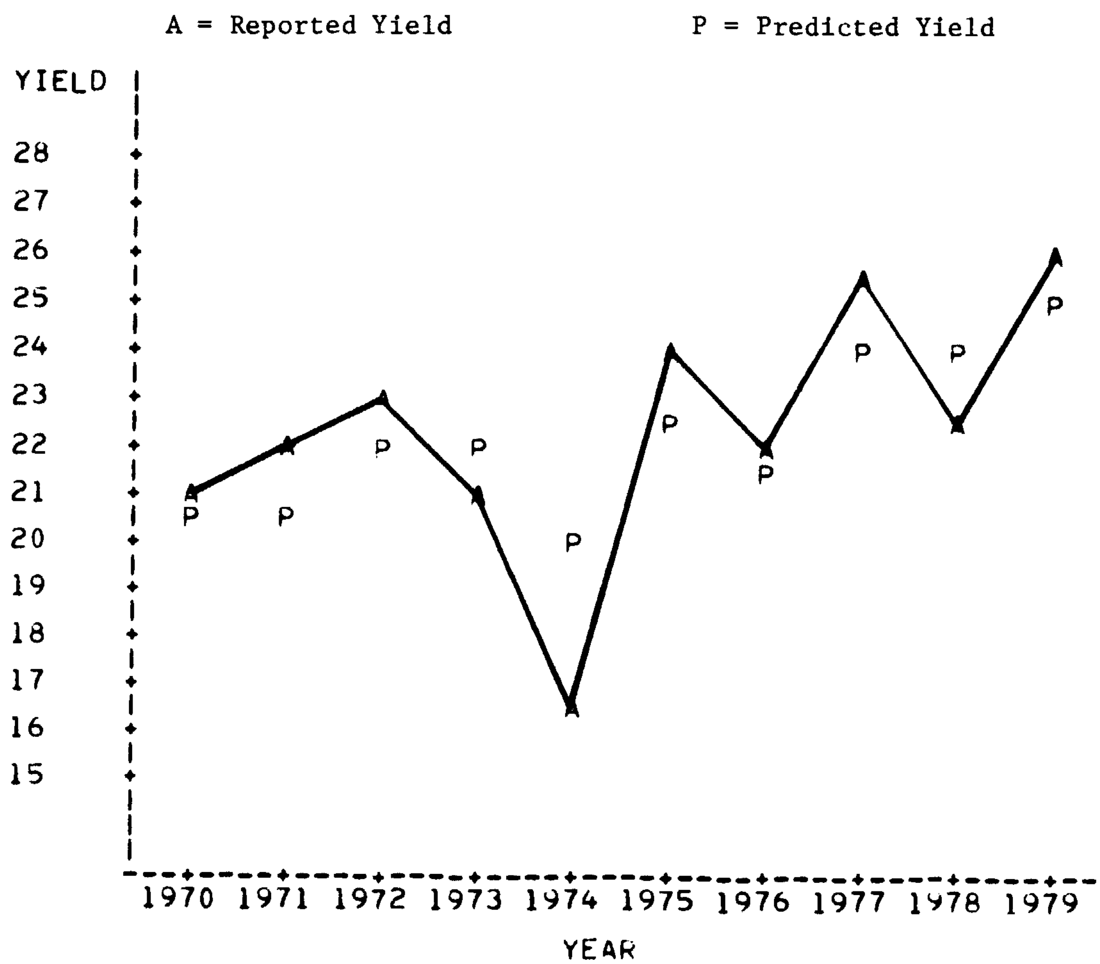


Figure 8

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

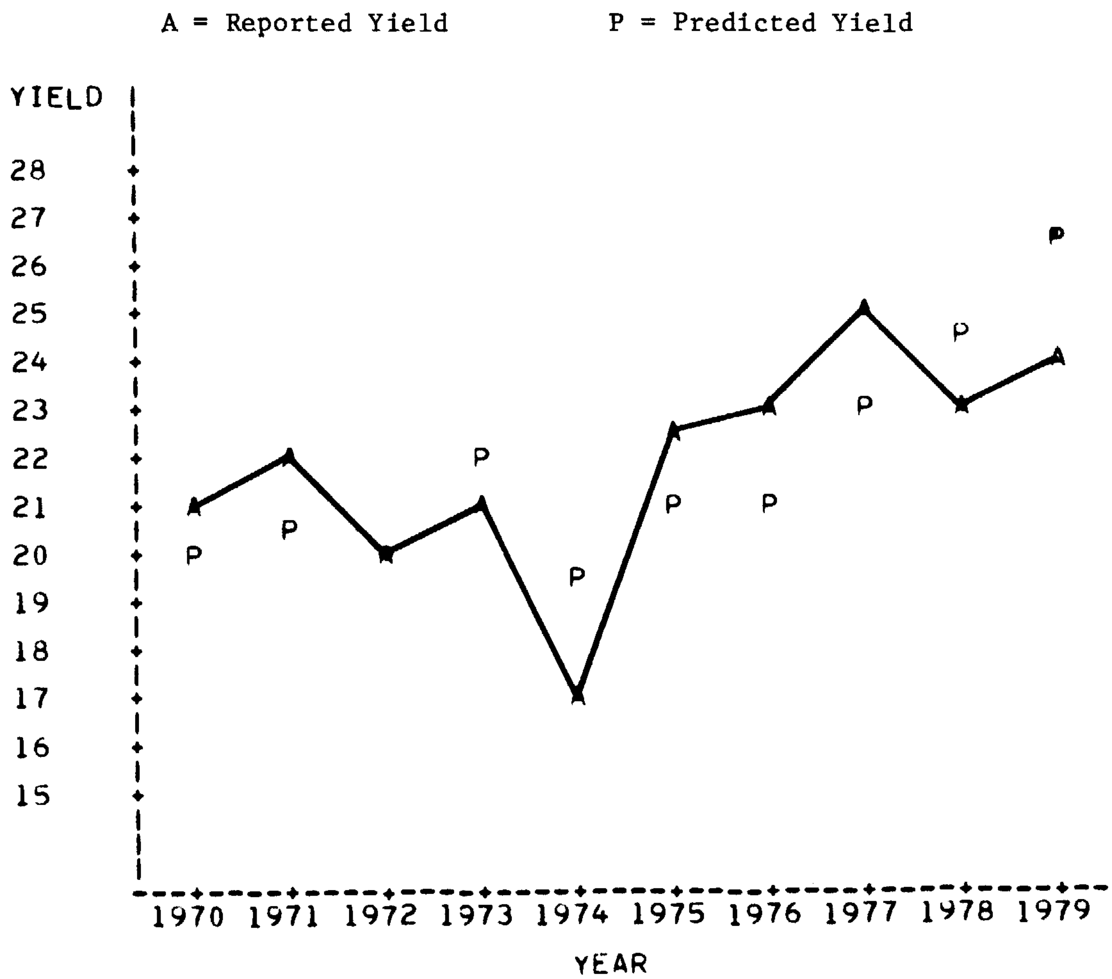


Table 4
Indicators of Yield Reliability
Based on Reported and Predicted Yields

Thompson Model - Soybeans
Iowa, Illinois, Indiana 1970-1979

STATE	CRD	PERCENT OF YEARS DIRECTION OF CHANGE IS CORRECT: FROM PREVIOUS YEAR	FROM BASE PERIOD	PEARSON CORR. COEF.
IOWA	10	67	86	0.70
	20	78	57	0.52
	30	67	43	0.69
	40	67	71	0.77
	50	78	86	0.78
	60	78	100	0.83
	70	22	71	0.39
	80	56	57	0.32
	90	67	86	0.53
STATE MODEL		44	86	0.69
CRDS AGGR.		67	57	0.65
ILLINOIS	10	89	71	0.77
	20	78	57	0.58
	30	56	57	0.48
	40	67	57	0.76
	50	67	57	0.64
	60	67	57	0.63
	70	67	57	0.73
	80	67	71	0.73
	90	89	86	0.73
STATE MODEL		89	57	0.81
CRDS AGGR.		89	57	0.75
INDIANA	10	67	71	0.67
	20	44	71	0.53
	30	67	71	0.64
	40	56	57	0.54
	50	56	86	0.72
	60	44	71	0.61
	70	56	71	0.72
	80	56	86	0.57
	90	56	43	0.48
STATE MODEL		78	86	0.74
CRDS AGGR.		56	86	0.70
REGION MODEL				
CRDS AGGR.		89	86	0.73
STATES AGGR.		67	57	0.75

Figure 9. Percent of test years (1970-1979) the direction of change from the previous year in yield as predicted by the Thompson-type soybean models agree with the direction of change in the reported yields. Darker shades indicate CRDs with higher production.

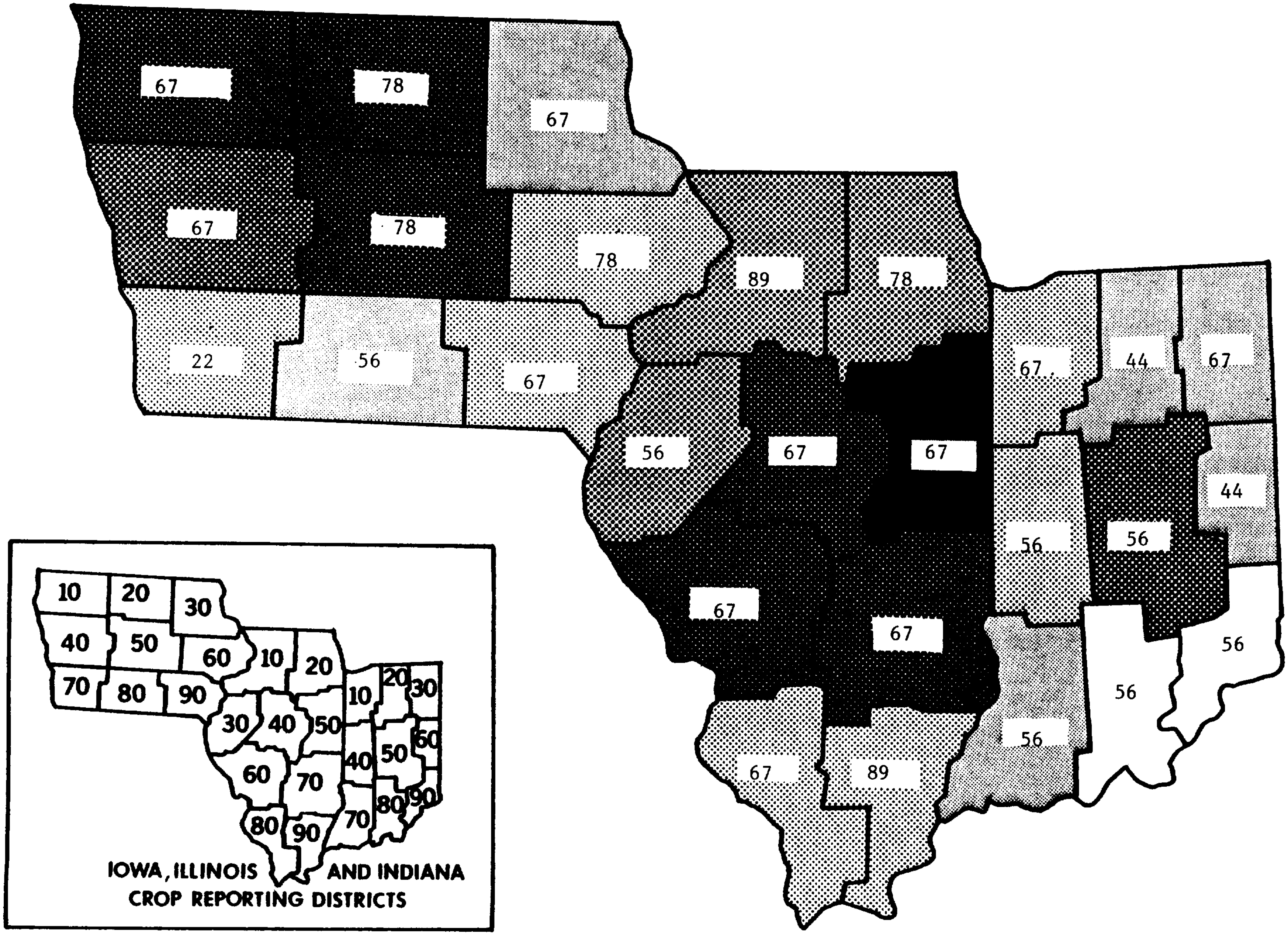


Figure 10. Percent of test years (1970-1979) the direction of change from the previous three years average yield as predicted by the Thompson-type soybean models agree with the direction of change in the reported yield. Darker shades indicate CRDs with higher production.

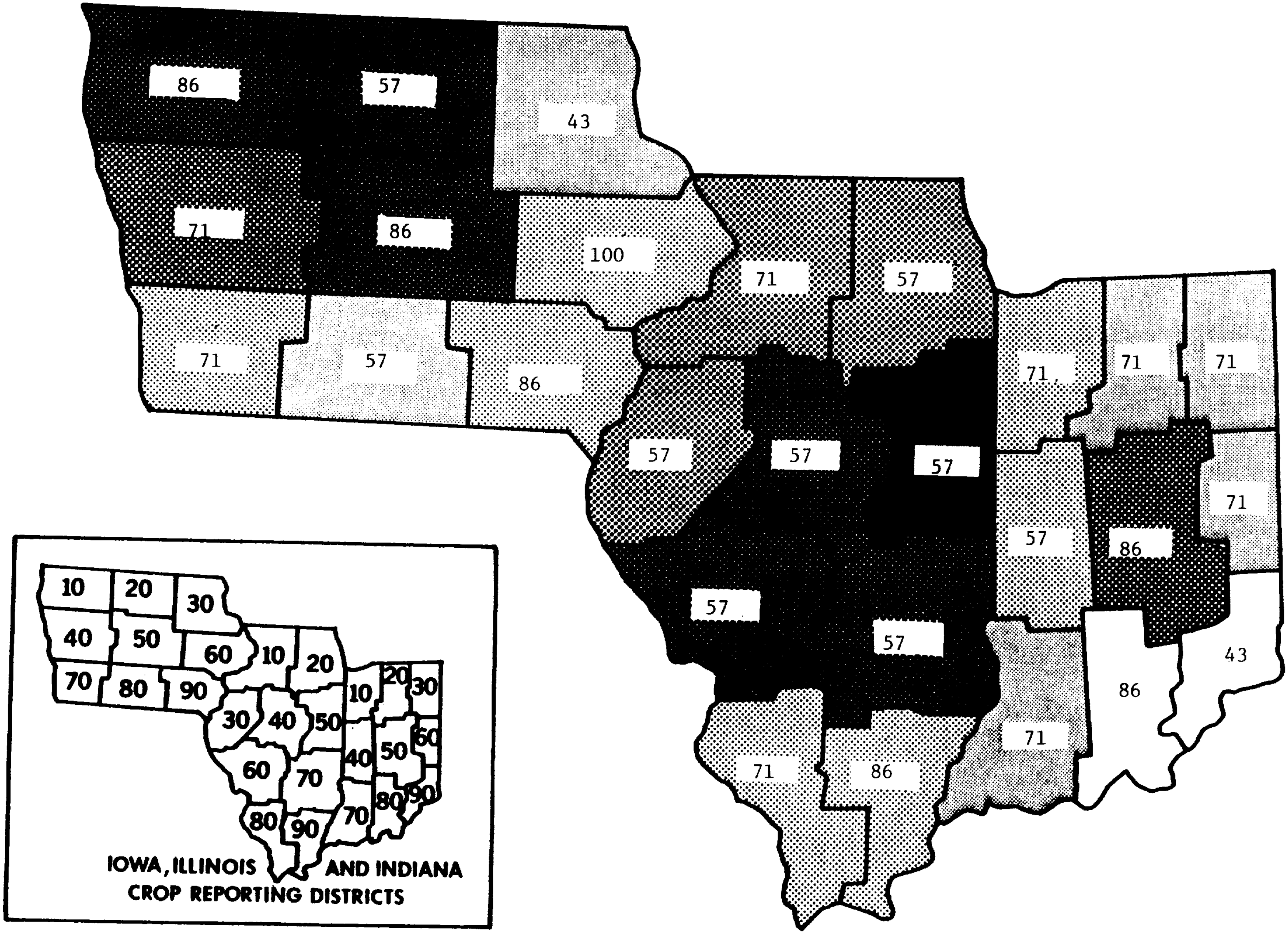
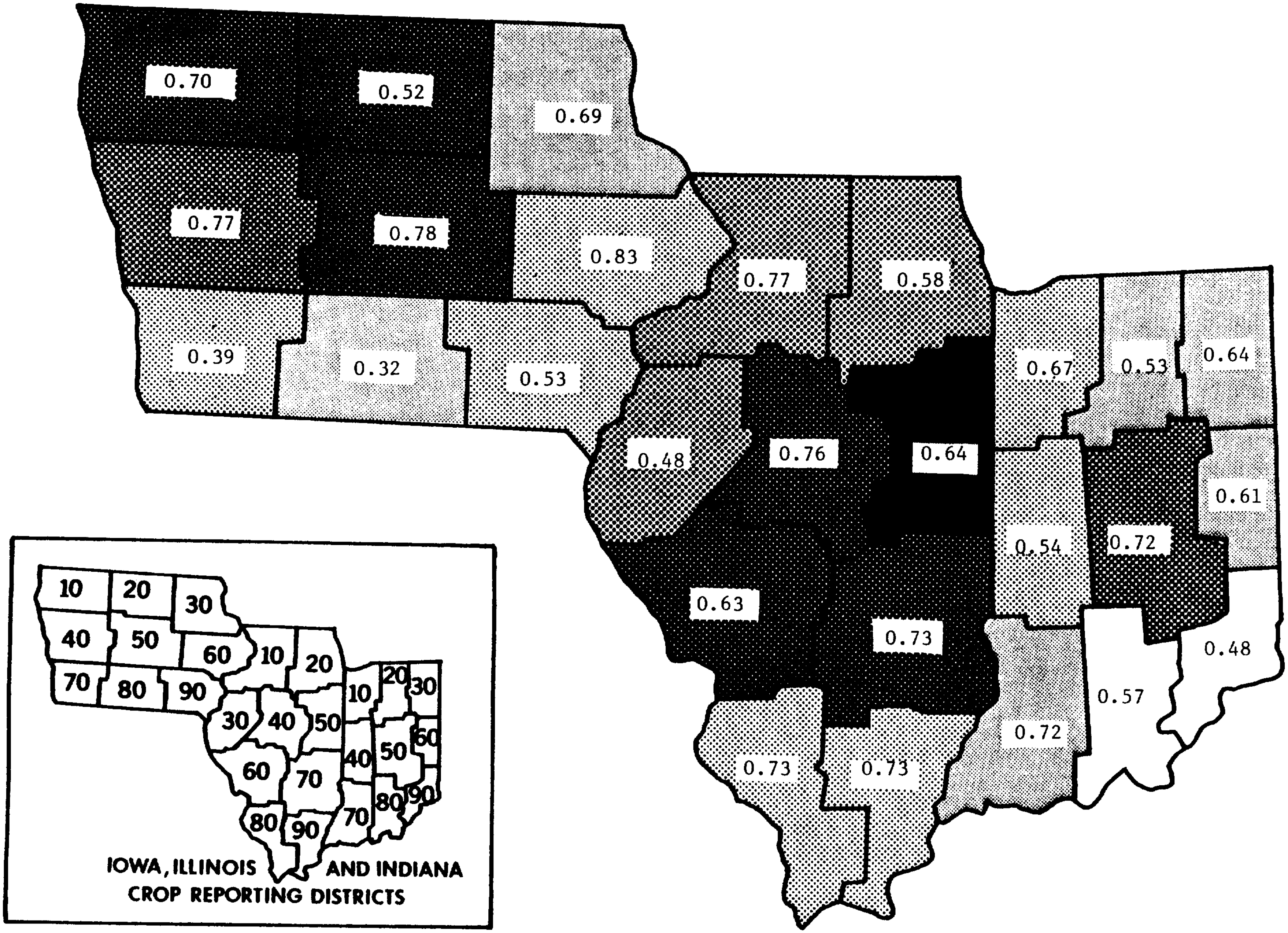


Figure 11. Pearson correlation coefficients between reported yield and yield as predicted by Thompson-type soybean models for the test years 1970-1979. Darker shades indicate CRDs with higher production.



At the state level there appears little difference between state models and aggregated CRD results, although the state models do give slightly greater correlation coefficients. Similarly, the method of aggregation does not seem significant at the region level.

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

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

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

The MSE values of Table 2 are also given in Table 5. In all but one case (CRD 60 in Iowa) the independent test MSEs were greater than the corresponding average base period residual mean square, and even larger than the highest corresponding base period residual mean square. Obviously, use of the residual mean square indicators of fit as indicators of predicted yield reliability would be misleading.

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

Table 5
Residual Mean Square As An
Indicator of the Fit of the Model

Thompson Model - Soybeans
Iowa, Illinois, Indiana 1970-1979

STATE	CRD	BASE PERIOD RESIDUAL MEAN SQUARE LOW	HIGH	AVERAGE	INDEPENDENT TEST MSE
IOWA	10	1.72	2.00	1.88	4.86
	20	1.72	2.00	1.88	2.05
	30	1.72	2.00	1.88	3.00
	40	1.72	2.00	1.88	3.27
	50	1.72	2.00	1.88	2.64
	60	1.72	2.00	1.88	1.70
	70	1.72	2.00	1.88	4.71
	80	1.72	2.00	1.88	5.31
	90	1.72	2.00	1.88	4.37
STATE MODEL		1.07	1.32	1.18	2.49
ILLINOIS	10	1.38	1.84	1.58	4.60
	20	1.38	1.84	1.58	5.30
	30	1.38	1.84	1.58	6.33
	40	1.38	1.84	1.58	5.42
	50	1.38	1.84	1.58	4.44
	60	1.38	1.84	1.58	4.90
	70	1.38	1.84	1.58	4.42
	80	1.38	1.84	1.58	3.17
	90	1.38	1.84	1.58	3.33
STATE MODEL		1.07	1.32	1.18	2.66
INDIANA	10	1.31	1.75	1.48	3.30
	20	1.31	1.75	1.48	6.51
	30	1.31	1.75	1.48	6.53
	40	1.31	1.75	1.48	6.01
	50	1.31	1.75	1.48	3.44
	60	1.31	1.75	1.48	5.59
	70	1.31	1.75	1.48	1.91
	80	1.31	1.75	1.48	3.75
	90	1.31	1.75	1.48	5.39
STATE MODEL		1.07	1.32	1.18	2.46

Table 6
Correlation Between Observed and Predicted Yields As An Indicator of the Fit of the Model Based on the Model Development Base Period

Thompson Model - Soybeans
Iowa, Illinois, Indiana 1970-1979

TEST STATE	CRD	BASE PERIOD CORRELATION COEF. LOW	HIGH	AVERAGE	INDEPENDENT CORR. COEF.
IOWA	10	0.89	0.92	0.91	0.70
	20	0.89	0.92	0.91	0.52
	30	0.89	0.92	0.91	0.69
	40	0.89	0.92	0.91	0.77
	50	0.89	0.92	0.91	0.78
	60	0.89	0.92	0.91	0.83
	70	0.89	0.92	0.91	0.39
	80	0.89	0.92	0.91	0.32
	90	0.89	0.92	0.91	0.53
STATE MODEL		0.95	0.96	0.95	0.69
ILLINOIS	10	0.96	0.96	0.96	0.77
	20	0.96	0.96	0.96	0.58
	30	0.96	0.96	0.96	0.48
	40	0.96	0.96	0.96	0.76
	50	0.96	0.96	0.96	0.64
	60	0.96	0.96	0.96	0.63
	70	0.96	0.96	0.96	0.73
	80	0.96	0.96	0.96	0.73
	90	0.96	0.96	0.96	0.73
STATE MODEL		0.95	0.96	0.95	0.81
INDIANA	10	0.94	0.95	0.95	0.67
	20	0.94	0.95	0.95	0.53
	30	0.94	0.95	0.95	0.64
	40	0.94	0.95	0.95	0.54
	50	0.94	0.95	0.95	0.72
	60	0.94	0.95	0.95	0.61
	70	0.94	0.95	0.95	0.72
	80	0.94	0.95	0.95	0.57
	90	0.94	0.95	0.95	0.48
STATE MODEL		0.95	0.96	0.95	0.74

square indicators of fit discussed above, all base period CRD level values of R are the same in a given year and state. The average values range from 0.91 to 0.96.

The Pearson correlation coefficient values from Table 4 are also shown in Table 6. They range in value from 0.32 to 0.83. In every case the independent test correlation coefficients were smaller than even the lowest base period R values. Base period R^2 values will increase with each additional model parameter to be estimated. Every Thompson-type yield model estimates 14 parameters; this very large number may be an important factor as to why R^2 (and thus R) values are so high. Thus, the base period R values are overestimating the independent performance of the models.

Models Are Objectively Defined and Used

The variables included in each model were determined at the time of model development. To predict yield in a future year, calculated weather and "yield with normal weather" values are used with estimated regression coefficients derived during model development. These steps are all part of a well defined and objective procedure. No subjective decisions are called for in adjusting any of the model forms. Every model uses the same weather and trend variables, and it is assumed that subsequent models in future years will continue to do so. However, trend may need to be re-specified in order to keep up with the current impact of technology on yields. This re-specification may involve subjective decisions.

Some subjectivity was involved in the initial choice of weather variables to use. Other possible weather and weather-related variables (such as evapotranspiration or available soil moisture) were not discussed.

Model Results and Scientific Evidence Suggest Fewer or Different Input Variables Needed

The Thompson-type soybean yield models use two types of variables: (1) trend (year) as a surrogate for technology and (2) weather variables expressed as deviations from normal.

Trends terms are an important component of the Thompson-type yield models. Technological changes have had important impacts on soybean yields over time, but inclusion of technological variables into yield models are often impossible because of a lack of continuous, long-term data bases. For this reason trend terms are used as surrogates for technological advances. The choice of trend term determines the residuals of the trend which are assumed to be dependent on the weather variables in the model. Therefore, if trend is incorrectly handled in a model, results may be substantially affected.

As stated in a previous section, a "yield with normal weather" input value was included in the Thompson-type models. This value was calculated in each state and year by first regressing yields on a linear trend variable, year minus 1929, and then multiplying the resulting trend coefficient times the value of trend in that particular year. The decision to use the simple linear term was based in part on a graphical review of yields vs. year over a five state region (Thompson 1970). Figures 12-14 show plots of state level yield vs year for Iowa, Illinois, and Indiana separately, and give no obvious cause for rejecting a simple linear trend as appropriate. The numerical values of the trend coefficients for the simple linear regression of yield on trend for all CRDs and states using data through 1979 are listed in the Appendix (p. 40). Trend coefficients ranged from 0.23 to 0.42 in Iowa while in Indiana and Illinois the range was only from 0.23 to 0.32. There is no readily available scientific explanation for this higher rate of increase in soybean yields due to technology in Iowa.

Thompson also justified the use of a linear trend based on fertilizer application practices and varietal improvement history. According to him, soybeans have benefited more from the residual effects of fertilizer on corn than on direct application, and that an even more important influence than fertilizer on soybean yields has been the development of improved varieties. Because of this cultural background, it is argued, yield increases have been slow and steady rather than piecewise or curvilinear. These relationships are possibly true, but no other references or sources are quoted by Thompson.

Entering trend and weather as distinct variables in a single regression equation does not clearly separate the impact of weather and non-weather influences on yield. More research needs to be done on alternate methods of distinguishing the effects of weather and technology.

The Thompson-type soybean yield models use monthly weather data. The monthly weather data available on a climatic division basis are total precipitation and average temperature. Total precipitation over several months is also derived. A long term "normal" or average is calculated for each monthly precipitation, monthly temperature, and accumulated precipitation over several months, and these normals are subtracted from each monthly (or cumulated monthly) value to arrive at departures from normal. One set of normals was calculated at each state level for use in the pooled state models; i.e., for calculating departures from normal at the individual CRD levels within each state. Similarly one regional set of normals was calculated for use in the pooled regional model and was used to calculate departures from normal at the individual state level. This method of calculating "pooled" normals instead of calculating normals individually by CRD and state was done in order to closely adhere to the Thompson approach. A comparison of bootstrap coefficients developed using the two different normals (not given here) showed little difference in value as a result of using either form of normal.

There are several problems inherent in the use of monthly weather data. One of these stems from the association of a monthly weather figure to large areas such as states or CRDs. It is assumed that the weather data are representative of the entire area over the entire month, when in actuality the weather may be representative of only a small subsection of the area or a portion of the month. Another problem arises from the fact that monthly divisions may have little correspondence to the beginning or ending of growth states in crop development, which in turn specify the changing temperature and moisture needs of the crop. Both of these problems will show large year-to-year fluctuations as well.

Figure 12

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

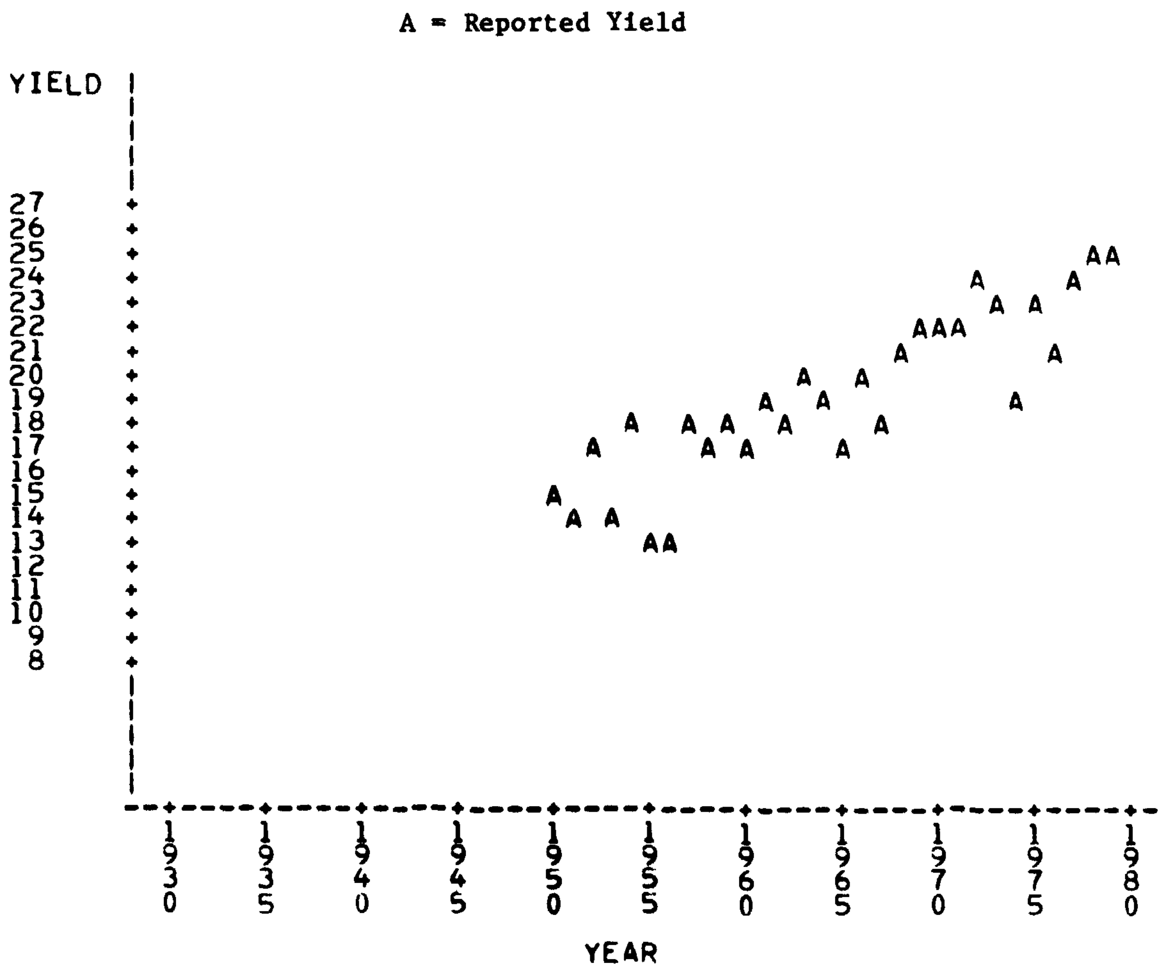


Figure 13

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

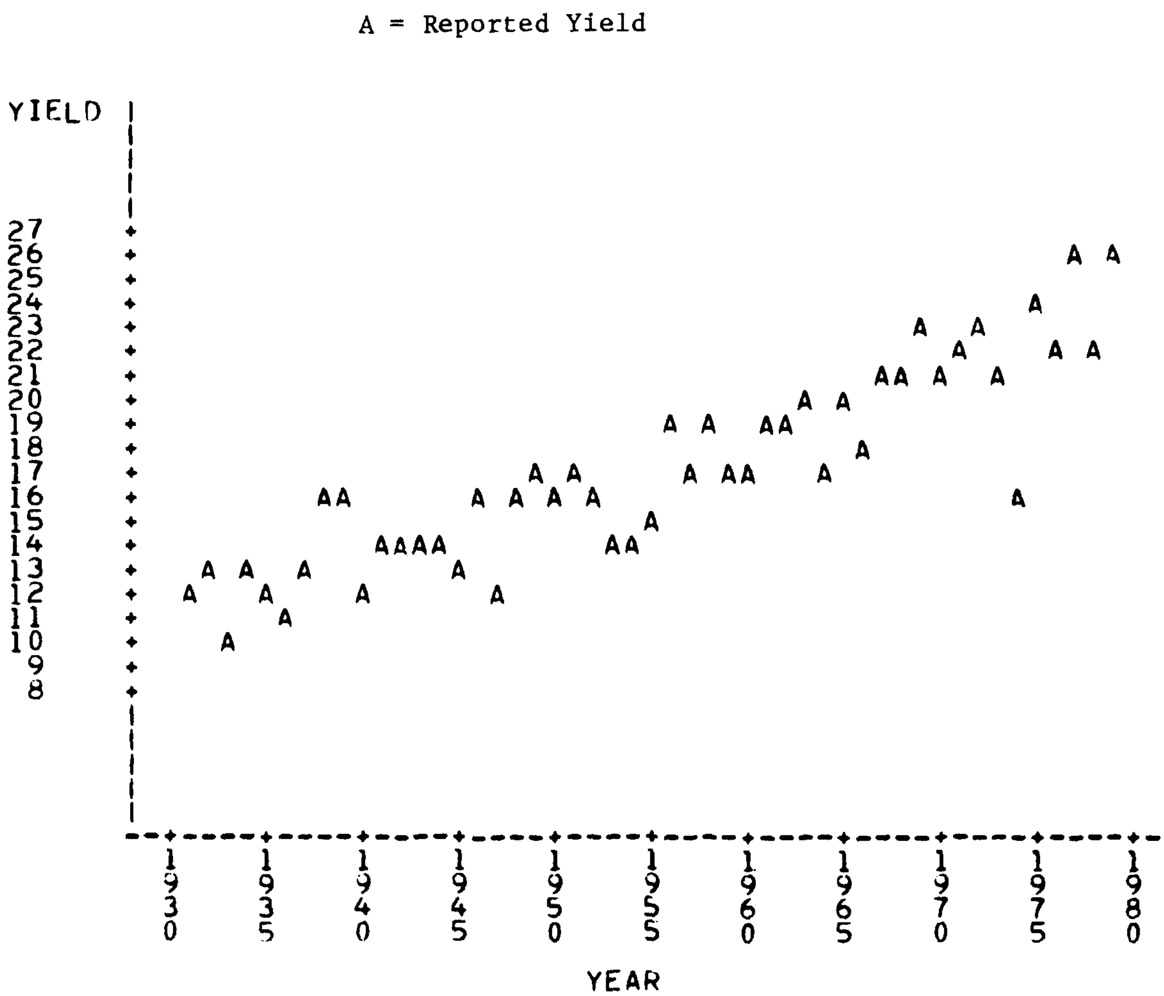
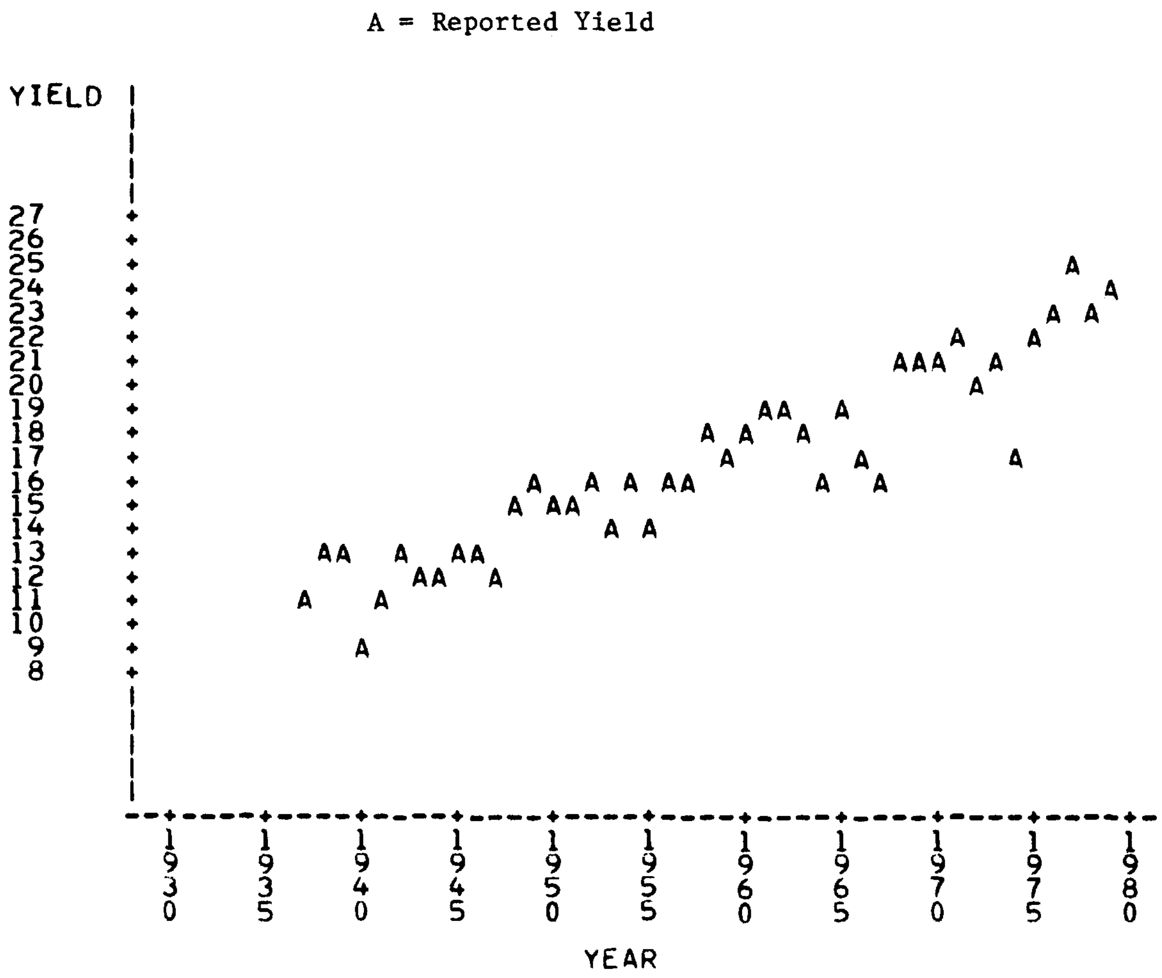


Figure 14

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



In the Thompson-type models both the linear and the quadratic components of each departure from normal weather variable are included. The inclusion of the quadratic terms was done because weather variables were assumed to be related to yield in a curvilinear pattern (Thompson, 1970). This assumption, although undefended, seems reasonable. For instance, it is likely that reductions in yield will occur during times of drought as well as during times of excess moisture.

The state and regional models were run using all data through 1979. In the Appendix (p. 41) is a table listing the resulting model coefficients and their significance levels. In every model there were three to five weather variables which were not significant. In most cases this included July and August temperature variables. It is known that monthly rainfall and temperatures are negatively correlated with each other in many situations; extremely high temperatures are usually associated with droughts. Thus, late season rains (July and August) which are important to crop yields (coefficients are positive and significant) provide enough information about the crop growing conditions as to make temperature variables unnecessary. However, June temperature coefficients are positive and significant as well, showing that soybeans respond to early season higher temperatures (before flowering). Also, all significant squared weather variables, whether precipitation or temperature, were negatively signed. This is in keeping with Thompson's assumption about the use of quadratic forms (noted above). Because these squared term coefficients were so small (on the order of 10^{-3} to 10^{-6}), it would take large departures from normal to significantly and adversely affect predicted soybean yields.

The stability of the signs of the coefficients over the bootstrap testing period were also reviewed. In a majority of cases the coefficients which fluctuated in sign (positive and negative) over the ten year test period were not significant when data through 1979 were used to develop the models.

A variety of possible methods for variable selection is now available. Based on the evaluations of these models and other scientific evidence, it is probable that soybean yield models could be developed that would need fewer weather variables for input and would better reflect agronomic and meteorological interactions.

Thompson-Type Models Could Be Easily Developed To Predict Yields in Other Geographic Areas

These models were originally developed by Thompson to model yields on a five-state regional scale and have since been applied to state and CRD levels. They could be developed for any geographical region for which yearly yield and monthly weather data were available. Because of the large number of input variables involved, a long-term time series of data (probably at least 25 years) would be necessary for adequate results. Using the Thompson approach to model development, no changes in model form would be necessary. The models evaluated here used climatic division weather data. The number of weather stations per division varies; in Indiana, for instance, the range is from seven to nineteen. Comparable results may be less stable in areas with fewer weather stations (county level for instance).

Timely Estimates Can Be Made Using Approximated Weather Data And/or Assumed Normal Weather

End-of-year yields can conceivably be predicted as early as September in the harvest year but this would be dependent on the availability of the weather data. It normally takes about three months after the end of a month to receive that month's average temperature and total precipitation at the climatic division level from the National Climatic Center in Ashville, N.C. Estimates of these climatic division values can be prepared earlier; these weather data approximations could be used in the model equations in the first week of the month following the month for which the data pertains.

If within-season yield forecasts are desirable, a combination of approximate monthly data estimates for past months and assumed normal weather for months yet to come can also be used to give rough predictions of yield.

Thompson-Type Yield Models Are Not Costly to Operate

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

The more expensive part of the process is the maintenance of the historic agricultural and meteorological data bases. The maintenance of the data bases requires the part-time efforts of persons familiar with meteorological data, agricultural data, and the computer system being used. The re-development of the models in future years, incorporating recent yield and weather data, would require someone skilled in regression methodology.

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

The Models Are Easy to Understand and Use

The variables contained in these models are very simple and straightforward, both to understand and use, as the form of the models is always fixed. Calculating the departures from normal is perhaps the most difficult task but can be done easily with a simple computer program. Once the historic weather and yield data bases are created, they can be saved and used repeatedly to recalculate departures from normal and re-develop models in future years.

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

The CRD and state values of the Spearman correlation coefficient between the estimate of the standard error of a predicted yield and the absolute value of the corresponding difference between the actual and predicted yield were computed and are listed in Table 7. The CRD correlation coefficient values are displayed in Figure 15. Most of the CRD models produced negative correlation coefficients, and only three of the correlations were significantly greater than zero at the 5 percent significance level (CRDs 20 and 80 in Illinois and CRD 20 in Indiana). The largest positive coefficient was in Illinois CRD 80 (+0.64). Correlation coefficients for the state results were similarly low; only Indiana had a correlation coefficient significantly greater than zero. Thus, the use of $s_{\hat{y}}$ as an indicator of model predicted yield reliability is not appropriate.

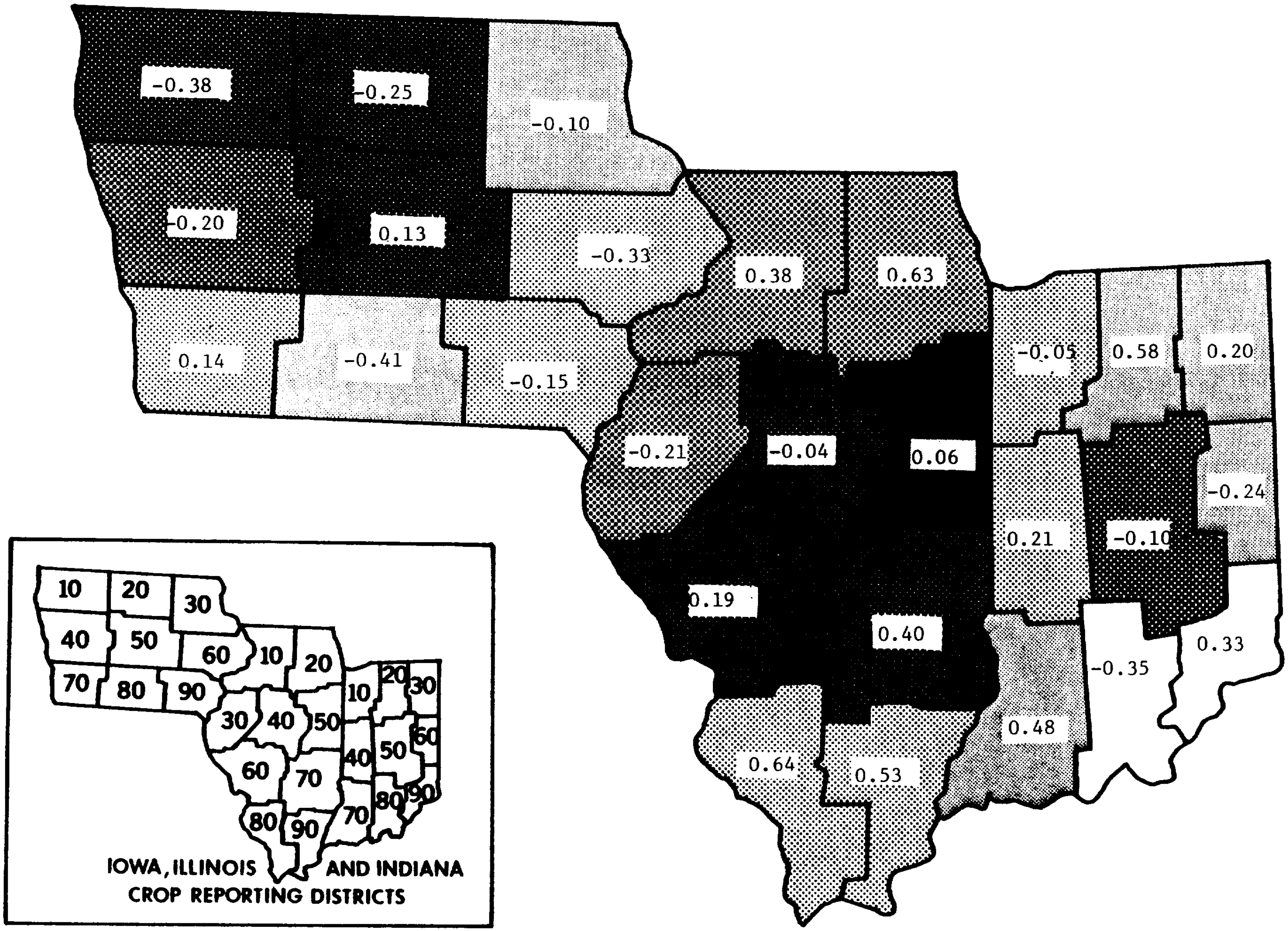
Table 7
Current Indication of
Modeled Yield Reliability

Agreement Between Base Period Predicted
and Test Year Reported Accuracy

Thompson Model - Soybeans
Iowa, Illinois, Indiana 1970-1979

STATE	CRD	SPEARMAN CORRELATION COEF.
IOWA	10	-0.38
	20	-0.25
	30	-0.10
	40	-0.20
	50	0.13
	60	-0.33
	70	0.14
	80	-0.41
	90	-0.15
STATE MODEL		-0.19
ILLINOIS	10	0.38
	20	0.63
	30	-0.21
	40	-0.04
	50	0.06
	60	0.19
	70	0.40
	80	0.64
	90	0.53
STATE MODEL		0.20
INDIANA	10	-0.05
	20	0.58
	30	0.20
	40	0.21
	50	-0.10
	60	-0.24
	70	0.48
	80	-0.35
	90	0.33
STATE MODEL		0.60

Figure 15. Spearman correlation coefficient between the estimate of the standard error of a predicted value from the Thompson-type soybean base period model and the absolute value of the difference between predicted and reported yield in the test years 1970-1979. Darker shades indicate CRDs with higher production.



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APPENDIX

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

Thompson-Type Soybean Yield Models
Iowa, Illinois, Indiana

		MODEL											
		Pooled		Unpooled		Pooled		Unpooled		Pooled		Unpooled	
State	CRD	RMSE	Rank	RMSE	Rank	SD	Rank	SD	Rank	Bias	Rank	Bias	Rank
Iowa	10	2.20	(1)	3.73	(2)	2.00	(1)	3.64	(2)	-0.93	(2)	-0.80	(1)
	20	1.43	(1)	2.67	(2)	1.43	(1)	2.55	(2)	-0.11	(1)	0.78	(2)
	30	1.73	(1)	1.80	(2)	1.64	(1)	1.79	(2)	-0.57	(2)	0.17	(1)
	40	1.81	(1)	3.68	(2)	1.80	(1)	3.65	(2)	0.10	(1)	-0.48	(2)
	50	1.63	(2)	1.34	(1)	1.57	(2)	1.23	(1)	0.41	(1)	0.55	(2)
	60	1.30	(1)	2.41	(2)	1.15	(1)	2.40	(2)	0.61	(2)	0.21	(1)
	70	2.17	(1)	3.82	(2)	1.64	(1)	3.64	(2)	1.42	(2)	1.14	(1)
	80	2.30	(1)	3.05	(2)	2.30	(1)	3.02	(2)	0.02	(1)	-0.41	(2)
	90	2.09	(1)	4.21	(2)	2.07	(1)	4.09	(2)	-0.28	(1)	-0.96	(2)
State Model		1.58	(1)	1.99	(2)	1.55	(1)	1.92	(2)	-0.31	(1)	0.52	(2)
CRDs Aggr.		1.46	(1)	1.76	(2)	1.46	(1)	1.75	(2)	0.00	(1)	0.07	(2)
Illinois	10	2.14	(1)	2.26	(2)	2.07	(1)	2.26	(2)	-0.55	(2)	-0.00	(1)
	20	2.30	(1)	2.81	(2)	2.28	(1)	2.73	(2)	-0.34	(1)	-0.64	(2)
	30	2.52	(1)	2.63	(2)	2.41	(2)	2.27	(1)	-0.72	(1)	-1.33	(2)
	40	2.33	(2)	2.31	(1)	2.30	(2)	2.20	(1)	-0.37	(1)	-0.71	(2)
	50	2.11	(2)	1.92	(1)	2.06	(2)	1.79	(1)	-0.45	(1)	-0.71	(2)
	60	2.21	(2)	1.88	(1)	2.08	(2)	1.51	(1)	-0.75	(1)	-1.11	(2)
	70	2.10	(2)	2.02	(1)	1.94	(2)	1.73	(1)	-0.80	(1)	-1.04	(2)
	80	1.78	(1)	1.90	(2)	1.78	(2)	1.77	(1)	0.02	(1)	-0.68	(2)
	90	1.83	(2)	1.68	(1)	1.79	(2)	1.65	(1)	0.38	(2)	-0.32	(1)
State Model		1.63	(1)	1.98	(2)	1.61	(2)	1.55	(1)	-0.28	(1)	-1.24	(2)
CRDs Aggr.		1.92	(2)	1.78	(1)	1.86	(2)	1.60	(1)	-0.48	(1)	-0.78	(2)
Indiana	10	1.82	(1)	2.24	(2)	1.66	(1)	2.18	(2)	-0.73	(2)	-0.50	(1)
	20	2.55	(2)	1.81	(1)	2.26	(2)	1.79	(1)	-1.18	(2)	-0.31	(1)
	30	2.56	(2)	1.99	(1)	1.92	(2)	1.51	(1)	-1.69	(2)	-1.30	(1)
	40	2.45	(1)	3.29	(2)	2.29	(1)	2.90	(2)	-0.88	(1)	-1.55	(2)
	50	1.85	(1)	2.56	(2)	1.79	(1)	2.44	(2)	-0.47	(1)	-0.79	(2)
	60	2.36	(1)	2.50	(2)	1.73	(1)	2.22	(2)	-1.61	(2)	-1.14	(1)
	70	1.38	(1)	1.79	(2)	1.38	(1)	1.79	(2)	0.07	(2)	-0.02	(1)
	80	1.94	(2)	1.70	(1)	1.61	(1)	1.70	(2)	1.07	(2)	-0.04	(1)
	90	2.32	(2)	1.97	(1)	1.97	(2)	1.73	(1)	1.22	(2)	0.93	(1)
State Model		1.57	(1)	1.95	(2)	1.57	(1)	1.95	(2)	-0.03	(1)	0.08	(2)
CRDs Aggr.		1.76	(1)	1.93	(2)	1.60	(1)	1.79	(2)	-0.74	(2)	-0.72	(1)
Region													
CRDs Aggr.		1.50	(2)	1.47	(1)	1.47	(2)	1.40	(1)	-0.33	(1)	-0.44	(2)
States Aggr.		1.45	(2)	1.35	(1)	1.43	(2)	1.31	(1)	-0.23	(1)	-0.33	(2)

APPENDIX

Model Comparison Based on Paired-Sample Statistical Tests
Thompson-Type Pooled and Unpooled Models
(*=P<.10, **=P<.05, ***=P<.01)

Thompson-Type Soybean Yield Models
Iowa, Illinois, Indiana

		PARAMETRIC T-TEST				NONPARAMETRIC RANK TEST			
		AVERAGE |D| MODEL		DIFFERENCE OF		% SMALLER |D| MODEL		DIFFERENCE OF	
STATE	CRD	UNPOOL	POOL	AVERAGES		UNPOOL	POOL	PERCENTAGE	
IOWA	10	2.8	1.9	0.9		40	60	20	
	20	2.3	1.2	1.1	**	30	70	40	**
	30	1.7	1.5	0.2		40	60	20	
	40	2.4	1.4	0.9		50	50	0	
	50	1.1	1.3	0.1		60	40	20	
	60	1.9	1.0	0.9		30	70	40	**
	70	3.0	1.5	1.5		30	70	40	**
	80	2.4	1.6	0.8		40	40	0	
	90	2.6	1.7	0.9		60	30	30	
STATE MODEL		1.7	1.3	0.4		40	60	20	
CRDS AGGR.		1.5	1.1	0.4		40	60	20	
ILLINOIS	10	1.6	1.5	0.0		30	60	30	
	20	2.4	1.8	0.6	**	10	80	70	***
	30	2.3	2.0	0.3		40	60	20	
	40	1.9	1.8	0.1		50	50	0	
	50	1.6	1.7	0.1		40	40	0	
	60	1.8	1.9	0.1		60	40	20	
	70	1.7	1.8	0.1		50	50	0	
	80	1.5	1.6	0.2		50	40	10	
	90	1.4	1.4	0.0		60	30	30	
STATE MODEL		1.8	1.4	0.5		20	50	30	*
CRDS AGGR.		1.6	1.6	0.0		30	60	30	
INDIANA	10	1.7	1.5	0.2		40	60	20	
	20	1.6	2.0	0.4		40	60	20	
	30	1.7	2.0	0.3		60	30	30	
	40	2.6	2.0	0.6		10	80	70	**
	50	2.0	1.4	0.6	*	10	90	80	**
	60	1.9	1.9	0.1		70	30	40	
	70	1.5	1.1	0.4		30	70	40	
	80	1.5	1.5	0.1		50	40	10	
	90	1.5	1.9	0.3		60	40	20	
STATE MODEL		1.8	1.4	0.4	**	10	70	60	***
CRDS AGGR.		1.5	1.5	0.0		30	50	20	
REGION									
CRDS AGGR.		1.2	1.1	0.1		50	40	10	
STATES AGGR.		1.1	1.2	0.1		60	40	20	

APPENDIX

Coefficients of Trend Terms From Regressions of Yield on Trend Using Data Through 1979*

CRD	Iowa	Illinois	Indiana
10	0.39	0.29	0.31
20	0.38	0.25	0.28
30	0.42	0.27	0.23
40	0.32	0.30	0.30
50	0.32	0.27	0.30
60	0.38	0.28	0.26
70	0.30	0.24	0.32
80	0.23	0.30	0.26
90	0.30	0.25	0.29
State	0.34	0.25	0.29

* Data from Iowa is for years 1950-1979; data from Illinois is for years 1932-1979; data from Indiana is for years 1937-1979.

APPENDIX

Model Coefficients and Significance Levels for Thompson-Type State and Region Models Using Data Through 1979[y]

Variable	Iowa Coefficient	S.L.[t]	Illinois Coefficient	S.L.	Indiana Coefficient	S.L.	Region Coefficient	S.L.
Intercept	0.77		3.01	***	2.40	***	2.38	***
Yield with normal weather	1.02	***	0.89	***	0.92	***	0.92	***
Cumulative precipitation	2.1E-3	***	-2.8E-5		2.8E-4		9.5E-4	
(Cumulative precipitation)^2	-3.1E-5	***	-6.6E-6	***	-7.2E-6	***	-1.0E-5	***
July precipitation	0.02	***	0.02	***	0.02	***	0.03	***
(July precipitation)^2	-3.9E-5	*	-1.0E-4	***	-1.7E-4	***	-1.5E-5	***
August precipitation	0.01	***	0.02	***	0.02	***	0.02	***
(August precipitation)^2	-5.2E-5	**	-2.9E-5		-1.2E-4	***	5.1E-5	
June temperature	0.30	***	0.10	**	0.14	***	0.19	**
(June temperature)^2	-0.04	*	-0.08	***	-0.05	**	-0.11	***
July temperature	-0.02		-0.17	***	-0.08		-0.08	
(July temperature)^2	-0.02		0.01		-0.01		0.04	
August temperature	0.06		-0.01		-0.04		0.07	
(August temperature)^2	-0.09	**	-0.05	**	-0.05	*	-0.07	*

t - S.L. stands for "significance level"
* - significant at 0.10 level
** - significant at 0.05 level
*** - significant at 0.01 level
y - Data from Iowa is for years 1950-1979; data from Illinois is for years 1932-1979; data from Indiana is for years 1937-1979.

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.

APPENDIX

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.

APPENDIX

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.

APPENDIX

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.

APPENDIX

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.

APPENDIX

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.

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E.* PRED.
IOWA	10	1970	19.1	18.4	-0.7	-3.7	1.41
		1971	21.6	19.8	-1.8	-8.3	1.44
		1972	25.3	21.4	-3.9	-15.4	1.36
		1973	24.7	22.4	-2.3	-9.3	1.35
		1974	19.8	22.6	2.8	14.1	1.40
		1975	24.1	22.3	-1.8	-7.5	1.48
		1976	20.0	21.0	1.0	5.0	1.47
		1977	26.3	23.0	-3.3	-12.5	1.47
		1978	26.9	26.5	-0.4	-1.5	1.45
		1979	24.9	26.0	1.1	4.4	1.44
	20	1970	22.2	20.7	-1.5	-6.8	1.39
		1971	21.4	20.4	-1.0	-4.7	1.49
		1972	23.4	22.7	-0.7	-3.0	1.37
		1973	22.8	21.4	-1.4	-6.1	1.37
		1974	19.4	22.3	2.9	14.9	1.39
		1975	23.2	23.0	-0.2	-0.9	1.46
		1976	21.7	22.9	1.2	5.5	1.43
		1977	24.6	23.0	-1.6	-6.5	1.50
		1978	24.3	25.8	1.5	6.2	1.44
		1979	23.6	23.3	-0.3	-1.3	1.90
	30	1970	21.8	19.5	-2.3	-10.6	1.37
		1971	19.1	18.5	-0.6	-3.1	1.48
		1972	22.0	21.5	-0.5	-2.3	1.37
		1973	21.0	18.9	-2.1	-10.0	1.39
		1974	18.3	20.0	1.7	9.3	1.40
		1975	20.4	21.3	0.9	4.4	1.45
		1976	19.8	21.0	1.2	6.1	1.42
		1977	25.0	21.5	-3.5	-14.0	1.52
		1978	24.6	23.3	-1.3	-5.3	1.43
		1979	24.1	24.9	0.8	3.3	1.45
	40	1970	19.3	20.1	0.8	4.1	1.38
		1971	20.1	20.4	0.3	1.5	1.44
		1972	24.5	22.5	-2.0	-8.2	1.35
		1973	22.1	21.5	-0.6	-2.7	1.37
		1974	19.4	22.9	3.5	18.0	1.39
		1975	23.2	22.0	-1.2	-5.2	1.46
		1976	18.5	21.5	3.0	16.2	1.45
		1977	22.9	22.9	0.0	0.0	1.46
		1978	26.7	24.6	-2.1	-7.9	1.43
		1979	25.5	24.8	-0.7	-2.7	1.43

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

APPENDIX
BOOTSTRAP TEST RESULTS FOR SOYBEAN YIELDS IN IOWA, ILLINOIS, AND INDIANA USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
IOWA	50	1970	24.4	23.3	-1.1	-4.5	1.39
		1971	23.2	22.6	-0.6	-2.6	1.49
		1972	25.1	24.8	-0.3	-1.2	1.38
		1973	24.5	23.6	-0.9	-3.7	1.36
		1974	19.3	23.1	3.8	19.7	1.42
		1975	23.5	23.9	0.4	1.7	1.47
		1976	21.9	23.9	2.0	9.1	1.44
		1977	21.0	23.1	2.1	10.0	1.73
		1978	27.0	26.1	-0.9	-3.3	1.44
		1979	26.9	26.5	-0.4	-1.5	1.44
	60	1970	24.5	24.1	-0.4	-1.6	1.39
		1971	24.3	24.0	-0.3	-1.2	1.49
		1972	24.6	25.2	0.6	2.4	1.39
		1973	23.4	22.1	-1.3	-5.6	1.41
		1974	19.9	22.0	2.1	10.6	1.49
		1975	24.3	25.1	0.8	3.3	1.46
		1976	22.6	25.3	2.7	11.9	1.43
		1977	26.0	26.1	0.1	0.4	1.62
		1978	25.5	27.0	1.5	5.9	1.44
		1979	28.0	28.3	0.3	1.1	1.45
	70	1970	21.8	22.1	0.3	1.4	1.39
		1971	21.6	22.9	1.3	6.0	1.46
		1972	23.9	24.1	0.2	0.8	1.36
		1973	21.6	21.3	-0.3	-1.4	1.48
		1974	18.9	24.0	5.1	27.0	1.48
		1975	20.9	22.3	1.4	6.7	1.52
		1976	20.6	23.6	3.0	14.6	1.42
		1977	23.3	23.1	-0.2	-0.9	2.09
		1978	22.8	25.6	2.8	12.3	1.45
		1979	24.7	25.3	0.6	2.4	1.43
	80	1970	22.1	19.9	-2.2	-10.0	1.41
		1971	21.0	19.5	-1.5	-7.1	1.44
		1972	22.4	21.7	-0.7	-3.1	1.35
		1973	20.0	18.5	-1.5	-7.5	1.50
		1974	13.6	19.9	6.3	46.3	1.41
		1975	19.4	19.7	0.3	1.5	1.47
		1976	20.2	20.7	0.5	2.5	1.41
		1977	20.2	19.8	-0.4	-2.0	1.78
		1978	20.9	21.8	0.9	4.3	1.43
		1979	22.4	20.9	-1.5	-6.7	1.42

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
IOWA	90	1970	23.1	21.4	-1.7	-7.4	1.53
		1971	23.7	21.5	-2.2	-9.3	1.49
		1972	24.3	22.3	-2.0	-8.2	1.36
		1973	21.5	20.0	-1.5	-7.0	1.48
		1974	16.8	21.7	4.9	29.2	1.41
		1975	22.6	22.2	-0.4	-1.8	1.47
		1976	22.6	23.3	0.7	3.1	1.42
		1977	24.8	23.9	-0.9	-3.6	1.50
		1978	23.4	25.0	1.6	6.8	1.44
		1979	26.4	25.1	-1.3	-4.9	1.43
STATE MODEL		1970	21.9	20.6	-1.3	-5.9	1.11
		1971	21.9	19.7	-2.2	-10.0	1.25
		1972	24.2	23.0	-1.2	-5.0	1.11
		1973	22.9	23.4	0.5	2.2	1.09
		1974	18.8	21.9	3.1	16.5	1.20
		1975	22.9	20.4	-2.5	-10.9	1.22
		1976	20.8	20.6	-0.2	-1.0	1.24
		1977	23.9	24.3	0.4	1.7	1.69
		1978	25.2	24.8	-0.4	-1.6	1.20
		1979	25.2	25.9	0.7	2.8	1.21
CRDS AGGR.		1970	21.9	21.0	-0.9	-4.1	
		1971	21.9	21.1	-0.8	-3.7	
		1972	24.2	23.0	-1.2	-5.0	
		1973	22.9	21.5	-1.4	-6.1	
		1974	18.8	22.3	3.5	18.6	
		1975	22.9	22.7	-0.2	-0.9	
		1976	20.8	22.6	1.8	8.7	
		1977	23.9	23.0	-0.9	-3.8	
		1978	25.2	25.4	0.2	0.8	
		1979	25.2	25.1	-0.1	-0.4	

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	10	1970	23.4	23.2	-0.2	-0.9	1.20
		1971	23.0	22.4	-0.6	-2.6	1.20
		1972	24.4	24.8	0.4	1.6	1.22
		1973	23.5	22.9	-0.6	-2.6	1.22
		1974	17.0	21.5	4.5	26.5	1.25
		1975	26.4	23.3	-3.1	-11.7	1.30
		1976	22.3	21.7	-0.6	-2.7	1.33
		1977	27.3	23.8	-3.5	-12.8	1.37
		1978	24.6	24.4	-0.2	-0.8	1.37
		1979	28.1	26.5	-1.6	-5.7	1.39
	20	1970	21.0	20.9	-0.1	-0.5	1.20
		1971	20.6	21.1	0.5	2.4	1.21
		1972	22.0	22.7	0.7	3.2	1.25
		1973	21.4	20.9	-0.5	-2.3	1.22
		1974	17.0	20.5	3.5	20.6	1.23
		1975	25.0	21.9	-3.1	-12.4	1.30
		1976	20.5	21.1	0.6	2.9	1.32
		1977	25.9	21.2	-4.7	-18.1	1.36
		1978	22.2	24.0	1.8	8.1	1.36
		1979	26.8	24.7	-2.1	-7.8	1.39
	30	1970	23.1	22.9	-0.2	-0.9	1.24
		1971	24.3	21.5	-2.8	-11.5	1.21
		1972	25.0	22.4	-2.6	-10.4	1.20
		1973	22.0	23.0	1.0	4.5	1.23
		1974	16.6	21.9	5.3	31.9	1.23
		1975	25.0	22.4	-2.6	-10.4	1.30
		1976	23.3	22.7	-0.6	-2.6	1.32
		1977	25.6	23.6	-2.0	-7.8	1.37
		1978	23.6	23.8	0.2	0.8	1.36
		1979	27.1	24.2	-2.9	-10.7	1.37
	40	1970	22.7	23.4	0.7	3.1	1.21
		1971	25.7	23.3	-2.4	-9.3	1.21
		1972	26.4	24.3	-2.1	-8.0	1.21
		1973	24.8	24.7	-0.1	-0.4	1.23
		1974	16.7	22.4	5.7	34.1	1.24
		1975	27.1	25.6	-1.5	-5.5	1.31
		1976	25.1	24.1	-1.0	-4.0	1.32
		1977	28.0	25.5	-2.5	-8.9	1.35
		1978	25.6	26.2	0.6	2.3	1.37
		1979	28.1	27.0	-1.1	-3.9	1.37

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	50	1970	23.1	22.6	-0.5	-2.2	1.20
		1971	25.7	22.7	-3.0	-11.7	1.22
		1972	24.4	23.3	-1.1	-4.5	1.21
		1973	22.7	23.5	0.8	3.5	1.23
		1974	17.6	21.9	4.3	24.4	1.23
		1975	26.4	24.4	-2.0	-7.6	1.31
		1976	23.7	22.4	-1.3	-5.5	1.32
		1977	27.3	24.4	-2.9	-10.6	1.40
		1978	24.9	25.4	0.5	2.0	1.36
		1979	26.8	27.5	0.7	2.6	1.39
	60	1970	21.0	21.4	0.4	1.9	1.21
		1971	23.3	21.3	-2.0	-8.6	1.20
		1972	24.0	22.0	-2.0	-8.3	1.20
		1973	22.0	22.7	0.7	3.2	1.23
		1974	17.8	21.7	3.9	21.9	1.23
		1975	24.3	22.7	-1.6	-6.6	1.30
		1976	23.0	21.3	-1.7	-7.4	1.32
		1977	26.6	23.2	-3.4	-12.8	1.32
		1978	22.9	23.8	0.9	3.9	1.36
		1979	27.5	24.8	-2.7	-9.8	1.37
	70	1970	18.3	17.9	-0.4	-2.2	1.20
		1971	19.6	18.9	-0.7	-3.6	1.21
		1972	21.7	19.0	-2.7	-12.4	1.20
		1973	18.6	19.8	1.2	6.5	1.22
		1974	15.2	18.1	2.9	19.1	1.23
		1975	21.6	20.9	-0.7	-3.2	1.30
		1976	22.3	19.4	-2.9	-13.0	1.31
		1977	24.2	20.7	-3.5	-14.5	1.32
		1978	21.9	22.8	0.9	4.1	1.36
		1979	25.1	23.0	-2.1	-8.4	1.41
	80	1970	18.0	16.8	-1.2	-6.7	1.20
		1971	17.2	18.6	1.4	8.1	1.19
		1972	20.0	19.7	-0.3	-1.5	1.20
		1973	17.2	17.8	0.6	3.5	1.24
		1974	15.4	17.7	2.3	14.9	1.22
		1975	21.6	20.0	-1.6	-7.4	1.30
		1976	17.9	19.6	1.7	9.5	1.32
		1977	23.1	20.3	-2.8	-12.1	1.32
		1978	19.2	21.4	2.2	11.5	1.37
		1979	23.3	21.2	-2.1	-9.0	1.37

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
ILLINOIS	90	1970	15.6	15.8	0.2	1.3	1.20
		1971	16.2	17.2	1.0	6.2	1.19
		1972	18.7	18.5	-0.2	-1.1	1.20
		1973	15.2	16.0	0.8	5.3	1.23
		1974	13.9	16.8	2.9	20.9	1.22
		1975	19.0	18.2	-0.8	-4.2	1.30
		1976	18.1	17.7	-0.4	-2.2	1.32
		1977	20.3	19.1	-1.2	-5.9	1.32
		1978	15.1	19.0	3.9	25.8	1.36
		1979	22.0	19.6	-2.4	-10.9	1.38
STATE MODEL		1970	20.8	20.6	-0.2	-1.0	1.10
		1971	22.2	20.4	-1.8	-8.1	1.15
		1972	23.2	22.0	-1.2	-5.2	1.13
		1973	21.2	21.8	0.6	2.8	1.25
		1974	16.5	20.1	3.6	21.8	1.21
		1975	24.2	22.5	-1.7	-7.0	1.16
		1976	22.2	21.3	-0.9	-4.1	1.18
		1977	25.6	24.2	-1.4	-5.5	1.36
		1978	22.5	23.8	1.3	5.8	1.19
		1979	26.2	25.1	-1.1	-4.2	1.19
CRDS AGGR.		1970	20.8	20.7	-0.1	-0.5	
		1971	22.2	20.9	-1.3	-5.9	
		1972	23.2	21.9	-1.3	-5.6	
		1973	21.2	21.7	0.5	2.4	
		1974	16.5	20.4	3.9	23.6	
		1975	24.2	22.4	-1.8	-7.4	
		1976	22.2	21.2	-1.0	-4.5	
		1977	25.6	22.5	-3.1	-12.1	
		1978	22.5	23.6	1.1	4.9	
		1979	26.2	24.5	-1.7	-6.5	

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	10	1970	21.7	20.3	-1.4	-6.5	1.17
		1971	22.8	21.5	-1.3	-5.7	1.18
		1972	20.2	21.1	0.9	4.5	1.23
		1973	21.1	21.4	0.3	1.4	1.20
		1974	17.2	19.6	2.4	14.0	1.21
		1975	23.1	20.8	-2.3	-10.0	1.24
		1976	22.3	21.2	-1.1	-4.9	1.26
		1977	25.0	21.2	-3.8	-15.2	1.29
		1978	22.7	23.0	0.3	1.3	1.33
		1979	25.2	23.9	-1.3	-5.2	1.35
	20	1970	20.7	20.2	-0.5	-2.4	1.16
		1971	21.5	20.0	-1.5	-7.0	1.19
		1972	19.6	20.8	1.2	6.1	1.21
		1973	21.3	21.8	0.5	2.3	1.19
		1974	15.9	17.6	1.7	10.7	1.23
		1975	23.8	18.8	-5.0	-21.0	1.29
		1976	22.5	21.0	-1.5	-6.7	1.26
		1977	25.1	20.2	-4.9	-19.5	1.33
		1978	21.6	22.3	0.7	3.2	1.33
		1979	25.6	23.1	-2.5	-9.8	1.34
	30	1970	19.9	18.3	-1.6	-8.0	1.17
		1971	20.5	17.8	-2.7	-13.2	1.18
		1972	19.2	19.1	-0.1	-0.5	1.21
		1973	20.5	21.1	0.6	2.9	1.19
		1974	15.9	16.9	1.0	6.3	1.24
		1975	20.7	17.2	-3.5	-16.9	1.28
		1976	21.6	19.2	-2.4	-11.1	1.26
		1977	25.5	20.0	-5.5	-21.6	1.30
		1978	21.2	20.9	-0.3	-1.4	1.33
		1979	24.3	21.9	-2.4	-9.9	1.34
	40	1970	21.2	20.2	-1.0	-4.7	1.17
		1971	24.0	20.8	-3.2	-13.3	1.19
		1972	21.6	21.0	-0.6	-2.8	1.20
		1973	22.4	23.1	0.7	3.1	1.20
		1974	15.5	19.3	3.8	24.5	1.25
		1975	23.4	21.1	-2.3	-9.8	1.24
		1976	24.2	20.8	-3.4	-14.0	1.25
		1977	25.0	21.0	-4.0	-16.0	1.46
		1978	24.5	25.0	0.5	2.0	1.34
		1979	24.4	25.1	0.7	2.9	1.44

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	50	1970	22.1	22.3	0.2	0.9	1.17
		1971	24.1	21.1	-3.0	-12.4	1.18
		1972	20.7	21.3	0.6	2.9	1.22
		1973	23.6	24.1	0.5	2.1	1.20
		1974	17.8	20.7	2.9	16.3	1.25
		1975	24.4	22.8	-1.6	-6.6	1.23
		1976	24.5	23.3	-1.2	-4.9	1.25
		1977	26.7	23.2	-3.5	-13.1	1.32
		1978	26.3	26.6	0.3	1.1	1.37
		1979	25.5	25.6	0.1	0.4	1.44
	60	1970	20.1	19.1	-1.0	-5.0	1.16
		1971	21.2	17.4	-3.8	-17.9	1.18
		1972	18.5	17.8	-0.7	-3.8	1.22
		1973	21.3	20.6	-0.7	-3.3	1.19
		1974	16.9	17.6	0.7	4.1	1.26
		1975	22.2	18.5	-3.7	-16.7	1.23
		1976	21.5	19.1	-2.4	-11.2	1.25
		1977	23.2	18.9	-4.3	-18.5	1.30
		1978	23.5	22.7	-0.8	-3.4	1.33
		1979	22.5	23.1	0.6	2.7	1.53
	70	1970	19.4	19.5	0.1	0.5	1.18
		1971	20.4	20.5	0.1	0.5	1.18
		1972	19.8	20.9	1.1	5.6	1.19
		1973	18.6	20.6	2.0	10.8	1.21
		1974	17.4	16.3	-1.1	-6.3	1.58
		1975	21.3	20.9	-0.4	-1.9	1.24
		1976	22.7	20.6	-2.1	-9.3	1.25
		1977	23.1	22.5	-0.6	-2.6	1.33
		1978	21.6	24.2	2.6	12.0	1.35
		1979	22.1	21.1	-1.0	-4.5	1.62
	80	1970	19.3	18.6	-0.7	-3.6	1.17
		1971	19.2	20.0	0.8	4.2	1.17
		1972	17.6	19.9	2.3	13.1	1.19
		1973	16.3	19.8	3.5	21.5	1.22
		1974	16.5	16.4	-0.1	-0.6	1.42
		1975	15.1	18.5	3.4	22.5	1.24
		1976	19.7	19.1	-0.6	-3.0	1.24
		1977	21.1	20.2	-0.9	-4.3	1.34
		1978	20.3	22.7	2.4	11.8	1.35
		1979	19.8	20.4	0.6	3.0	1.48

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	90	1970	18.9	19.1	0.2	1.1	1.17
		1971	19.7	20.8	1.1	5.6	1.17
		1972	16.1	19.2	3.1	19.3	1.19
		1973	15.7	19.6	3.9	24.8	1.23
		1974	17.3	17.4	0.1	0.6	1.33
		1975	17.6	18.1	0.5	2.8	1.23
		1976	21.8	19.8	-2.0	-9.2	1.24
		1977	22.0	20.7	-1.3	-5.9	1.31
		1978	19.7	23.2	3.5	17.8	1.35
		1979	19.9	23.0	3.1	15.6	1.37
STATE MODEL		1970	20.8	20.2	-0.6	-2.9	1.08
		1971	22.2	20.5	-1.7	-7.7	1.12
		1972	19.8	20.0	0.2	1.0	1.15
		1973	21.2	22.1	0.9	4.2	1.16
		1974	16.8	19.3	2.5	14.9	1.18
		1975	22.5	21.2	-1.3	-5.8	1.20
		1976	22.9	21.1	-1.8	-7.9	1.17
		1977	24.9	23.1	-1.8	-7.2	1.28
		1978	23.2	24.3	1.1	4.7	1.19
		1979	24.2	26.4	2.2	9.1	1.32
CRDS AGGR.		1970	20.8	20.2	-0.6	-2.9	
		1971	22.2	20.2	-2.0	-9.0	
		1972	19.8	20.4	0.6	3.0	
		1973	21.2	21.9	0.7	3.3	
		1974	16.8	18.5	1.7	10.1	
		1975	22.5	20.3	-2.2	-9.8	
		1976	22.9	21.0	-1.9	-8.3	
		1977	24.9	21.2	-3.7	-14.9	
		1978	23.2	23.8	0.6	2.6	
		1979	24.2	23.6	-0.6	-2.5	

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
REGION CRDS AGGR.		1970	21.2	20.7	-0.5	-2.4	
		1971	22.1	20.8	-1.3	-5.9	
		1972	22.8	21.9	-0.9	-3.9	
		1973	21.8	21.7	-0.1	-0.5	
		1974	17.4	20.8	3.4	19.5	
		1975	23.4	22.1	-1.3	-5.6	
		1976	21.8	21.7	-0.1	-0.5	
		1977	24.8	22.5	-2.3	-9.3	
		1978	23.6	24.3	0.7	3.0	
		1979	25.5	24.6	-0.9	-3.5	
STATES AGGR.		1970	21.2	20.5	-0.7	-3.3	
		1971	22.1	20.2	-1.9	-8.6	
		1972	22.8	21.9	-0.9	-3.9	
		1973	21.8	22.4	0.6	2.8	
		1974	17.4	20.6	3.2	18.4	
		1975	23.4	21.5	-1.9	-8.1	
		1976	21.8	21.0	-0.8	-3.7	
		1977	24.8	24.0	-0.8	-3.2	
		1978	23.6	24.3	0.7	3.0	
		1979	25.5	25.7	0.2	0.8	

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APPENDIX
BOOTSTRAP TEST RESULTS
FOR SOYBEAN YIELDS IN
IOWA, ILLINOIS, AND INDIANA
USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
INDIANA	90	1970	18.9	19.1	0.2	1.1	1.17
		1971	19.7	20.8	1.1	5.6	1.17
		1972	16.1	19.2	3.1	19.3	1.19
		1973	15.7	19.6	3.9	24.8	1.23
		1974	17.3	17.4	0.1	0.6	1.33
		1975	17.6	18.1	0.5	2.8	1.23
		1976	21.8	19.8	-2.0	-9.2	1.24
		1977	22.0	20.7	-1.3	-5.9	1.31
		1978	19.7	23.2	3.5	17.8	1.35
		1979	19.9	23.0	3.1	15.6	1.37
STATE MODEL		1970	20.8	20.2	-0.6	-2.9	1.08
		1971	22.2	20.5	-1.7	-7.7	1.12
		1972	19.8	20.0	0.2	1.0	1.15
		1973	21.2	22.1	0.9	4.2	1.16
		1974	16.8	19.3	2.5	14.9	1.18
		1975	22.5	21.2	-1.3	-5.8	1.20
		1976	22.9	21.1	-1.8	-7.9	1.17
		1977	24.9	23.1	-1.8	-7.2	1.28
		1978	23.2	24.3	1.1	4.7	1.19
		1979	24.2	26.4	2.2	9.1	1.32
CRDS AGGR.		1970	20.8	20.2	-0.6	-2.9	
		1971	22.2	20.2	-2.0	-9.0	
		1972	19.8	20.4	0.6	3.0	
		1973	21.2	21.9	0.7	3.3	
		1974	16.8	18.5	1.7	10.1	
		1975	22.5	20.3	-2.2	-9.8	
		1976	22.9	21.0	-1.9	-8.3	
		1977	24.9	21.2	-3.7	-14.9	
		1978	23.2	23.8	0.6	2.6	
		1979	24.2	23.6	-0.6	-2.5	

APPENDIX
BOOTSTRAP TEST RESULTS FOR SOYBEAN YIELDS IN IOWA, ILLINOIS, AND INDIANA USING A THOMPSON-TYPE MODEL

STATE	CRD	YEAR	YIELD (Q/H) ACTUAL	PRED.	D	RD	S.E. PRED.
REGION CRDS	AGGR.	1970	21.2	20.7	-0.5	-2.4	
		1971	22.1	20.8	-1.3	-5.9	
		1972	22.8	21.9	-0.9	-3.9	
		1973	21.8	21.7	-0.1	-0.5	
		1974	17.4	20.8	3.4	19.5	
		1975	23.4	22.1	-1.3	-5.6	
		1976	21.8	21.7	-0.1	-0.5	
		1977	24.8	22.5	-2.3	-9.3	
		1978	23.6	24.3	0.7	3.0	
		1979	25.5	24.6	-0.9	-3.5	
STATES	AGGR.	1970	21.2	20.5	-0.7	-3.3	
		1971	22.1	20.2	-1.9	-8.6	
		1972	22.8	21.9	-0.9	-3.9	
		1973	21.8	22.4	0.6	2.8	
		1974	17.4	20.6	3.2	18.4	
		1975	23.4	21.5	-1.9	-8.1	
		1976	21.8	21.0	-0.8	-3.7	
		1977	24.8	24.0	-0.8	-3.2	
		1978	23.6	24.3	0.7	3.0	
		1979	25.5	25.7	0.2	0.8	

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