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ANALYSIS OF CROP YIELD TRENDS AND DEVELOPMENT OF SIMPLE CORN AND SOYBEAN "STRAW MAN" MODELS FOR INDIANA, ILLINOIS AND IOWA

Richard A. Kestle

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ABSTRACT

"Straw Man" linear regression crop yield models using time as the single independent variable were created for corn and soybeans at the crop reporting district and State levels in Indiana, Illinois, and Iowa. Since yield trends may shift over time, several approaches to finding the "best fitting" model were evaluated, including simple one-line models, objectively selected 2- and 3-line segmented models, and models for which shifts in yield trends were systematically tested for 5- and 7-year groups of data. Comparisons of the models were based on relative percent differences of predicted 1979 yields from actual 1979 yields, and residual MSE values. Results show simple linear models had less fluctuations in relative predicted differences (1%-22% as compared to 0%-39%) than the 2- and 3-line models, but consistently higher residual MSE values. Simple linear models were the first choice in all corn yield models, while soybean yield models had no consistently superior model. A simple linear model was then selected as the single "Straw Man" model for all states and crops, and yield predictions for 1980 were generated.

Key words: Yield modeling, linear regression, segmented line model, yield trend.

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 ESS or USDA.

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by
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AgRISTARS
Yield Model Development
Project

YMD-2-11-1(80-11.1)

FORWARD

Initially, several rather limited reasons were identified for wanting to develop "straw man" crop yield models. These models were referred to as "straw man" because they were not targeted to be superior yield models and it was certainly hoped they could be "knocked down" very easily by more successful models.

Then, why should such models be developed? The primary initial reason was to have available several very simple models with which to gain experience in applying AgRISTARS 1/ model test and evaluation criteria. This would allow the initial experience in test and evaluation to be concentrated on the methods to be applied rather than on difficulties introduced by the models tested. Another reason was to utilize test results for these models to produce a useful precedent setting test and evaluation report. As alluded to above, another initial reason was to identify the most desirable "straw man" model for use as a below base model for comparison with models to be tested in the future. Thus, models which did not meet or exceed performance levels of the selected "straw man" could be quickly discarded without wasteful expenditure of resources in their further evaluation.

In retrospect, several beneficial by-products of this research can be identified. The report provides some comparisons of subjective versus objective methods of handling the trend (applied technology) variable in simple yield models. The analyses presented also provide some clues as to the nature of applied technology yield impacts over time. Finally, this research leads to the selection of a simple model which can be adapted for use in any area where historic yield data can be obtained, even though meteorological or production input data is either unavailable or unreliable.

Wendell W. Wilson, Head
Yield Evaluation Staff
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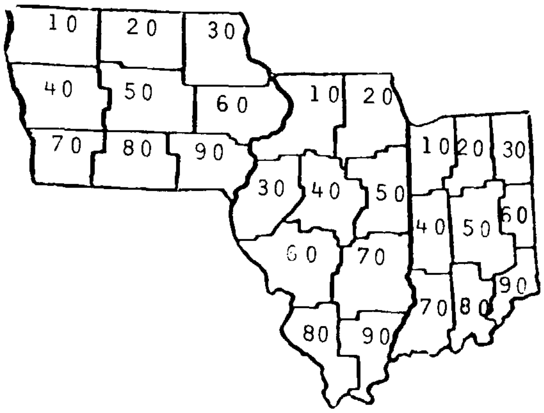
Statistical Research Division



Iowa, Illinois and Indiana Crop Reporting Districts

1/ AgRISTARS is a multi-agency research program to meet some current and new information needs of the U.S. Department of Agriculture.

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Analysis of Crop Yield Trends and Development of Simple Corn and Soybean "Straw Man" Models for Indiana, Illinois, and Iowa

Richard A. Kestle

INTRODUCTION

One of the major tasks in the AgRISTARS program is to test and evaluate candidate yield models with respect to a variety of desirable model characteristics. One such evaluation criterion is the increased yield indication reliability of the candidate models as compared to some predetermined "below base" model. The "straw man" 1/ models, developed only from trend analysis, provide a standard to compare the yield indication reliabilities of candidate models. Models which fail to predict as reliably as the "straw man" can then be rejected from further evaluation. The creation and documentation of these "straw man" models is the focus of this report. "Straw man" models are developed for corn and soybean yields at the Crop Reporting District (CRD) and state levels in Iowa, Indiana, and Illinois.

A very simple yield model is a linear regression model with but one independent variable: year (i.e., trend). Such a model will often explain a significant portion of the variability in yield data. For example, a simple linear model for CRD corn yields in Iowa which uses year as the only independent variable "explains" from 39 to 80 percent of the year-to-year variability in yield.

However, it can be seen (Figures 1 to 3) that yields have not only increased but yield trends may have shifted over time. Advances in technology are thought to play an important role in the upward shifts in yields trends. Shifts in yield trends vary with each state and CRD as they may occur at different times, different rates, or not at all. The identification of the beginning and ending points of such trend shifts is difficult, but may be important in producing an efficient "straw man" model.

It then seems reasonable to develop "straw man" models which take into consideration trend shifts over time, yet retain the use of only time as the independent variable. Such models are simple and may give reasonable yield indications without sophisticated weather, soil, or economic inputs. It follows that any candidate model using these additional inputs would be expected to predict yield at least as well; if not, such a candidate model would be disqualified without further review.

Model Development

There are a variety of potential "straw man" models. Since we are concerned only with fitting simple linear models to yield data, and since it is apparent that yield trends have shifted over time, the problem in selecting

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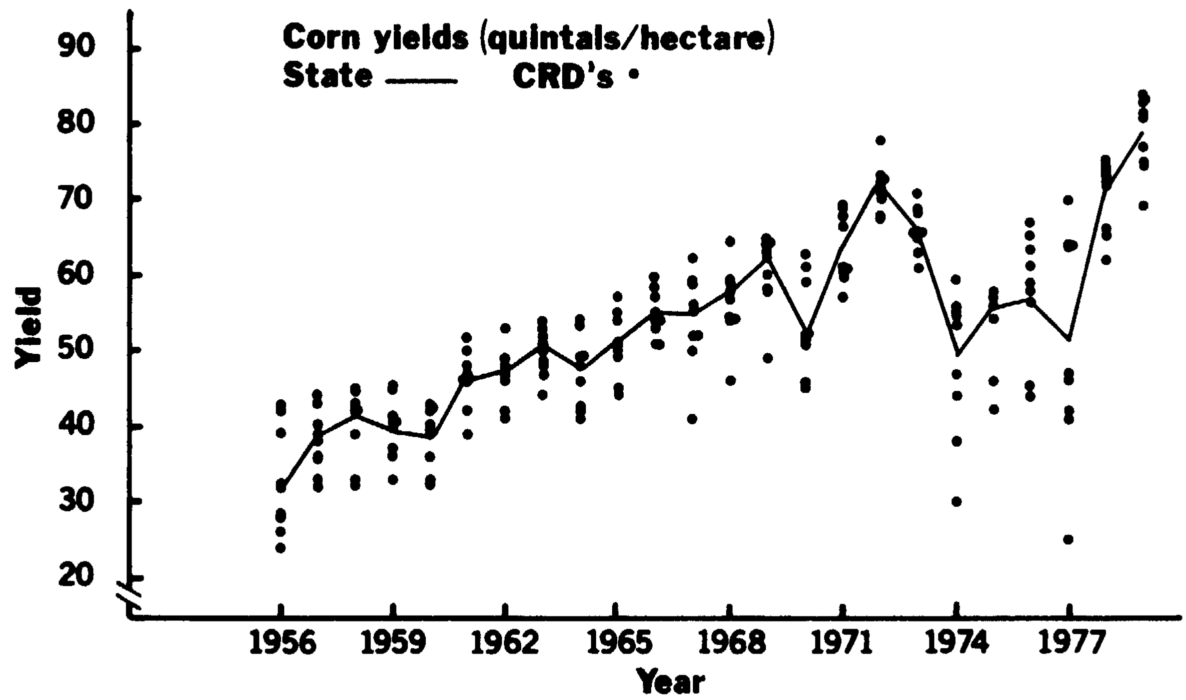
1/ According to The American Heritage Dictionary, William Morris, ed., 1976, "straw man" is defined as "one set up as an opponent to be easily defeated or refuted."

Figure 1: IOWA Corn and Soybean Yield



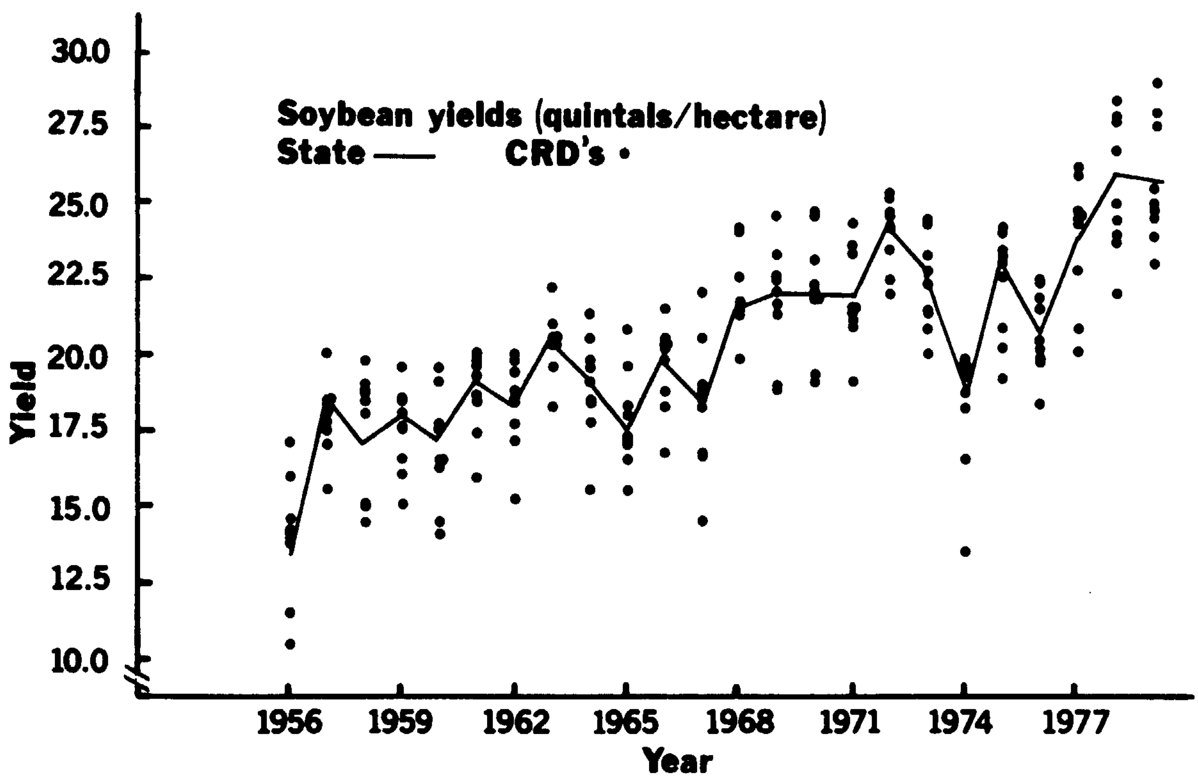
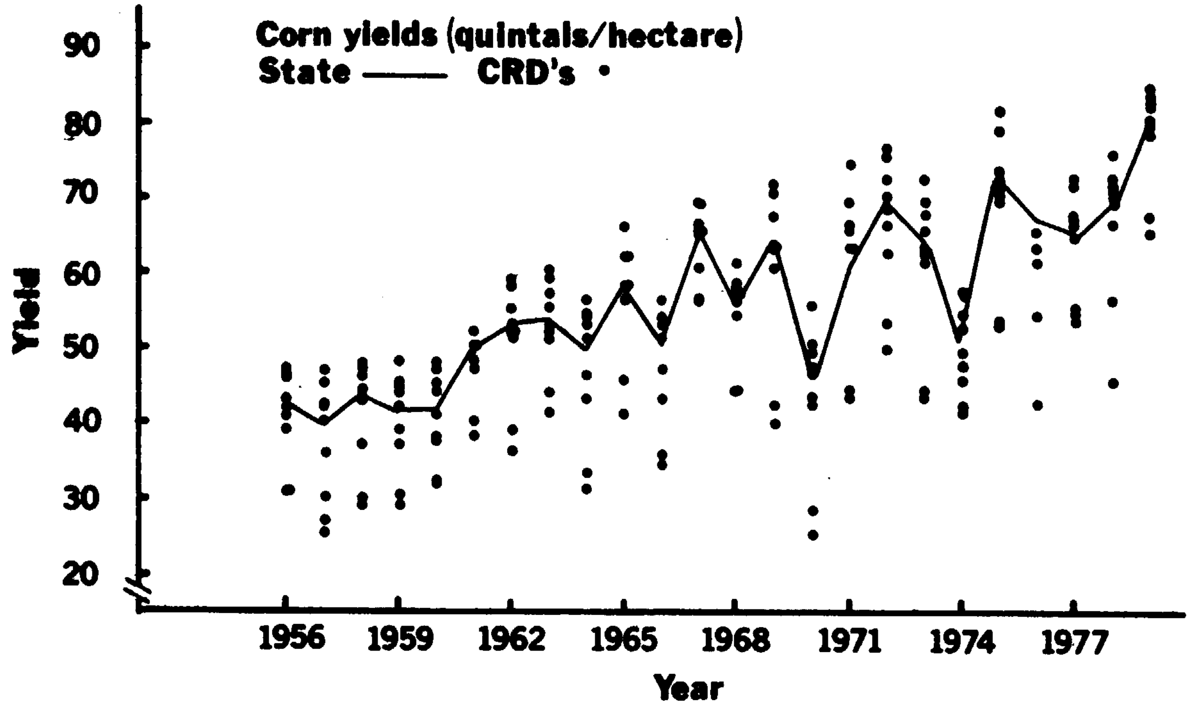


Figure 2: ILLINOIS Corn and Soybean Yield



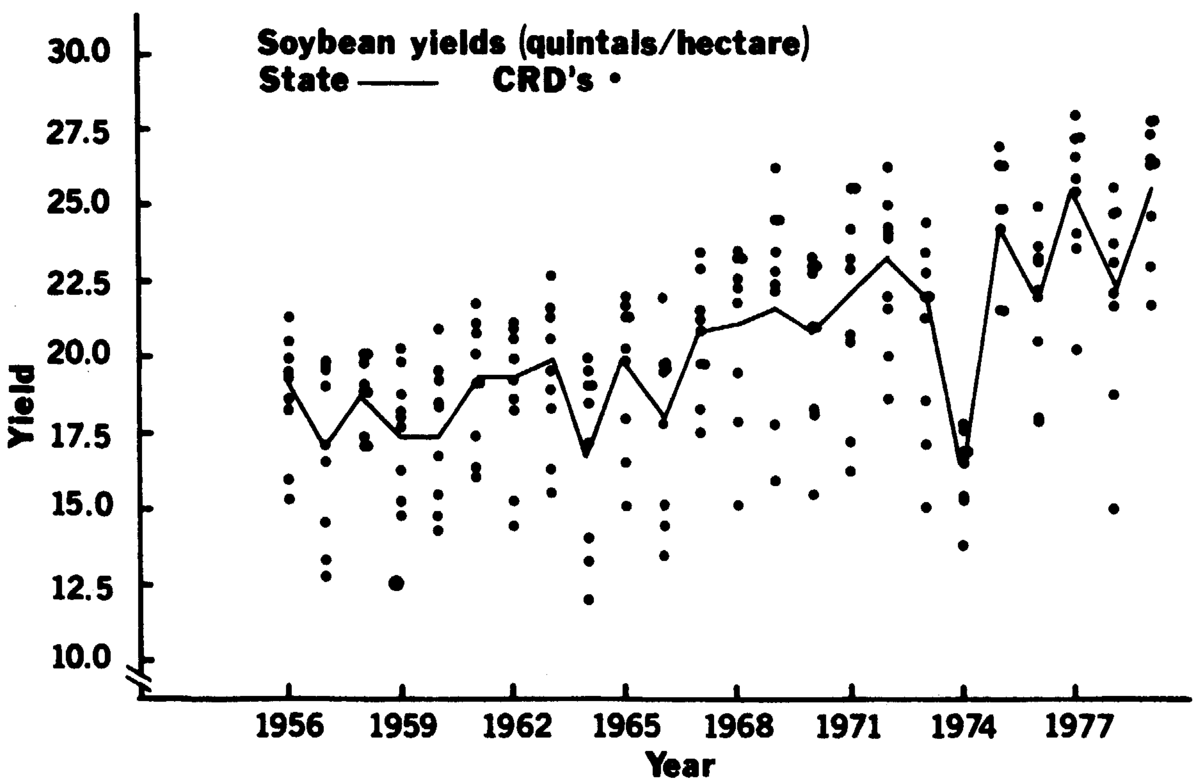
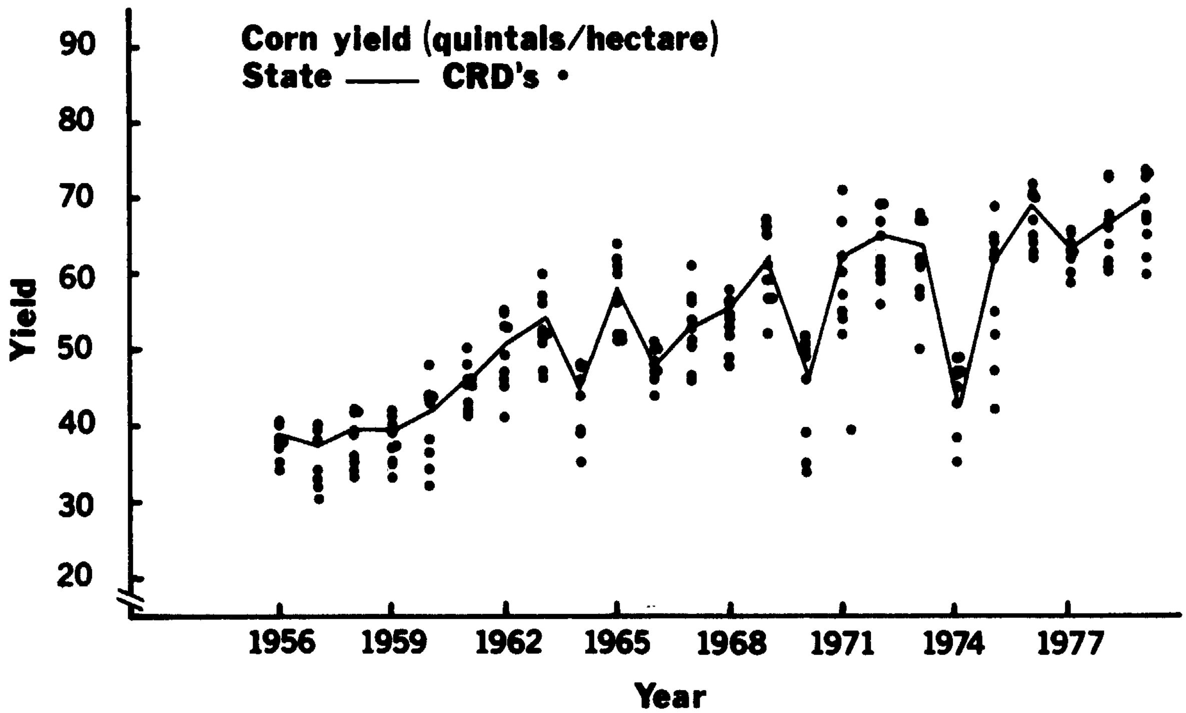
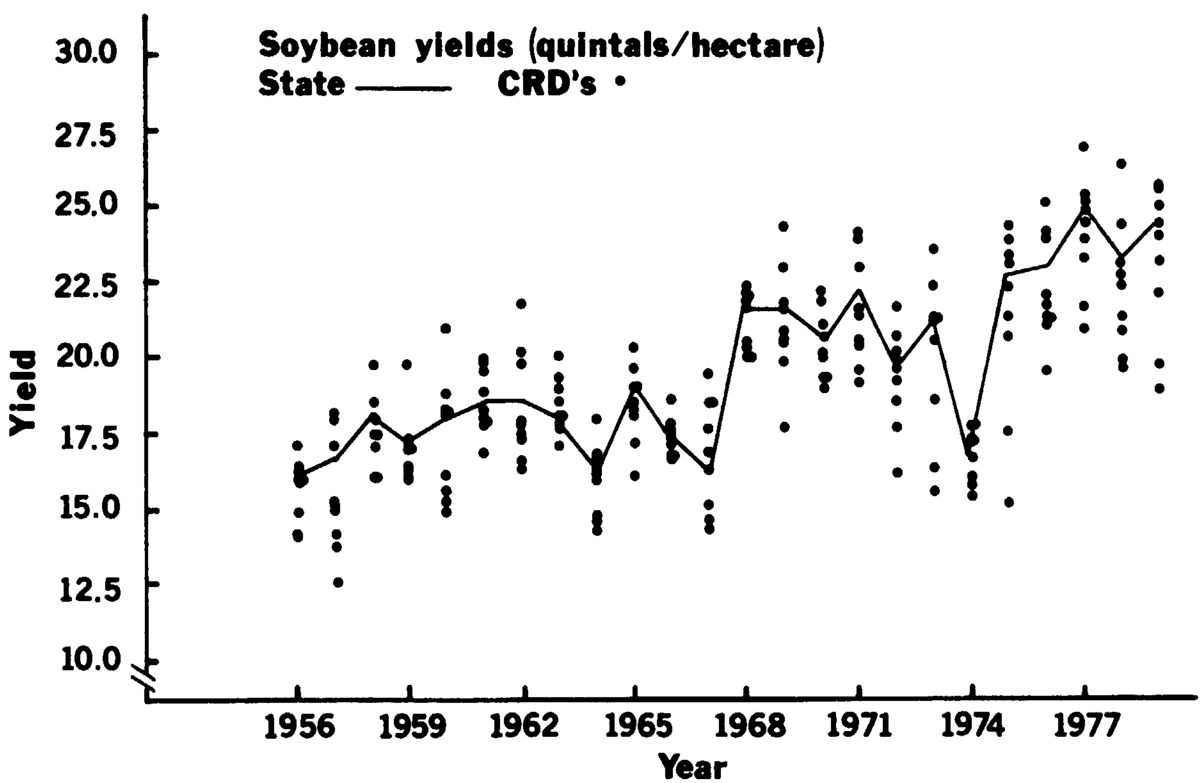


Figure 3: INDIANA Corn and Soybean Yield





the "best" model is in many respects the problem of identifying the length and slope of the latest yield trend.

Of course, the model which most closely "fits" the actual yields over time will be an important model to consider. To best measure a model's "fit" we use the residual MSE (mean squared error, which is equal to the residual sum of squares divided by the degrees of freedom). Generally speaking, the lower the MSE the better the model "fit." A second measure of some comparative use is R^2 (coefficient of determination, which identifies the percent of total variation accounted for by the model). Again, generally speaking, the higher the R^2 the better the model "fit."

However, the point of greatest concern for a model is its predictive ability; how close does it come to predicting actual yield? Therefore our foremost interest is in accurately fitting a model to the latest identifiable trend, even at the expense of higher residual MSE or lower R^2 values.

Much of this work in model development has been directed towards finding ways to objectively identify the beginning and ending years for the shifting yield trends in each state and CRD. Then for each segment of years we will fit a linear model, with special attention to be given to the last segment.

For comparison purposes we took four general approaches to generating models for each state and CRD. All of the models were run using yield data complete through 1978. Predicted 1979 yields were then derived, and the $\pm$ percentage deviations from actual 1979 estimates were compared along with residual MSE and R^2 values. On the basis of these comparisons one model was selected for each CRD and state, and its equational form and 1980 predicted yield are listed in the Appendix (Tables A1.-A6.).

The four general approaches are as follows:

- o Fit a simple one-line regression equation to all the data, without taking into account shifts in trends.

- o Review graphs and subjectively select join-point years for 2- and 3-line models. These models will be less acceptable because the subjectivity involved makes it difficult to access their consistency of performance. Still, they are of interest for comparative purposes.

- o Conduct tests for changes in the slopes of the trends by systematically observing 5- and 7-year groups of data. These tests of hypotheses were conducted at the 10% and 15% level of significance, and are an objective (though inefficient) way of determining the length in years of the latest yield trend.

- o Use of the completely objective segmented-line approach developed by J. Sebaugh at the Kansas State University. This approach selects the "best" of <u>all</u> possible 2- and 3-line models by minimizing the residual sum of squares and exactly identifying the segment join-points.

In the following sections of this report each state/crop combination is reviewed separately. The listing of <u>all</u> generated models and statistics would be quite burdensome, so tables have been kept to a minimum and are only used to augment the discussions. Before proceeding with these discussions, however, a more in-depth review of the models will be made and the data bases will be described.

Model Review

Simple linear regression line.

In all cases the equation will be of the form:

$$Y = \alpha_0 + \beta_1(X), \text{ where } Y = \text{yield and } X = (\text{year} - 1956).$$

All simple linear models used to predict 1979 data have 21 degrees of freedom (n - 2, where n = 23 years of data).

Subjective 2- and 3-line models.

Subjective models were derived for the entire available data set. The join-points of the various segments were identified by eye from observing graphs of the yield curves.

Two-lined models were developed by using 2 independent variables. The first variable was held constant at a value of one while the second increased by one with yearly increments until the join-point was reached. At that point the first variable was allowed to begin increasing by one with yearly increments while the second was held constant at whatever value it had attained upon reaching the join-point.

Thus the equation would be of the form:

$$Y = \alpha_0 + \beta_1(X_1) + \beta_2(X_2), \text{ where } Y = \text{yield},$$

$$X_1 = (\text{year}') \text{ if year} \leq \text{year of join-point}$$
$$= (K) \text{ if year} > \text{year of join-point}$$

$$X_2 = 1 \text{ if year} \leq \text{year of join-point}$$
$$= (\text{year}'') \text{ if year} > \text{year of join-point},$$

and the transformed independent variables are:

$$\text{year}' = \text{year} - 1930,$$

$$K = \text{year of join-point} - 1930$$

$$\text{year}'' = \text{year} - \text{year of join-point}.$$

In a similar manner a 3-line model would be of the form:

$$Y = \alpha_0 + \beta_1(X_1) + \beta_2(X_2) + \beta_3(X_3).$$

Because these models were derived over the entire available data set, there would be (n - 3) degrees of freedom for a 2-line model and (n - 4) degrees of freedom for a 3-line model (where n = number of years of data).

5- and 7-year models.

As a means to objectively find the length in years of the latest yield trend, the slope of the trend line for the last 5 years of data (1974-1978) was compared with the slope of the trend line for the 5 years previous to it (1969-1973). F-tests were run for the null hypothesis that these trend slopes were equal. The probability of rejecting the null hypothesis when it is true was set at .10 and .15.

If the null hypothesis was not rejected, all 10 years of data were grouped, a new slope of the trend line for the 10 year period was determined, and it in turn was compared with the slope of the trend line for the next 5 year period (1964-1968). As long as the significance levels did not fall below 10% or 15% we continued accumulating and testing groups of data as far back as the data would allow (1956).

If the null hypothesis was rejected, the conclusion was that a significant shift in the yield trend had occurred. Then a simple linear model would be developed using only the latest group of 5 or 10 (or similar multiple of 5) years of data. In a like manner, tests were also done using groups of 7 years of data.

The end results were a series of four possible linear equations:

- for 5-year groups of data tested at an $\alpha = .10$ level;
- for 5-year groups of data tested at an $\alpha = .15$ level;
- for 7-year groups of data tested at an $\alpha = .10$ level;
- for 7-year groups of data tested at an $\alpha = .15$ level.

All equations were of the form:

$Y = \alpha_0 + \beta_1(X)$, where Y = yield and X = (year - 1930).

If no tests of hypothesis resulted in a rejection of the null hypothesis, then all years of data were used and the model becomes exactly the same as the simple linear model explained above.

The degrees of freedom for each model varied from 21 (all 1956-1978 data used) to 3 (only 1974-1978 data used).

It can be seen that this method of identifying changes in yield trend, though systematic and objective, will not efficiently catch all major trend shifts. Tables showing significance levels for the various tests in each state can be found in the Appendix (Tables A7.-A12.).

Objective 2- and 3-line models (segmented-line approach).

A Fortran program[1/] was used to develop models which use a series of intersecting straight lines. The lines intersect at join-points identified by the program. Least squares estimators of the line coefficients and join-points are calculated for every possible combination of join-points and the program selects those which give the smallest residual sum of squares.

Only 2- and 3-line models were developed in this study. Each model is fitted over the entire data set, so that 2-line models have 19 degrees of freedom (n - 4, where n = 23 years of data) and 3-line models have 17 degrees of freedom (n - 6). Each line is of the form:

$$Y = \alpha_0 + \beta_1(X), \text{ where } Y = \text{yield and } X = (\text{year} - 1956).$$

Only the line segment for the most recent years is used in projecting yields for the next year. Therefore, although the full 23-year data series does provide more degrees of freedom, the last line segment could represent as few as two years. Predictions from such a model could be much worse than a 1-line model which was based on the most recent 5- to 7-year period.

Data Bases

Yield data sets for corn for grain and soybeans for beans (in quintals per hectare) were assembled for Iowa, Illinois, and Indiana. (Table 1. shows some bushels/acre to quintals/hectare conversions for comparative purposes). All three data sets are revised through 1978 (as of June 1, 1980) and contain preliminary 1979 data. The yields are at both the CRD and state level. The following table lists the earliest date of considered yield data for each crop and state:

	Iowa	Illinois	Indiana
Corn	1956	1954	1931
Soybeans	1950	1931	1937

There are corn and soybean yield data available for earlier years in these states. However, changes in definition and reporting of the data have occurred. For the purpose of selecting "straw man" models for use in 1980 all data sets were limited to data back through 1956 only. This was done for several reasons.

- Because of technological advances in agricultural practices (including increased fertilizer and chemical applications, hybrid seed development, etc.) there would really be little value in comparing yield trends of the past few years with 25 or more years ago.

1/ See note page 22.

Table 1: Comparisons of Yields in Bushels/Acre to Yields in Quintals/Hectare.

Corn Yields*

Bush/Acre	60	70	80	90	100	110	120
Qntl/Hect	37.66	43.93	50.21	56.49	62.76	69.04	75.32

*where yield in $\left(\frac{\text{Qntl}}{\text{Hect}}\right) = \left(\frac{\text{Bush}}{\text{Acre}}\right) \text{ X } \left(\frac{.254}{.404694}\right)$

Soybean Yields**

Bush/Acre	15	20	25	30	35	40	45
Qntl/Hect	10.09	13.45	16.81	20.18	23.54	26.90	30.26

**where yield in $\left(\frac{\text{Qntl}}{\text{Hect}}\right) = \left(\frac{\text{Bush}}{\text{Acre}}\right) \text{ X } \left(\frac{.27216}{.404694}\right)$

- Only post-1955 data could be used for Iowa because of a definitional change in Iowa corn for grain data prior to 1956. Thus, Iowa more or less acts as a "least common denominator" for all the other data sets. If we are to draw comparisons of a general nature over all states, it would seem that each should use a data set for the same period.
- In the AgRISTARS program the USDA will be developing models for several countries, most of which will have data sets for a limited number of years. Experience gained in using U.S. data sets for similar lengths of time may prove beneficial.

State/Crop Combination Results

Iowa corn

Simple linear models fitted to 1956-1978 yield data for the 9 CRD's show yield trend slopes of .98 to 1.46 with a state yield slope of 1.24. In comparison, a subjective 2-line model with a join-point at 1970 show slopes in the last line segment of from -1.01 to 1.02. In all but one of the CRD's (CRD 30) residual MSE's were lower in the subjective models than in the simple linear model. R^2 values in the subjective models were also greater than or equal to the R^2 values in the simple linear model for all CRD's.

A review of the generated 5- and 7-year group models shows that a vast majority of them use all of the data. Five-year groupings showed significan changes in trend at the $\alpha = .10$ level in only CRD 20, and at the $\alpha = .15$ level in CRD's 20 and 30. Seven-year groupings showed significant changes at the $\alpha = .10$ level in only CRD 50, and at the $\alpha = .15$ level in CRD's 50 and 90. In 3 of the 4 significant CRD's, MSE values were far larger than MSE values resulting from any other model.

Objective 2- and 3-line models show reduced residual MSE. Indeed, the 3-line model resulted in the lowest MSE in 8 out of the 10 cases (9 CRD's and state total). Join-points for the 2-line models were of various years (1961, 1967, 1970, 1971, 1972, and 1976) while practically all 3-line models (7 out of 10) showed join-points in the years 1972 and 1974. This reflects poor crop years and steep drops in yields. The result of these join-points being in the later years is that the last line segment (from which 1979 is to be predicted) is of very short length. Slopes of these segments were as high as 25.54! Only 2 models showed slopes in the last segment as being under 2.00 and most were over 4.00. Nevertheless, only the most extreme slopes produced predicted yields greater than actual yields (see Table 2).

The results of the predictive ability of all the models are shown in Table 2. The prediction of every model was well below the true yield in 1979. The models which came closest were the simple linear models (5 out of 10) and the objective 3-line model (5 out of 10). Five out of 10 of the predicted yields which were farthest from the true yield occurred in the objective 2-line model. It seems apparent that the only realistic choice in model performance lies between a simple linear model and the 3-line segmented model. A closer comparison between these models is in order.

Table 3 presents the square root of the residual MSE values in the original units (quintals/hectare) for these two models. It is obvious that the 3-lined segmented model reduces the squared errors by significant amounts, and where the MSE's are lowest (CRD's 20, 30, and 60) the predicted yields are acceptably close to true yields. It might also be said that while the simple linear model had the closest predicted values in one-half of the models, this was not due to any remarkably accurate capacity of its own but rather to the terribly inaccurate prediction of the others.

If there is any redeeming feature to the simple linear model, it is its consistency. There is little chance of its missing the actual yield by such wide margins as 22%, 31% or 39% as exhibited in other models. Since the last 7-10 years of crop yields in Iowa have shown a penchant for wide fluctuations this factor is of no little worth.

Models using 1979 data have been generated in order to predict 1980 yields. In them, it can be seen that most of the 3-line models have retained 1974 as the join-point for the last line segment. Several, however, have shown a jump to 1977 for the join-point. Predicted 1980 yields are up in almost every CRD with many showing increases of 5-20 quintals per hectare over actual 1979 yields. Meanwhile simple linear models show much more modest increases of 1-5 quintals per hectare over predicted 1979 values, and most are still below actual 1979 yields.

Taking all these facts into consideration along with a review of parameter estimates of the model for 1980, we select the simple linear models to be used in all CRD's and at the state level. However, we will complete a review of all other states and crops in order to come up with one overall model selection which best fits the various data in general.

Table 2: Relative Percent Difference of Predicted 1979 Yields from Actual 1979 Yields.

IOWA CORN

MODEL	CRD 10	20	30	40	50	60	70	80	90	State
Simple Linear	-12	-11	-14	-16	-16	-14	-19	-17	-17	-15
Subj. 2-Lines	-19	-20	-17	-28	-30	-20	-32	-33	-27	
5-Yr Groups*		-20	- 5							
7-Yr Groups*					-36				-33	
Obj. 2-Lines	-22	-20	- 3	-22	-35	-19	-34	-39	-32	-27
Obj. 3-Lines	+17	- 4	- 2	+31	-20	- 8	-11	-24	-26	-11

* Models were developed for $\alpha = .15$ significance level (which includes all those models developed at the $\alpha = .10$ level). Blank entries are for CRD's where no significant changes in trend occurred, so that the model would be a simple linear model.

Table 3: Comparison of the Square Root of Residual MSE Values (in Quintals/Hectare) for the Simple Linear and 3-Line Segmented Models.

IOWA CORN

MODEL	CRD 10	20	30	40	50	60	70	80	90	State
Simple Linear	7.9	5.8	5.0	8.9	8.2	5.1	9.8	9.8	7.0	6.2
Obj. 3-Lines	5.7	3.1	4.0	6.3	6.4	4.0	7.3	8.6	6.0	3.9

Iowa soybeans

Simple linear models fitted to 1956-1978 yield data for the nine CRD's show yield trend slopes of .29 to .41 with a state yield slope of .34. Residual MSE values were also fairly consistent, ranging from only 2.11 to 5.64. All in all, soybean yields in Iowa did not seem to show much of a yield trend shift except for one exceptional year (1974), as a review of Figure 1. and the following discussion in this section will bear out.

No subjective models were run over the test period (1956-1978), but 2-line subjective models with join-points at 1970 were run for the period 1950-1978. In a comparison with simple linear models run over the same data set it was seen that residual MSE values were not greatly changed (4 CRD's had lower MSE and 5 had higher than in the simple linear models) and predicted yields in the subjective models were farther from the true yields in 6 of 9 CRD's. Because of the rather consistent trend in soybeans it was difficult to subjectively select a join-point for a 2-line model.

Returning to the test period (1956-1978), a series of 5- and 7-year group models were generated with interesting results. No 7-year groups showed significant trend changes, so that all such groupings resulted in simple linear models. Five-year groups did produce significant changes at $\alpha = .10$ in CRD's 60, 70, and 90, and at $\alpha = .15$ in CRD's 20, 30, 60, 70, 80, 90, and at the state level. In every case the join-point came in 1974. Residual MSE's were quite good, and in 3 CRD's they proved to be lower than any MSE value produced by all the other models.

Objective 2-line methods resulted in models with join-points at 1957, 1969, 1970, and 1976. In almost every case residual MSE were reduced from the simple linear model. However, objective 3-line models showed even further reductions in MSE. Seven of 10 possible cases (9 CRD's and the state total) had their lowest MSE value in the 3-line model. Six of 10 cases had their join-points in 1972 and 1974, with all others having their last join-point in either 1975 or 1976.

It can be seen that there is a direct relationship between shortness of the last line segment, steepness of the slope of that line segment, and a greater percentage error in predicted yields. CRD's 40 and 50 had their last join-point in 1976, the steepest slopes of all models (4.38 and 6.32 respectively), and a relative error in predicting the true yield of 24% (see Table 4). Those CRD's with the last join-point in 1974 had slopes of 1.06 to 2.11 and relative predicting errors of less than 10%.

A review of the predictive abilities of each model is given in Table 4. Very accurate predictions occurred in the simple linear, 5-year group, and 3-line segmented models. The predicted yields for the 5-year group and 3-line models are the same in CRD's 20, 60, 70, 80, 90, and state total. This is because in these cases both models used 1974-1978 as the length of the last line segment from which to predict.

Table 4: Relative Percent Difference of Predicted 1979 Yields from Actual 1979 Yields.

IOWA SOYBEANS

MODEL	CRD 10	20	30	40	50	60	70	80	90	State
Simple Linear	+ 1	+ 3	- 5	- 6	- 8	- 8	- 6	- 9	-13	- 5
5-Yr Groups*		+10	+10			0	+ 1	+ 5	- 1	+ 5
7-Yr Groups*										
Obj. 2-Lines	+23	+ 2	+14	- 9	-10	-13	- 9	-13	-15	- 6
Obj. 3-Lines	+24	+ 9	+16	+24	+24	0	+ 1	+ 5	- 1	+ 5

* Models were developed for $\alpha = .15$ significance level (which includes all models developed at the $\alpha = .10$ level). Blank entries are for CRD's where no significant changes in trend occurred, so that the model will be a simple linear model.

The recommendation of just one model is difficult. Best all-around predictive ability is exhibited in the 5-year group models, but this seems to be the case because of the extraordinary effect of 1974 yields. Models using 1979 data to predict 1980 have been run, and once again most of them show a trend change occurring after the first 5-year period (1979-1975) as well as some remarkably low residual MSE's (.47 and .27 in CRD's 70 and 80, respectively).

The high errors (16% and 24%) in the predictions of the 3-line models mar their usefulness. However, to their credit it can be seen that new models run with 1979 data (for 1980 yield predictions) show 1974 to be once again the join-point for the last segment in 7 out of 10 cases, extreme slopes are nonexistent (the largest is 2.21 in CRD 50) and residual MSE's are again the lowest in the majority of cases (7 out of 10).

The first choice is that the 5-year group models be used for Iowa soybeans in all CRD's and at the state total. However, the simple linear model will be acceptable also, as would the 3-line segmented model.

Illinois corn

Simple linear models fitted to 1956-1978 yield data for the 9 CRD's show yield trend slopes of .97 to 1.41 with a state yield slope of 1.28. Residual MSE's varied from 30.70 to 53.12. In comparison, subjective 2-line models fitted over an extended data set of 2 extra years (1954-1978) with a join-point at 1961 show slopes in the last line segment of .77 to 1.25, and residual MSE's of 30.32 to 51.33. In a CRD-by-CRD comparison, MSE showed little or no reduction when going from the simple linear to the subjective model.

Only 3 CRD's (50, 60, and 70) showed significant changes at the α = .15 level when using 5-year groups for testing. All 3 trend shifts came at 1964. Yield predictions were not noticeably affected, and residual MSE's were in every instance higher, when compared to the simple linear models. No significant changes in trend were discovered when testing 7-year groups.

Join-points for the objective 2-line models occurred in a number of years (1962, 1963, 1965, 1967, 1972, 1974, 1976). In only one CRD (30) did residual MSE decrease from the value derived in the simple linear model. Objective 3-line models also had a variety of join-point combinations with the most prevalent being 1972-1974 (4 instances). Residual MSE's for these models were lower than MSE in simple linear models in only 5 out of 10 cases. One interesting note on these 3-line models is that in 2 CRD's (30 and 40) slopes of the last line segment were actually negative.

A review of the predictive abilities of the various models (Table 5) confirms the previous observation that no one model stands out as clearly "best." The 3-line segmented model again exhibits the best and the worst predictions, and the simple linear model again proves to be the most consistent. However, this time the majority of "closest" predictions comes with the 3-line model.

Models using 1979 data to predict 1980 yields were derived and increases in the value of all slopes occurred. All models have positive slopes now. However, the previous two worst cases (CRD's 30 and 40) for the 3-line models now show the last join-point at 1977. In effect, only 3 years of data are used to predict 1980, and slopes are now extreme (13.62 and 10.73). CRD 60 also has a slope of 15.44 because its last join-point is in 1977. This underlies the major weakness of the segmented models as mentioned earlier (see page 8 of this report).

Even though excellent predictions were made in some or even most CRD's, the possibility of large deviations (20%-30% from actual yields) detracts from the desirability of the 3-line segmented models. This seems to be the case here for Illinois corn yields. Since there is little distinction between the results of the simple linear models or 3-line segmented models, the simple linear model would be preferred.

Illinois soybeans

Simple linear models were run for the base period (1956-1978). Slopes of the trend lines in the 9 CRD's ranged from 0.14 to 0.30 with a state yield slope of 0.26. Residual MSE values ranged from 3.26 to 5.09.

Since Illinois soybean yields are available back to 1931, simple linear models were also developed for the extended time period (1931-1978). Slopes of the extended linear models ranged from 0.23 to 0.29. MSE values ranged from 2.57 to 4.04. Both the slopes and MSE values were comparable to those developed from the shorter base period.

Table 5: Relative Percent Difference of Predicted 1979 Yields From Actual 1979 Yields.

ILLINOIS CORN

MODEL	CRD 10	20	30	40	50	60	70	80	90	State
Simple Linear	-11	-13	-14	- 7	-16	-12	- 9	-22	-20	-11
Subj. 2-Lines*	- 9	-14	-16	- 9	-11	-15	-12	-24	-22	
5-Yr Groups[t]					-12	-15	-11			
7-Yr Groups[t]										
Obj. 2-Lines	-13	- 6	-23	-20	-12	-17	-12	- 9	-22	-14
Obj. 3-Lines	0	0	-26	-15	- 6	-16	-12	-15	-14	- 8

* The subjective model was run with an extended data set (1954-1978) instead of the test period 1956-1978 as were all other models.

[t] Models were developed at the α = .15 significance level. There were no significant changes in trend at α = .10. Blank entries are for CRD's where the models are simple linear.

Predicted yields are practically identical to those from the test period, with differences of no more than 4% and most by less than 2%. All other models run over the data sets show similar results: residual MSE's are lowered by 0.50 to 1.00 with little change in predicted yields. Only R^2 values were significantly changed, with decreases of .20 to .50 for the shorter test period. Nevertheless, these results support using the shorter test period (see Data Bases).

A review of the 5- and 7-year group models shows little to report. Only one CRD (70) showed significant trend change at the α = .15 level, and none at the α = .10 level for 5-year groups. Two CRD's (80, 90) were significant at the α = .10 level for 7-year groups. In all 3 CRD's, residual MSE were the highest of any MSE values for all models in those CRD's.

Objective 2-line models showed a variety of different join-points (1957, 1958, 1963, 1964, 1970, 1974) depending upon which CRD. Also, interestingly enough, residual MSE were larger than MSE from the simple linear models in almost every case. Objective 3-line models showed the lowest residual MSE in almost every case, and in 7 out of 10 cases the 2 join-points occurred in 1972 and 1974. Slopes in the last line segment ranged from -1.78 to 1.77. However, there was only one negative slope (occurring in CRD 90) and this came about because the last join-point occurred in 1976. Again, there is a problem when only 3 years of data were used to predict a yield.

Results of the predictive ability of each model are summarized in Table 6. Some excellent predictions were made with the use of the 2- and 3-line segmented models. As with other states and crops, the simple linear models

Table 6: Relative Percent Difference of Predicted 1979 Yields From Actual 1979 Yields.

ILLINOIS SOYBEANS

	CRD									
MODEL	10	20	30	40	50	60	70	80	90	State
Simple Linear	-10	-14	- 8	- 5	- 4	-10	-12	-13	-19	-10
5-Yr Groups*							+ 4			
7-Yr Groups*								-12	-17	
Obj. 2-Lines	- 4	-11	-11	0	- 3	-10	- 1	-10	-16	- 8
Obj. 3-Lines	+ 1	-13	+ 2	+ 8	+ 8	- 1	+ 4	-13	-33	0

* Models were developed at the $\alpha = .15$ significance level (these include the same models developed at the $\alpha = .10$ level). Blank entries are for CRD's where the models are simple linear.

Table 7: Comparison of the Square Root of Residual MSE Values (in Quintals/Hectare) for the 2- and 3-Lined Segmented Models.

ILLINOIS SOYBEANS

	CRD									
MODEL	10	20	30	40	50	60	70	80	90	State
2-Line	2.0	1.9	2.0	2.3	2.0	1.9	2.1	1.9	1.9	1.8
3-Line	1.9	1.9	1.7	2.1	2.0	1.8	2.1	2.0	1.8	1.8

were consistently good to fair, but in this instance they were never the closest to the true yields. Three-lined models were within 8% of the actual yield 7 times out of 10, yet again showed the highest variability.

A closer comparison of the square root of the residual MSE values (in quintals/hectare) for the 2- and 3-line segmented models is found in Table 7. This table shows that even though MSE's were generally lower in the 3-lined models, the difference is not that large. Also, models using 1979 data to predict 1980 have been run, and a review shows that 9 out of 10 of the 2-line models have 1974 as a join-point, and all 10 cases of 3-lined models have the last join-point in 1974. Predicted yields for both models in all CRD's are very close to each other, as are residual MSE's.

On the basis of these data and comparisons, selection of one model for predicting 1980 yields is difficult. However, the 3-lined model was selected because of the number of CRD's with low predictive errors (see Table 6) and because the negative slope in CRD 90 which caused such an extreme error in the 1979 prediction has been eliminated in the model predicting 1980.

Indiana corn

Simple linear models run over the base period (1956-1978) showed yield trend slopes of 1.03 to 1.49 for the CRD's, and a state yield slope of 1.26. Residual MSE values ranged from 26.26 to 60.68.

Five- and 7-year group models were run, and most turned out to be simple linear. Only CRD's 30 and 60 had a significant change for 5-year groups at the $\alpha = .15$ level, and CRD 90 had a significant change for 7-year groups at the $\alpha = .15$ level. In all 3 CRD's, residual MSE's were higher than for the simple linear models.

Objective 2-line models had join-points in 1962, 1963, 1965, 1974 and 1975 with 1962 being the most commonly selected. Objective 3-line models showed 7 out of 10 cases with the join-points in 1972 and 1974. Residual MSE's were consistently higher in the 2-line models, and many of these MSE's were even higher than those derived in the simple linear models. Slopes of the last line segments in the 3-line models ranged from 2.36 to 5.83.

The predictive abilities of the various models are summarized in Table 8. From these results one can see that every model did good to excellent in predicting yields. Once again the 3-lined models showed the most variability, having the largest errors. Simple linear models were very consistent, predicting closest to true yields 5 times out of 10, and never having an extreme off-prediction.

Because of this consistency, and because (as can be seen in Table 9) residual MSE's compared very favorably to the lower MSE's of the 3-lined models, the simple linear models were selected for 1980 predictions.

Table 8: Relative Percent Difference of Predicted 1979 Yields From Actual 1979 Yields.

INDIANA CORN

MODEL	CRD 10	20	30	40	50	60	70	80	90	State
Simple Linear	- 2	- 6	- 9	- 4	- 3	- 7	+ 6	+ 2	- 1	- 3
5-Yr Group*			+10			- 6				
7-Yr Group*									+ 4	
Obj. 2-Line	- 6	- 7	- 1	- 8	- 5	- 9	+ 1	0	+11	- 6
Obj. 3-Line	+ 3	+ 4	+ 8	+ 6	+ 7	+ 2	+10	+19	+15	+ 7

* Models were developed at the α = .15 significance level. There were no models developed at the α = .10 level. Blank entries are for CRD's with models that are simple linear.

Table 9: Comparison of the Square Root of Residual MSE Values (in Quintals/Hectare) for the Simple Linear and 3-Line Segmented Models.

INDIANA CORN

MODEL	CRD 10	20	30	40	50	60	70	80	90	State
Simple Linear	6.5	6.0	6.0	7.8	6.4	5.1	7.3	6.8	5.6	5.9
Obj. 3-Line	5.7	5.8	5.0	7.7	6.3	5.0	7.2	7.0	5.1	5.6

Indiana soybeans

Simple linear models covering the base period (1956-1978) for all 9 CRD's had yield trend slopes of 0.18 to 0.35 with a state yield slope of 0.29. Residual MSE values were from 2.11 to 5.16.

Five-year group models were run, and significant (α = .15) changes in yield slopes occurred at 1974 in all CRD's except CRD 20 and 30. Slopes in these 5-year periods (1974-1978) ranged from 0.88 to 1.97. Residual MSE values were from 2.72 to 8.28 and were higher than comparable simple linear model MSE's in 6 of 8 cases. Seven-year group models were all simple linear in form because there were no significant (α = .15) changes in yield trends in the 7-year groups.

Objective 2-line models were developed with join-points in 1961, 1966, 1968 and 1974. The most commonly selected (6 of 10 cases) join-point was in 1974. One CRD (80) with a join-point in 1968 resulted in a negative slope of -0.01. There was little change in residual MSE values compared to those of the simple linear models; half were slightly lower while the other half were slightly higher.

Objective 3-line models resulted in a variety (7 different combinations) of join-points. Most of the join-points did occur in the 1970-1974 time period. Slopes of the yield trends in the last line segments of the models varied from the extremes of -0.94 (CRD 20) to 1.76 (CRD 40). Residual MSE's were lower in 7 of 10 cases than the MSE values of the simple linear models.

The relative predictive abilities of the various models are summarized in Table 10. It can be seen that the most accurate models were the simple linear and the 2-line segmented models. Fully half of the 3-line segmented model predictions were farther from the true yield than the worst predictions of these two models. There seems to be little predictive ability gained by using either of the two models.

Models using 1979 data to predict 1980 have been run, and a review of the join-points selected for the new set of 2-line models show almost no changes (1974 is now the join-point in 7 of 10 cases). Eight of the 10 2-line models now have smaller residual MSE's than the comparable simple linear model, but the differences remain very small (absolute differences were no greater than 0.31). In order to maintain consistency with other states and crops, the simple linear model was again selected although it appears that the 2-line model will predict just as accurately.

Conclusions

Some conclusions, observations, and remarks are as follows:

- The variability of the yields decreased as we move eastward. In Indiana all models predicted fairly well, and residual MSE's were relatively lower, when compared to results of the Iowa models.

Table 10: Relative Percent Differences of Predicted 1979 Yields From Actual 1979 Yields.

INDIANA SOYBEANS

MODEL	CRD 10	20	30	40	50	60	70	80	90	State
Simple Linear	-10	-11	-10	- 1	- 3	+ 1	- 3	+ 3	+ 4	- 5
5-Yr Groups*	+ 1			+16	+17	+15	+10	+16	+14	+ 9
7-Yr Groups*										
Obj. 2-Lines	- 3	- 8	+ 1	+ 7	+12	+ 5	+ 7	- 3	+ 1	+ 5
Obj. 3-Lines	0	-16	+ 5	+14	+15	+ 7	+ 9	+20	+15	+ 9

* Models were developed at the $\alpha = .15$ significance level. These include all models developed at the $\alpha = .10$ level. Blank entries are for CRD's with models that are simple linear.

o Simple linear models were the most consistent for all states and crops. Objectively selected 3-line models showed the most variability in predicted yields, being often the closest to true yields in one CRD, and 20%-30% off in a neighboring CRD.

o Predictive ability was not lowered when limiting the data set to the 1956-1978 test period. The addition of 1931-1955 data had little effect on the percent differences of predicted yields from actual yields.

o There was much fluctuation in the selection of join-points for 2-line models, but join-points in 1972 and 1974 were usually selected in 3-line models.

o Three-line models which selected join-points in years after 1974 invariably suffered in predictive ability. Such models might have extremely positive slopes, or even negative slopes. Prediction would be off by 15%-35% in such cases. A possible suggestion for future work in this area would be force 3-line (or 2-line) models to have positive slopes, and perhaps even force the last line segment to be at least 5 years in length.

The two most preferred models for each state/crop combination follow:

State/Crop	1st Model Choice	2nd Model Choice
Iowa/corn	simple linear	obj. 3-line
Iowa/soybeans	5-yr groups	simple linear
Ill./corn	simple linear	obj. 3-line
Ill./soybeans	obj. 3-line	obj. 2-line
Ind./corn	simple linear	obj. 2-line
Ind./soybeans	simple linear	obj. 2-line

When selecting a single model to be used to best predict yield in these three states, the apparent choice is the simple linear model. A listing of simple linear models (updated through 1979) for 1980 corn and soybean yield predictions are found in the Appendix (Tables A1-A6). It should be noted that simple linear models were consistently best for corn, while there was more variability between models when dealing with soybeans. It may be that the single model selected only for soybeans (independent of corn) should be an objective 2-line model.

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(Note: Hudson's paper served as a source for the algorithm used in the Fortran program which was written by Jeanne L. Sebaugh, USDA/ESS, Yield Evaluation Staff, Columbia, MO.

A P P E N D I X

Table A1: "Straw Man" Yield Models for 1980 Yield Predictions.

IOWA CORN

Model	CRD	MSE	R^2	Predicted 1980 $\hat{y}$
Y = 33.96 + 1.55(X) (X) = year - 1956	10	62.63	.67	71.16
Y = 39.29 + 1.53(X) (X) = year - 1956	20	34.42	.78	76.01
Y = 37.64 + 1.49(X) (X) = year - 1956	30	28.80	.80	73.40
Y = 38.39 + 1.14(X) (X) = year - 1956	40	81.75	.46	65.75
Y = 42.59 + 1.33(X) (X) = year - 1956	50	71.76	.56	74.51
Y = 43.73 + 1.27(X) (X) = year - 1956	60	30.39	.73	74.21
Y = 36.24 + 1.17(X) (X) = year - 1956	70	99.33	.42	64.32
Y = 34.05 + 1.10(X) (X) = year - 1956	80	97.45	.39	60.45
Y = 37.91 + 1.44(X) (X) = year - 1956	90	54.39	.67	72.47
Y = 38.58 + 1.36(X) (X) = year - 1956	State	42.51	.69	71.22

Table A2: "Straw Man" Yield Models for 1980 Yield Predictions.

IOWA SOYBEANS

Model	CRD	MSE	R^2	Predicted 1980 $\hat{y}$
Y = 14.99 + .45(X) (X) = year - 1956	10	5.52	.66	25.79
Y = 15.65 + .38(X) (X) = year - 1956	20	1.72	.81	24.77
Y = 13.72 + .42(X) (X) = year - 1956	30	2.46	.79	23.80
Y = 16.01 + .35(X) (X) = year - 1956	40	5.24	.56	24.41
Y = 17.88 + .32(X) (X) = year - 1956	50	4.21	.56	25.56
Y = 17.60 + .38(X) (X) = year - 1956	60	2.52	.75	26.72
Y = 17.86 + .24(X) (X) = year - 1956	70	2.99	.51	23.62
Y = 16.23 + .22(X) (X) = year - 1956	80	4.88	.34	21.51
Y = 16.63 + .35(X) (X) = year - 1956	90	4.03	.61	25.03
Y = 16.21 + .36(X) (X) = year - 1956	State	2.51	.73	24.85

Table A3: "Straw Man" Yield Models for 1980 Yield Predictions.

ILLINOIS CORN

Model	CRD	MSE	R^2	Predicted 1980 $\hat{y}$
Y = 45.63 + 1.15(X) (X) = year - 1956	10	34.42	.67	73.23
Y = 41.98 + 1.28(X) (X) = year - 1956	20	33.51	.72	72.70
Y = 42.01 + 1.33(X) (X) = year - 1956	30	45.22	.67	73.93
Y = 45.86 + 1.41(X) (X) = year - 1956	40	52.09	.67	79.70
Y = 43.96 + 1.49(X) (X) = year - 1956	50	50.22	.70	79.72
Y = 40.34 + 1.44(X) (X) = year - 1956	60	50.58	.68	74.90
Y = 36.09 + 1.57(X) (X) = year - 1956	70	51.75	.71	73.77
Y = 28.38 + 1.16(X) (X) = year - 1956	80	44.75	.61	56.22
Y = 29.37 + 1.10(X) (X) = year - 1956	90	51.96	.55	55.77
Y = 41.20 + 1.37(X) (X) = year - 1956	State	36.38	.73	74.08

Table A4: "Straw Man" Yield Models for 1980 Yield Predictions.

ILLINOIS SOYBEANS

Model	CRD	MSE	R^2	Predicted 1980 $\hat{y}$
Y = 18.77 + .29(X) (X) = year - 1956	10	4.01	.51	25.73
Y = 17.86 + .23(X) (X) = year - 1956	20	3.93	.42	23.38
Y = 17.66 + .32(X) (X) = year - 1956	30	3.71	.59	25.34
Y = 19.56 + .30(X) (X) = year - 1956	40	4.94	.49	26.76
Y = 18.51 + .30(X) (X) = year - 1956	50	3.91	.55	25.71
Y = 18.22 + .28(X) (X) = year - 1956	60	3.64	.54	24.94
Y = 15.40 + .30(X) (X) = year - 1956	70	4.70	.50	22.60
Y = 14.31 + .27(X) (X) = yield - 1956	80	3.79	.49	20.79
Y = 13.99 + .18(X) (X) = yield - 1956	90	3.90	.30	18.31
Y = 17.26 + .28(X) (X) = yield - 1956	State	3.36	.55	23.98

Table A5: "Straw Man" Yield Models for 1980 Yield Predictions

INDIANA CORN

Model	CRD	MSE	R^2	Predicted 1980 $\hat{y}$
Y = 42.53 + 1.26(X) (X) = year - 1956	10	39.68	.68	72.77
Y = 40.40 + 1.08(X) (X) = year - 1956	20	34.47	.64	66.32
Y = 37.33 + 1.09(X) (X) = year - 1956	30	35.61	.64	63.49
Y = 40.41 + 1.38(X) (X) = year - 1956	40	58.27	.63	73.53
Y = 40.23 + 1.38(X) (X) = year - 1956	50	39.72	.72	73.35
Y = 37.37 + 1.25(X) (X) = year - 1956	60	26.01	.76	67.37
Y = 35.66 + 1.45(X) (X) = year - 1956	70	51.40	.68	70.46
Y = 33.26 + 1.23(X) (X) = year - 1956	80	44.75	.64	62.78
Y = 34.53 + 1.21(X) (X) = year - 1956	90	29.88	.72	63.57
Y = 39.13 + 1.28(X) (X) = year - 1956	State	33.55	.72	69.85

Table A6: "Straw Man" Yield Models for 1980 Yield Predictions.

INDIANA SOYBEANS

Model	CRD	MSE	R^2	Predicted 1980 $\hat{y}$
Y = 16.27 + .31(X) (X) = year - 1956	10	3.09	.62	23.71
Y = 16.29 + .28(X) (X) = year - 1956	20	4.37	.48	23.01
Y = 15.51 + .28(X) (X) = year - 1956	30	3.75	.53	22.23
Y = 16.08 + .35(X) (X) = year - 1956	40	4.12	.61	24.48
Y = 17.77 + .31(X) (X) = year - 1956	50	4.95	.51	25.21
Y = 15.17 + .31(X) (X) = year - 1956	60	3.72	.57	22.61
Y = 15.54 + .31(X) (X) = year - 1956	70	2.03	.71	22.98
Y = 15.50 + .17(X) (X) = year - 1956	80	2.63	.38	19.58
Y = 15.13 + .22(X) (X) = year - 1956	90	3.02	.46	20.41
Y = 16.27 + .30(X) (X) = year - 1956	State	2.76	.63	23.47

Table A7: IOWA - 5 YR GROUPS
Significance Levels of F-Tests 1956-1978

CORN

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.47	.18	.14	.77	.60	.40	.32	.81	.49	.66
$T_{2-1} = T_3$	.62	.08	.11	.69	.28	.42	.67	.47	.53	.34
$T_{3-1} = T_4$	.68	.43	.47	.47	.36	.24	.45	.32	.19	.34

SOYBEANS

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.50	.15	.12	.47	.33	.01	.02	.10	.07	.10
$T_{2-1} = T_3$	.54	.33	.56	.99	.25	.36	.33	.54	.38	.58
$T_{3-1} = T_4$	.93	.70	.96	.36	.77	.40	.16	.24	.29	.57

* Circled values are significant at the α = .10 level.
Squared values are significant at the α = .15 level.

T_1 = slope of trend for years 1978-1974.

T_2 = slope of trend for years 1973-1969.

T_3 = slope of trend for years 1968-1964.

T_4 = slope of trend for years 1963-1959.

T_{2-1} = slope of trend for years 1978-1969.

T_{3-1} = slope of trend for years 1978-1964.

Table A8: IOWA - 7 YR GROUPS
Significance Levels of F-Tests 1956-1978

CORN

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.51	.26	.65	.53	(.08)	.89	.51	.20	[.10]	.29
$T_{2-1} = T_3$	.50	.42	.78	.39	.26	.22	.50	.39	.30	.34

SOYBEANS

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.65	.31	.96	.94	.23	.62	.56	.40	.33	.43
$T_{2-1} = T_3$	.99	.88	.47	.80	.85	.46	.94	.72	.89	.82

* Circled values are significant at the α = .10 level.
Squared values are significant at the α = .15 level.

T_1 = slope of trend for years 1978-1972.

T_2 = slope of trend for years 1971-1965.

T_3 = slope of trend for years 1964-1958.

T_{2-1} = slope of trend for years 1978-1965.

Table A9: ILLINOIS - 5 YR GROUPS
Significance Levels of F-Tests 1956-1978

CORN

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.40	.35	.47	.90	.71	.56	.59	.86	.46	.89
$T_{2-1} = T_3$	.70	.97	.60	.99	.91	.55	.68	.38	.64	.78
$T_{3-1} = T_4$	.63	.69	.31	.29	[.14]	[.11]	[.15]	.52	.25	.24

SOYBEANS

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.19	.33	.23	.22	.18	.25	[.11]	.54	.84	.22
$T_{2-1} = T_3$	.57	.79	.32	.40	.63	.22	.24	.23	.32	.30
$T_{3-1} = T_4$	.58	.37	.43	.58	.51	.35	.51	.72	.98	.63

* Circled values are significant at the α = .10 level.
Squared values are significant at the α = .15 level.

T_1 = slope of trend for years 1978-1974.

T_2 = slope of trend for years 1973-1969.

T_3 = slope of trend for years 1968-1964.

T_4 = slope of trend for years 1963-1959.

T_{2-1} = slope of trend for years 1978-1969.

T_{3-1} = slope of trend for years 1978-1964.

Table A10: ILLINOIS - 7 YR GROUPS
Significance Levels of F-Tests 1956-1978

CORN

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.59	.50	.46	.67	.82	.95	.57	.34	.40	.92
$T_{2-1} = T_3$	.58	.62	.56	.43	.21	.44	.41	.91	.46	.42

SOYBEANS

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.96	.99	.60	.90	.80	.86	.79	.83	.93	.91
$T_{2-1} = T_3$	.68	.36	.97	.92	.85	.65	.45	(.09)	(.09)	.52

* Circled values are significant at the $\alpha = .10$ level.
Squared values are significant at the $\alpha = .15$ level.

T_1 = slope of trend for years 1978-1972.

T_2 = slope of trend for years 1971-1965.

T_3 = slope of trend for years 1964-1958.

T_{2-1} = slope of trend for years 1978-1965.

Table A11: INDIANA - 5 YR GROUPS
Significance Levels of F-Tests 1956-1978

CORN

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	.47	.47	[.11]	.54	.39	.19	.81	.69	.19	.41
$T_{2-1} = T_3$	.64	.77	.58	.96	.96	.43	.78	.63	.79	.83
$T_{3-1} = T_4$	.22	.32	.25	.16	.24	[.11]	.20	.31	.20	.18

SOYBEANS

TEST	PROB (Reject H_0 when slopes are equal)*									
	CRD									STATE
	10	20	30	40	50	60	70	80	90	
$T_1 = T_2$	[.15]	.44	.28	(.09)	(.05)	(.07)	(.04)	(.01)	(.02)	(.07)
$T_{2-1} = T_3$	.36	.54	.64	.49	.91	.29	.54	.17	.10	.51
$T_{3-1} = T_4$	.77	.71	.68	.81	.59	.86	.79	.46	.65	.79

* Circled values are significant at the $\alpha = .10$ level.
Squared values are significant at the $\alpha = .15$ level.

T_1 = slope of trend for years 1978-1974.

T_2 = slope of trend for years 1973-1969.

T_3 = slope of trend for years 1968-1964.

T_4 = slope of trend for years 1963-1959.

T_{2-1} = slope of trend for years 1978-1969.

T_{3-1} = slope of trend for years 1978-1964.

Table A12: INDIANA - 7 YR GROUPS
Significance Levels of F-Tests 1956-1978

CORN

TEST	PROB (Reject H_0 when slopes are equal)* CRD 10	20	30	40	50	60	70	80	90	STATE
$T_1 = T_2$	.61	.96	.70	.83	.87	.84	.37	.51	[.14]	.83
$T_{2-1} = T_3$	.37	.68	.91	.32	.47	.55	.21	.76	.36	.40

SOYBEANS

TEST	PROB (Reject H_0 when slopes are equal)* 10	20	30	40	50	60	70	80	90	STATE
$T_1 = T_2$	.83	.87	.68	.77	.88	.59	.32	.26	.20	.90
$T_{2-1} = T_3$	.19	.21	.27	.59	.16	.16	.20	.99	.77	.19

* Circled values are significant at the α = .10 level.
Squared values are significant at the α = .15 level.

T_1 = slope of trend for years 1978-1972.

T_2 = slope of trend for years 1971-1965.

T_3 = slope of trend for years 1964-1958.

T_{2-1} = slope of trend for years 1978-1965.