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Evaluation of the Feyerherm '82 Winter Wheat Model for Estimating Yields in Indiana, Kansas, Montana and Ohio

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ABSTRACT

The Feyerherm '82 winter wheat yield model was evaluated for its ability to estimate yields at the State level in Indiana, Kansas, Montana and Ohio. This regression model uses a weather index which has been developed using agricultural experiment station data from a wide range of environmental conditions in the United States. Daily weather values are used to simulate stages of plant development and a soil moisture budget. Derived weather and soil moisture variables are then summarized over the stages of development for use in a weather index. The State-level model incorporates the weather index along with trend or technology-related variables. The use of a denser weather network, in contrast to the nine stations used by Feyerherm, is investigated. An alternate method for calculating the differential yielding ability values is described. The Feyerherm model demonstrates a lower root mean squared error than the LACIE (Large Area Crop Inventory Experiment) model for Kansas but a higher root mean squared error for Montana.

Key Words: Model evaluation, crop yield modeling, regression models, winter wheat yield models, weather index, dense weather network, differential yielding ability.

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EVALUATION OF THE FEYERHERM '82

WINTER WHEAT MODEL FOR ESTIMATING

YIELDS IN INDIANA, KANSAS, MONTANA AND OHIO

by

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This research was conducted as part of the AgRISTARS* Program and is part of the task identified as SRS-YES-I in the 1984 AgRISTARS Program Plan.

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

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EVALUATION OF THE FEYERHERM '82 WINTER WHEAT MODEL FOR ESTIMATING YIELDS IN INDIANA, KANSAS, MONTANA AND OHIO

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INTRODUCTION

The U. S. Department of Agriculture (USDA) is interested in improved procedures for forecasting and estimating crop yields over large areas. Previous work has been done with regression models based on historic values of yield, weather, and agronomic variables by the Assessment and Information Services Center, previously known as the Center for Climatic and Environmental Assessment Services (National Oceanic and Atmospheric Administration, U. S. Department of Commerce). The Statistical Reporting Service (SRS of USDA) uses multiple regression models to generate indicators of winter wheat yields at the state level during the growing season.

Presently, the weather variables used in the CEAS models are based on temperature averages and/or precipitation totals over calendar months. Sebaugh (1981a) in an evaluation of the CEAS trend and monthly weather data models points out:

> Of course, there is little year-to-year agronomic correspondence between the beginning and ending of a calendar month and the beginning and ending of stages of development for a wheat plant (and thus its changing temperature and moisture requirements). Also, wheat plants do not begin developmental stages at the same time each year. Therefore, an inherent difficulty exists in working with monthly weather data.

Dr. Arlin M. Feyerherm in the Department of Statistics at Kansas State University has constructed a crop yield regression model which has been provided to U.S.D.A. under research agreement No. 58-319T-0-0337X. This modeling approach was developed as part of the LACIE (Large Area Crop Inventory Experiment) project and is based on an approach developed over several years (Feyerherm 1977, 1979; Feyerherm and Paulsen 1981a,b). The objective was to develop a universal model which could be made applicable to other countries with only minor adjuistments necessary at the local level.

The new model is based on the use of a simulated crop calendar and soil moisture budget. The planting date can be provided or estimated by a "starter" model. Then the stages of crop development, from emergence through ripe, are simulated using daily weather values. Temperatures are averaged and precipitation is totaled over stages of development, such as heading to milk, rather than over calendar months. This method of defining the weather variables to be used in the regression analysis seems more consistent with available scientific knowledge about plant development.

Feyerherm's method also includes a "universal" weather index which could be used wherever winter wheat is being grown under conditions similar to the U.S. Great Plains. The coefficients of terms in the index are estimated from the relationship between agricultural experiment station plot yield data and weather data from nearby weather stations. The plot yields and weather cover conditions from Montana to Texas and Colorado to Ohio over a time span of 54 years (1920-1973). The term coefficients are regarded as constant over the entire area. The coefficient of the weather index is estimated along with the trend term when applied to a particular area.

This report represents the first evaluation of the Feyerherm winter wheat model with the objective of suggesting improvements based on these findings.

DESCRIPTION OF THE MODEL

Weather Index

The main component of the model is a weather index (WX). The weather index was developed by regressing wheat yields from agricultural experiment and cooperating farmer plots on weather-related variables created from daily values of precipitation and maximum and minimum temperatures measured at nearby weather stations. WRVPGM'82 is the program which generates the weather-related variables. Information on the use of the WRV program is contained in the "Users Manual for Weather Related Variables Program (WRVPGM'82)," (Feyerherm, 1982a). The weather index has the form:

$$WX = 72.6 + ET + XPR + TEMP$$

where

ET are evapotranspiration effects,

XPR are excessive precipitation effects, and

TEMP are temperature effects.

These components are in units of bushels per acre and are explicitly defined in an Appendix, page 47. The WX can be obtained for any point or region for which daily weather data are available. The WX values are then averaged over the region or state to produce the term used in the model, AWX.

An important aspect of the weather index concerns its development. Feyerherm used yield and weather data which cover a wide variety of environmental conditions, from Montana to Texas and Colorado to Ohio. The sample size consisted of 858 location-years over a time span of more than 50 years at some locations. The wheat yields were adjusted for varietal differences before performing the regression. Other variables involved in the plot level analysis include a term for the amount of applied nitrogen (AV_NI), indicator variables for locations, and a time variable to remove long-term trend. The STEPWISE procedure in SAS (Statistical Analysis System) was used to select the variables which would be combined to form the weather index. For a description of these variables, see the Appendix.

Form of the Large Area Model

The model may be written as:

$$YIELD = \beta_0 + \beta_1 T + \beta_2 *AWX + \varepsilon$$

where

YIELD = State yield of winter wheat per harvested acre,

T = A function of the year number, e.g., harvest year minus 1955,

AWX = Simple average of the weather index values for the state, and

ε = Random error.

Alternately, the yield may be adjusted for losses due to rust. The adjusted yield is defined as:

$$ADTYIELD = YIELD + LOSS$$

where

LOSS = [EEF/(100-EEF)] YIELD, and EEF is the percent loss due to rust.

Yield estimates for a test year (any year for which yield estimates are desired) can be obtained by defining the trend component in either of two ways. One way is to extrapolate trend substituting T = (Test year - 1955) into the prediction equation. The second is to let T = (Test year - 1 - 1955) and add on the change from the previous year in technology due to the improvement in varieties (AVE_DYA) and that due to nitrogen fertilizer (AV_NI). The change in technology from one year to the next is denoted by:

$$\Delta TECH = (TECH)_{test\ year} - (TECH)_{previous\ year}$$

where

TECH = AVE_DYA + .11*AV_NI.

The constant 0.11 was the estimate of the coefficient of AV_NI in the plot level regression described above.

Differential Yielding Ability

The formula for AVE_DYA is:

$$AVE\_DYA = \frac{\sum_{k=1}^{N} q_k * DYA_k}{\sum_{k=1}^{N} q_k}$$

where

q_k = percent of area planted to variety k,

DYA_k = the differential yielding ability of variety k,

N = number of varieties.

DYA values for a variety k are determined by averaging the yield differences between the yields for variety k and the yields for a standard. This procedure is described in "Data Base Documentation for Test Data for Winter Wheat Model" (Feyerherm, 1982b).

Data Base

Figures 1, 2, 3 and 4 show the historic winter wheat yields for Indiana, Kansas, Montana and Ohio as reported by U.S.D.A.'s Statistical Reporting Service. Although data are available back to the thirties, Feyerherm used the data from 1955. One reason is that daily weather values for many stations begin in 1948, and the soil moisture budget routine requires some years of running prior to its use. Also nitrogen data are not available prior to 1954. The meteorological data are available from the National Climatic Data Center (NCDC) located at Asheville, North Carolina.

EVALUATION OF THE MODEL

To begin the evaluation of the model, Cotter and Sebaugh (1982) prepared "An Evaluation of the Sources, Accuracy and Availability of the Input Data Required to Run Feyerherm's Winter Wheat Model and Preliminary Testing Performed by Feyerherm." This was followed by "Outline for Further Evaluation of the Feyerherm Winter Wheat Model" (Cotter and Sebaugh, 1982) which suggested areas for further investigation.

This section will present the results of the evaluation process. Indicators of yield reliability obtained from bootstrap tests (1970-1979) are shown for each of the four states for which Feyerherm performed preliminary testing. Further information about the indicators of yield reliability and bootstrap testing may be found in Wilson, et al. (1980) and Wilson and Sebaugh (1981).

Combining the two ways of defining yield and the two methods of estimating technology changes, the model can be evaluated under the following four categories:

Figure 1. Indiana U.S.D.A. reported winter wheat yields 1931-1980 (bushels/acre)

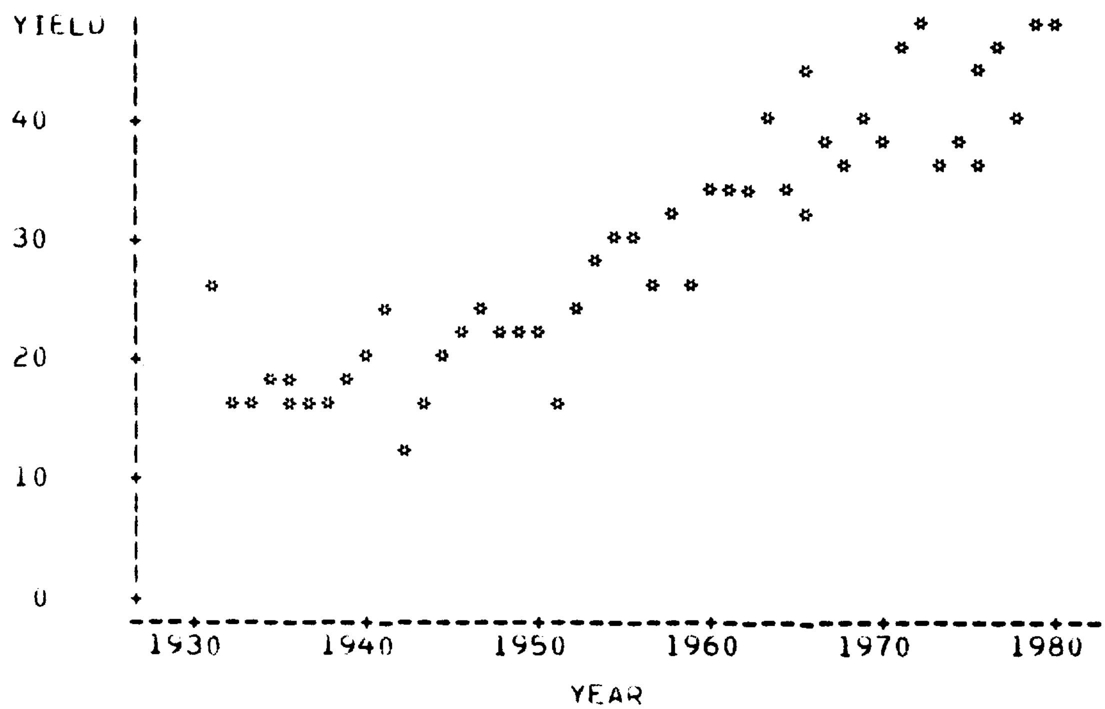


Figure 2. Kansas U.S.D.A. reported winter wheat yields 1931-1980 (bushels/acre)

Figure 3. Montana U.S.D.A. reported winter wheat yields 1931-1980 (bushels/acre)

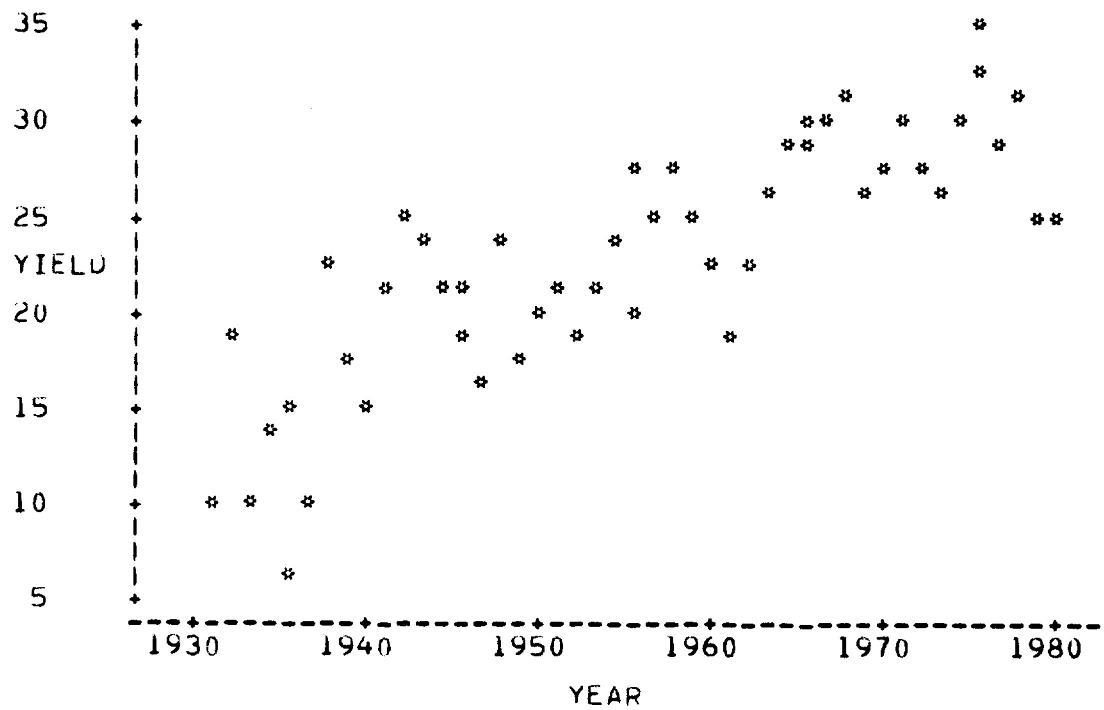
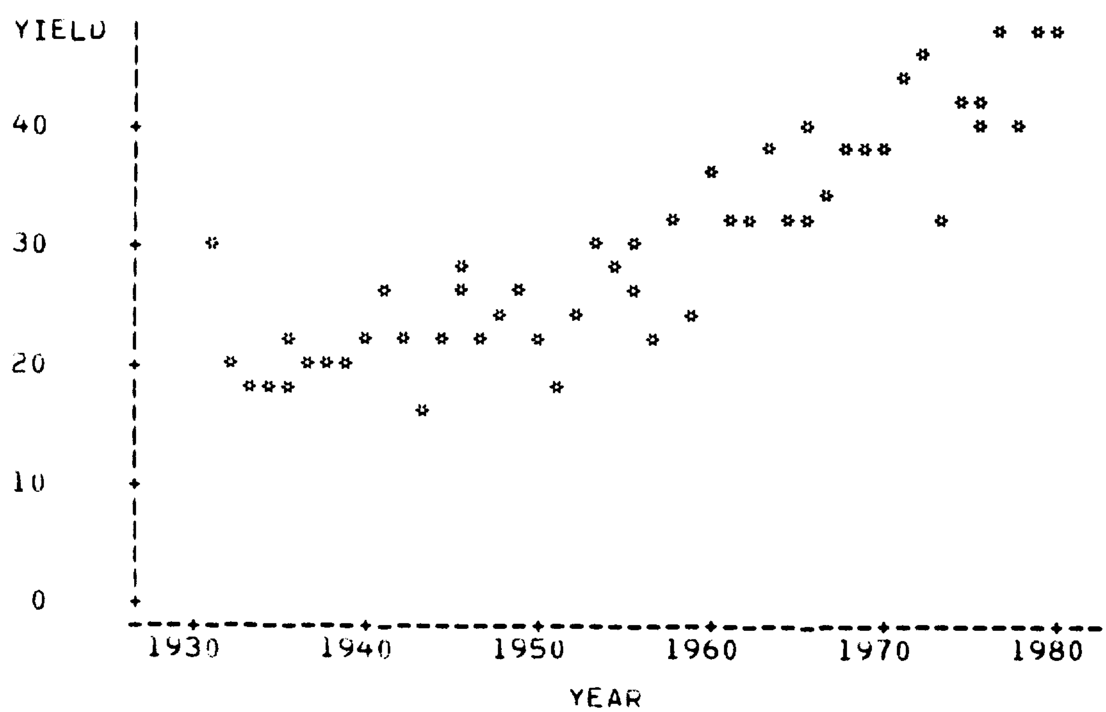


Figure 4. Ohio U.S.D.A. reported winter wheat yields 1931-1980 (bushels/acre)



Yield Defined Assuming Rust Loss	Estimating Technology Changes
No	Extrapolate trend term
No	Use of ΔTECH information
Yes	Extrapolate trend term
Yes	Use of ΔTECH information

These categories will be used in each of the tables which present indicators of yield reliability.

Corrected Data and Bootstrap Methods

Corrections were made to the input data values for nitrogen applied, some average differential yielding ability values and some yield values. These corrections are presented in the document "An Evaluation of the Sources, Accuracy and Availability of the Input Data Required to Run Feyerherm's Winter Wheat Model and Preliminary Testing Performed by Feyerherm" (Cotter and Sebaugh, 1982).

Tables 1, 2, 3 and 4 show the indicators of yield reliability for each of the four states for which Feyerherm performed preliminary tests. Overall, the Montana model demonstrated the best performance. The RMSEs (root mean square errors) ranged from 2.60 for Montana to 5.22 for Indiana. For Indiana, the RRMSE (relative root mean square error) ranged from 10.7% to 12.6%, Kansas - 10.5% to 11.3%, Montana - 8.9% to 9.9%, Ohio - 8.9% to 10.1%. The percent of years that the absolute value of the relative difference exceeds 10% varied from a low of 20% for Ohio to 60% for Indiana and Kansas. Based on the RMSE, preliminary bootstrap testing favored the use of the rust loss information in areas such as Kansas where rust loss is greatest. The use of the ΔTECH information gives lower RMSEs than extrapolation of the linear trend.

Figures 5, 6, 7 and 8 present plots for each of the test states of the USDA reported (observed) and predicted yields for each bootstrap test year using the rust information and ΔTECH.

For Indiana it is interesting that the three bootstrap test years which produced the highest relative differences (1973, 1974, 1978) were characterized as having a high disease problem according to the Agricultural Experiment Stations. The largest miss occurred in 1978 resulting in a 21 percent absolute value of the relative difference (see figure 5). The growing season for the 1978 Indiana crop was characterized by abnormalities. A cool wet autumn resulted in delayed planting and minimal growth before a long cold winter. Crop development then surged in May to finish up ahead of the average of the most recent five years. This unusual growing season along with the disease problems may help to explain the large miss.

The model performed somewhat better in Kansas than in Indiana with the largest miss (6.2 bushels per acre) also occurring in 1978. The year 1978 was characterized as having a medium severity of disease problems (Feyerherm 1983). A medium infestation translates into a 5-15% yield loss. The model's prediction was below the observed yield in 1971 which had the second largest absolute value of the relative difference. In that year the crop also sustained a medium infestation of disease.

Table 1. Indicators of Yield Reliability -
Feyerherm Winter Wheat Model
1970-1979

INDIANA

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	0.76	1.12	0.98	1.32
Relative Bias = RB (%)	1.8	2.7	2.4	3.2
Mean Square Error = MSE $(B/A)^2$	26.40	19.99	27.27	20.32
Root Mean Square Error = RMSE (B/A)	5.14	4.47	5.22	4.51
Relative Root Mean Square Error = RRMSE (%)	12.4	10.7	12.6	10.8
Variance = Var $(B/A)^2$	25.83	18.74	26.31	18.57
Standard Deviation = SD (B/A)	5.08	4.33	5.13	4.31
Relative Standard Deviation = RSD (%)	12.0	10.1	12.0	10.0
Percent of Years $\|rd\| >$ 10% (%)	60	50	60	50
Largest $\|rd\|$ (%)	26.7	21.5	26.2	21.0
Next Largest $\|rd\|$ (%)	17.1	15.1	19.1	16.9
Smallest $\|rd\|$ (%)	1.8	-0.2	-1.4	0.5
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	56	67	56	67
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	57	71	57	71
Pearson correlation coefficient between observed and predicted yields	0.12	0.40	0.07	0.39

Table 2. Indicators of Yield Reliability -
Feyerherm Winter Wheat Model
1970-1979

KANSAS

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	-0.25	-0.47	-0.59	-0.78
Relative Bias = RB (%)	-0.8	-1.5	-1.8	-2.4
Mean Square Error = MSE $(B/A)^2$	13.25	12.24	12.15	11.26
Root Mean Square Error = RMSE (B/A)	3.64	3.50	3.49	3.36
Relative Root Mean Square Error = RRMSE (%)	11.3	10.9	10.9	10.5
Variance = Var $(B/A)^2$	13.19	12.02	11.80	10.65
Standard Deviation = SD (B/A)	3.63	3.47	3.44	3.26
Relative Standard Deviation = RSD (%)	11.4	11.0	10.9	10.4
Percent of Years $\|rd\| > 10\%$ (%)	60	50	50	30
Largest $\|rd\|$ (%)	19.6	17.5	23.0	20.7
Next Largest $\|rd\|$ (%)	19.0	16.7	-13.9	-15.9
Smallest $\|rd\|$ (%)	-1.4	-1.3	1.4	-1.1
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	67	67	56	56
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	86	86	86	71
Pearson correlation coefficient between observed and predicted yields	0.35	0.41	0.42	0.48

Table 3. Indicators of Yield Reliability -
Feyerherm Winter Wheat Model
1970-1979

MONTANA

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	1.05	0.84	1.19	0.95
Relative Bias = RB (%)	3.6	2.9	4.1	3.2
Mean Square Error = MSE $(B/A)^2$	7.76	6.76	8.43	7.21
Root Mean Square Error = RMSE (B/A)	2.79	2.60	2.90	2.68
Relative Root Mean Square Error = RRMSE (%)	9.5	8.9	9.9	9.2
Variance = Var $(B/A)^2$	6.66	6.06	7.01	6.31
Standard Deviation = SD (B/A)	2.58	2.46	2.65	2.51
Relative Standard Deviation = RSD (%)	8.5	8.2	8.7	8.3
Percent of Years $\|rd\|$ > 10% (%)	30	40	30	40
Largest $\|rd\|$ (%)	21.2	18.8	21.6	18.8
Next Largest $\|rd\|$ (%)	13.7	13.0	14.4	13.7
Smallest $\|rd\|$ (%)	-0.3	0.7	-0.7	0.3
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	89	89	89	89
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	86	86	86	86
Pearson correlation coefficient between observed and predicted yields	0.43	0.50	0.41	0.48

Table 4. Indicators of Yield Reliability - Feyerherm Winter Wheat Model 1970-1979

OHIO

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	0.23	0.58	-0.02	0.37
Relative Bias = RB (%)	0.6	1.4	-0.0	0.9
Mean Square Error = MSE $(B/A)^2$	17.77	14.01	17.82	13.72
Root Mean Square Error = RMSE (B/A)	4.22	3.74	4.22	3.70
Relative Root Mean Square Error = RRMSE (%)	10.1	9.0	10.1	8.9
Variance = Var $(B/A)^2$	17.72	13.67	17.82	13.58
Standard Deviation = SD (B/A)	4.21	3.70	4.22	3.69
Relative Standard Deviation = RSD (%)	10.1	8.8	10.2	8.8
Percent of Years $\|rd\| >$ 10% (%)	20	20	20	20
Largest $\|rd\|$ (%)	25.6	26.6	25.0	25.9
Next Largest $\|rd\|$ (%)	18.2	13.1	17.4	12.3
Smallest $\|rd\|$ (%)	-1.0	0.0	-1.5	-0.3
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	67	78	67	78
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	43	71	43	71
Pearson correlation coefficient between observed and predicted yields	0.38	0.59	0.37	0.60

Figure 5. USDA reported (observed) and predicted yields in bushels per acre for each bootstrap test year using the rust and ΔTECH information.

INDIANA

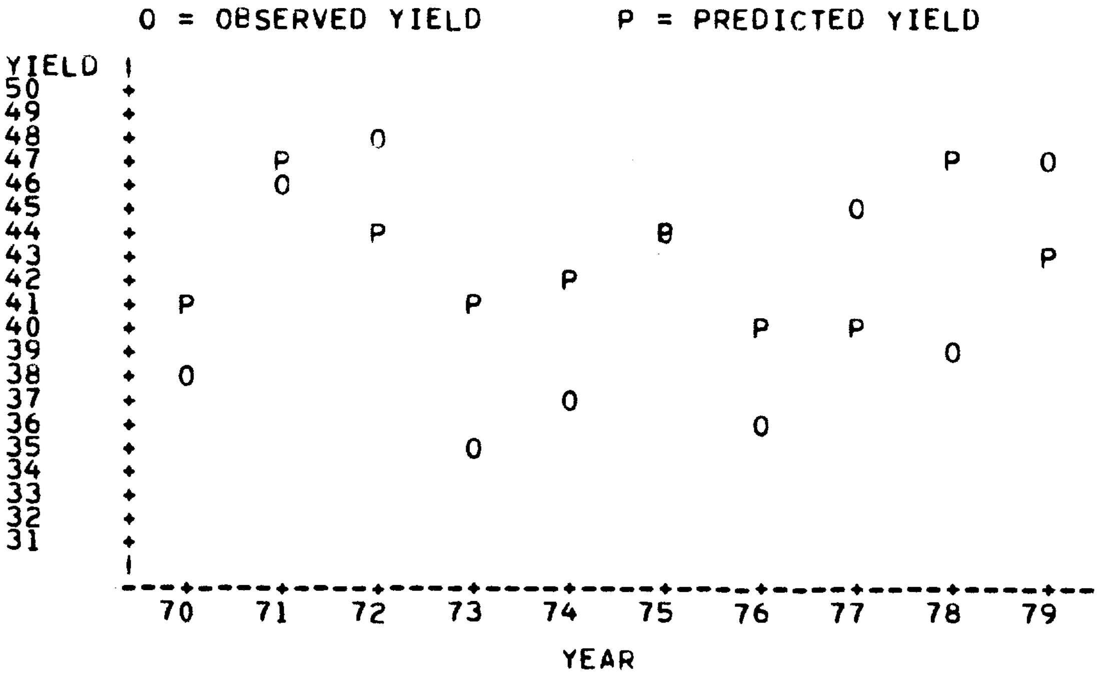


Figure 6. USDA reported (observed) and predicted yields in bushels per acre for each bootstrap test year using the rust and ΔTECH information.

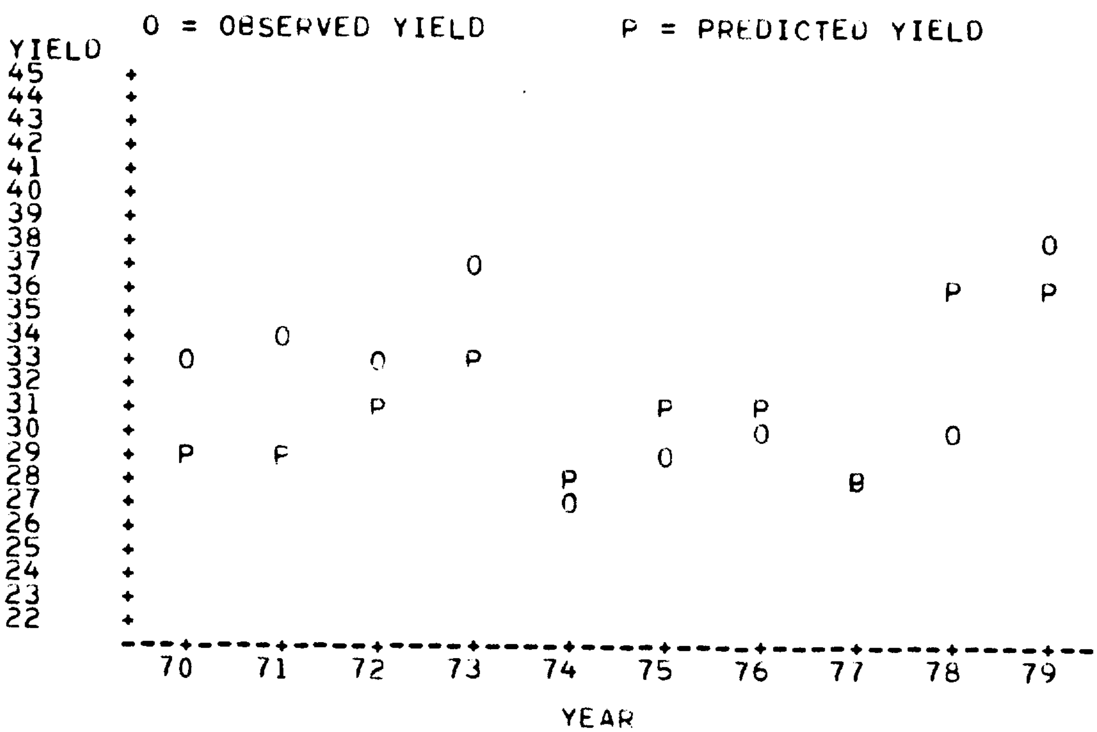


Figure 7. USDA reported (observed) and predicted yields in bushels per acre for each bootstrap test year using the rust and ΔTECH information.

MONTANA

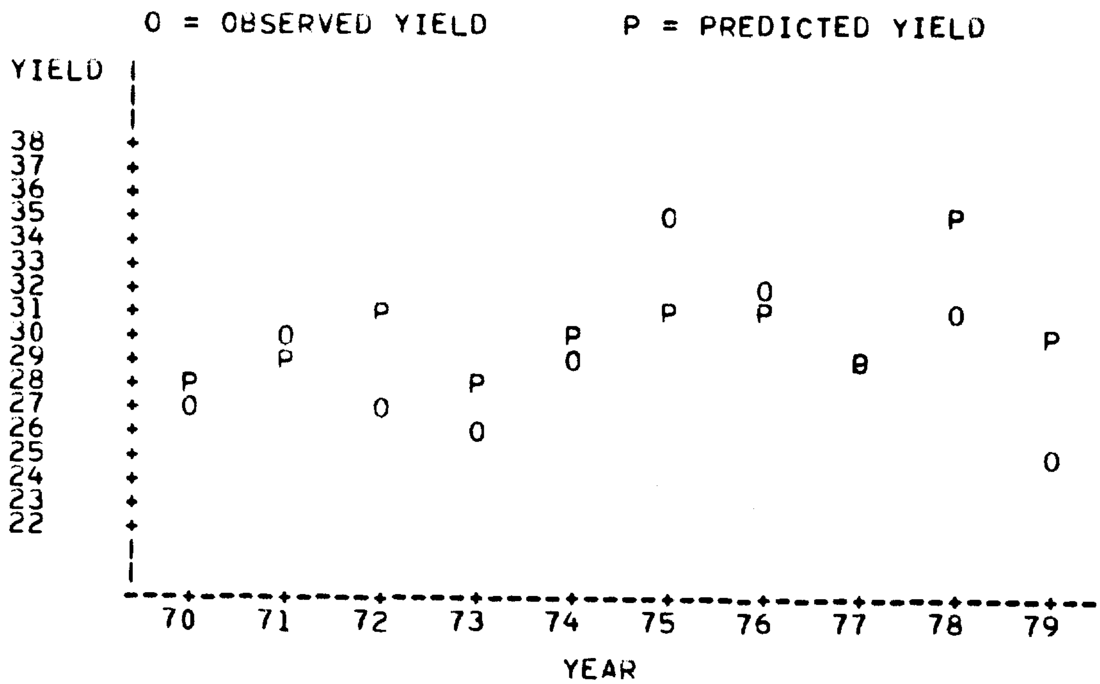
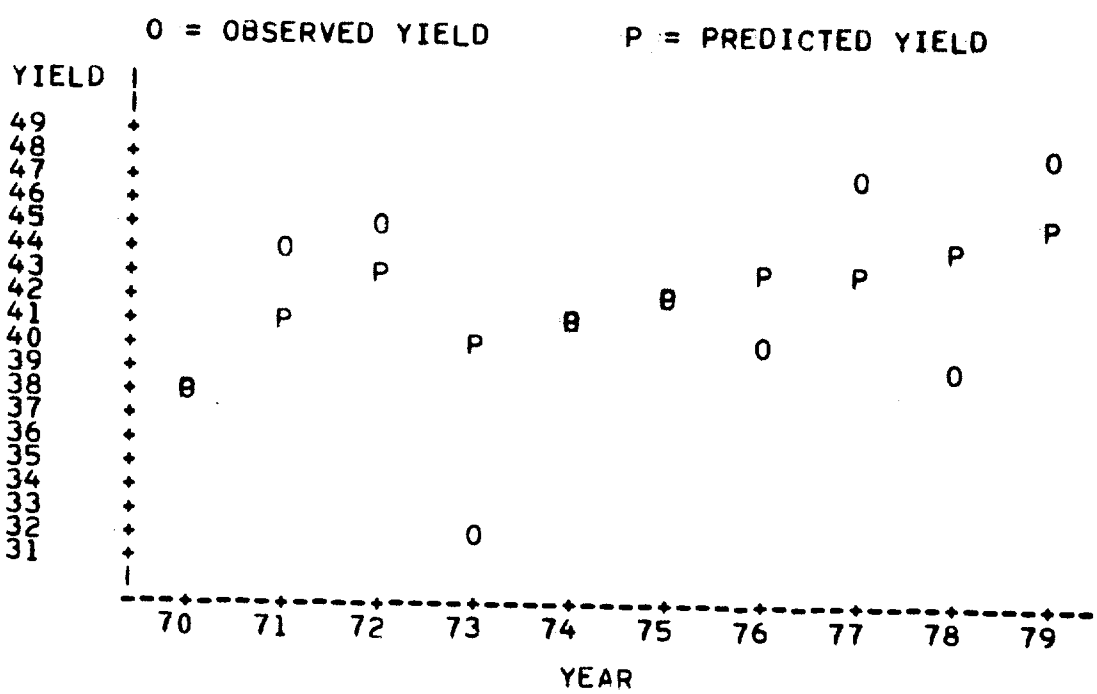


Figure 8. USDA reported (observed and predicted yields in bushels per acre for each bootstrap test year using the rust and ΔTECH information.

OHIO



Of the four state level models tested, the Montana model performed best (see Table 3 and Figure 7). The largest miss occurred in 1979 with a 4.8 bushels per acre difference. The next largest miss was in 1978 with a 4.0 bushels per acre difference. Both of these were overestimates. Since disease and insect losses seldom occur in Montana, the problem would appear to be with the weather index.

The largest difference between the predicted and observed yields in Ohio occurred in 1973. The difference was 8.3 bushels per acre (see Figure 8). The second largest difference, 4.8 bushels per acre, occurred in 1978. The year 1973 was characterized as having a high severity of disease (greater than 15% loss), and 1978 a medium severity of disease. The disease factor may be only part of the difference. A contradictory year is 1974 in which the severity of disease was rated as high, and yet the prediction was only 0.2 bushels per acre off.

Analysis of the Trend Component

Feyerherm defined his trend term to be linear and equal to:

Trend = harvest year minus 1955.

Feyerherm excluded the bootstrap test years (1970 to 1979) from his analysis of trend so that the bootstrap results would be independent of the trend specification. Sebaugh (1983) states "Of course, that independence is desirable but not at the expense of degrading the residuals from trend to be modeled by weather. Our use of data from 1970-1979 means that the bootstrap test results are not independent of the trend specification, but it improves our ability to evaluate the weather component of the model." The aim is to obtain the best set of residuals from trend in order to analyze the variability associated with the weather.

The analysis involves several steps. First, yield is modeled as a function of the weather index only. Residuals are computed and plotted over time. Next, a visual inspection of this plot may result in several ways to specify trend. The new trend is then incorporated in the model. Generally, many combinations are tried in an attempt to find one which results in a lower MSE than the author's model. If successful, then the model with the respecified trend is bootstrap tested and the indicators of yield reliability are computed and compared to the original model.

Of the four state models which were tested, analysis showed that an improved trend specification for Indiana and Montana resulted in better performance. No improvement could be made in the Kansas and Ohio models' trend specification. Figures 9, 10, 11 and 12 show the residuals after fitting the weather index alone for the four states studied.

Indiana

Figure 9 shows a plot of the residuals over time after fitting the weather index alone ($Y-\hat{Y}$) for Indiana. It is apparent from the plot that yield levels, after accounting for the effect of weather, were at a plateau until the early sixties when they began to trend upward into the early seventies. Throughout the seventies, yields were quite variable, and the trend becomes harder to distinguish.

Figure 9. Feyerherm winter wheat model residuals after fitting the weather index - Indiana. Units are bushels per acre.

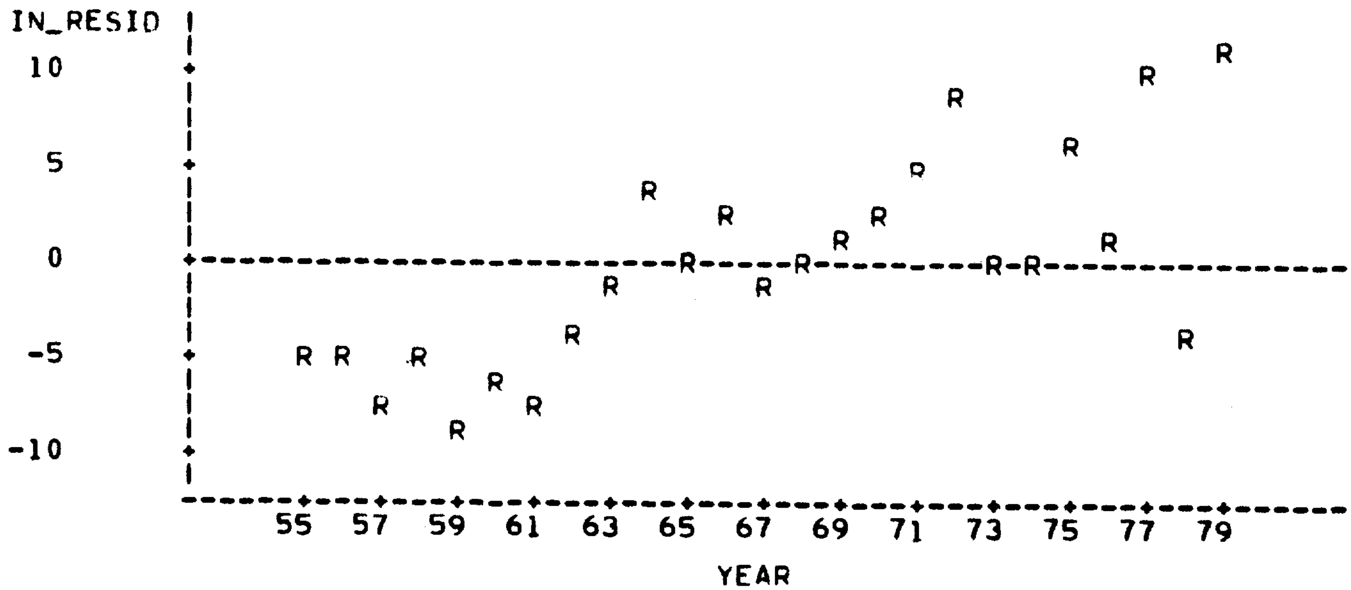


Figure 10. Feyerherm winter wheat model residuals after fitting the weather index - Kansas. Units are bushels per acre.

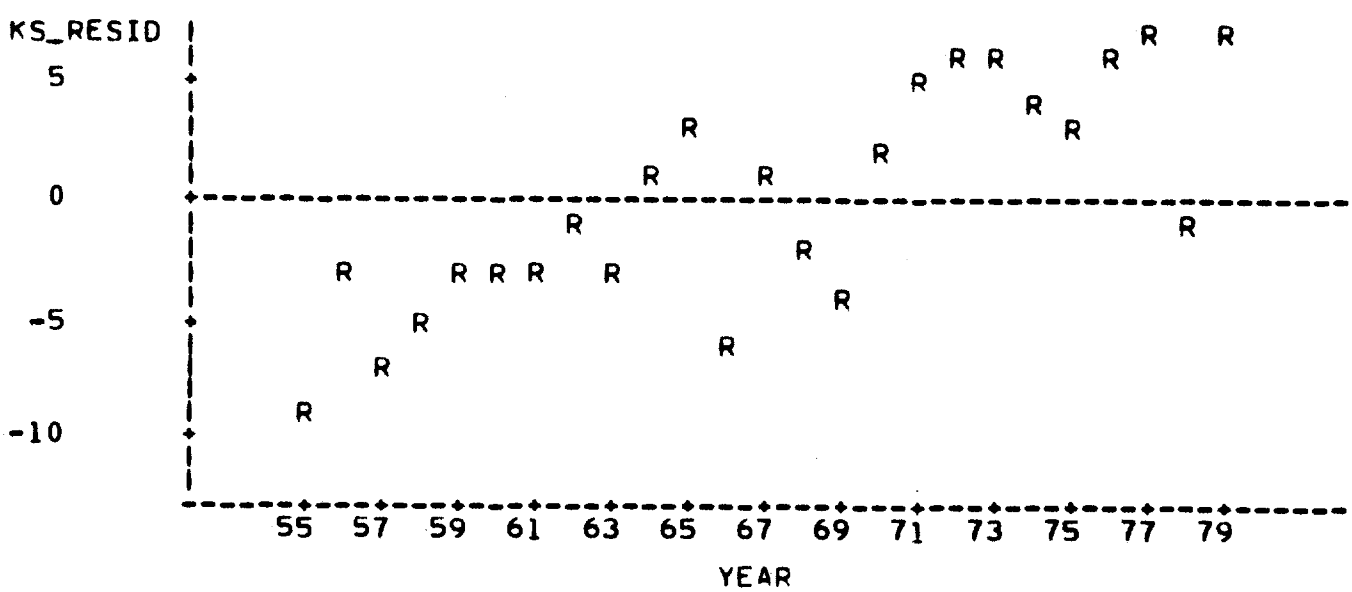


Figure 11. Feyerherm winter wheat model residuals after fitting the weather index - Montana. Units are bushels per acre.

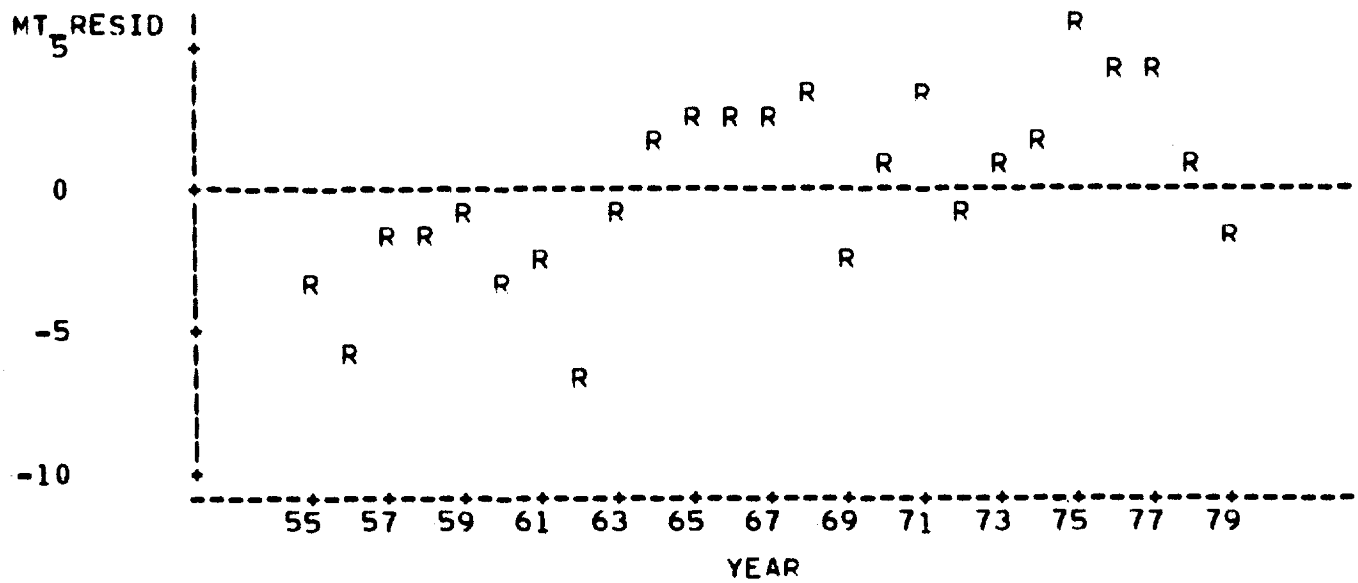
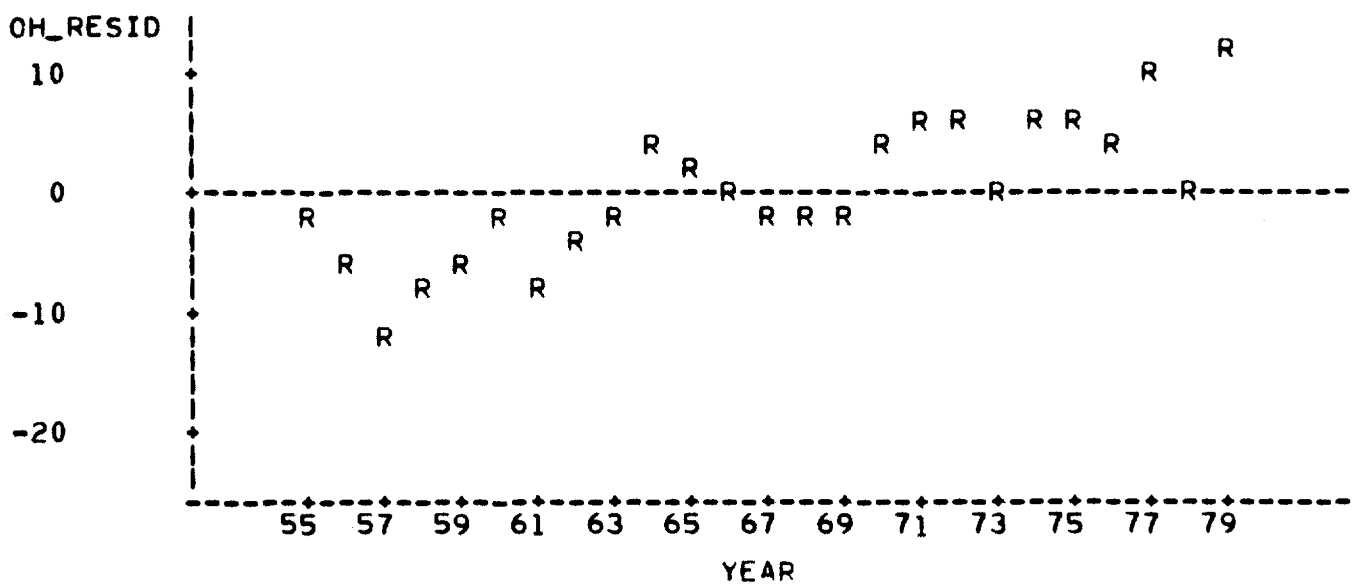


Figure 12. Feyerherm winter wheat model residuals after fitting the weather index - Ohio. Units are bushels per acre.



Some of this variability can be attributed to the disease and winterkill problems discussed earlier which apparently were not accounted for by the weather index.

Based on these observations, two general types of trends were suggested which were composed of piecewise linear components. The first type consisted of two piecewise linear trends: a flat portion followed by a positive trend with the break point varying from 1959-1962. The second type consisted of three linear trends: again a flat portion followed by a positive trend and then followed by a flat portion. The break points ranged from 1959-1962 for the first break and 1970-1974 for the second break. Twenty-four models were tested for Indiana.

The model which produced the lowest MSE was a three-line model with break points in 1959 and 1971. Figure 13 shows area planted to winter wheat in Indiana. Planted area dropped steadily throughout the 1960s, rising sharply in the 1970s. This pattern corresponds with government diversion programs in effect (Bond and Umberger 1979). As the planted area decreased during the 1960s, the soil with the lowest marginal productivity may have been pulled out of production. Therefore, a three-line model with break points of 1959 and 1971 appears reasonable. Comparison of the original model with the model incorporating the respecified trend shows (using all data):

	Original	Respecified
MSE	12.8	11.8

A bootstrap test was performed and the indicators of yield reliability computed. They are presented in Table 5. Comparing Table 5 with Table 1, we see various improvements have been made. Although not large to begin with, the bias has been reduced in absolute value for all combinations of defining trend and using (or not using) rust information. The MSEs have all decreased (a 14.4% decrease for the Extrapolation-Rust model). The percent of years the absolute value of the relative difference exceeds 10% did not change substantially. The largest or next largest absolute relative differences are all smaller indicating some improved performance in the more difficult years. The correlation coefficients between the observed and predicted yields improved slightly. Overall the improvements made by respecifying trend for Indiana are modest.

Montana

Figure 11 displays a plot of the residuals over time after fitting the weather index alone ($Y-\hat{Y}$) for Montana. Inspection of the plot shows residual staying below the zero reference through 1963, after which they stay generally above the zero reference. Within both of these groups, it is apparent that trend is not increasing at a constant rate; therefore, some possibilities exist for respecification and improvement.

Figure 14 shows the area planted to winter wheat in Montana from 1955 through 1979. Montana did not experience the steady decrease in planted area as in Indiana. Planted area remained fairly steady during the ten years prior to 1965, and then some large swings in area began to occur. Area planted fell to 1,638,000 acres in 1970 from 2,445,000 the year before. The next three years saw increases, although far below previous levels. According to the Montana Agricultural Statistics, Vol. XIV, the fall of 1969 was very dry and many

Figure 13. Area planted to winter wheat in Indiana (000 acres)

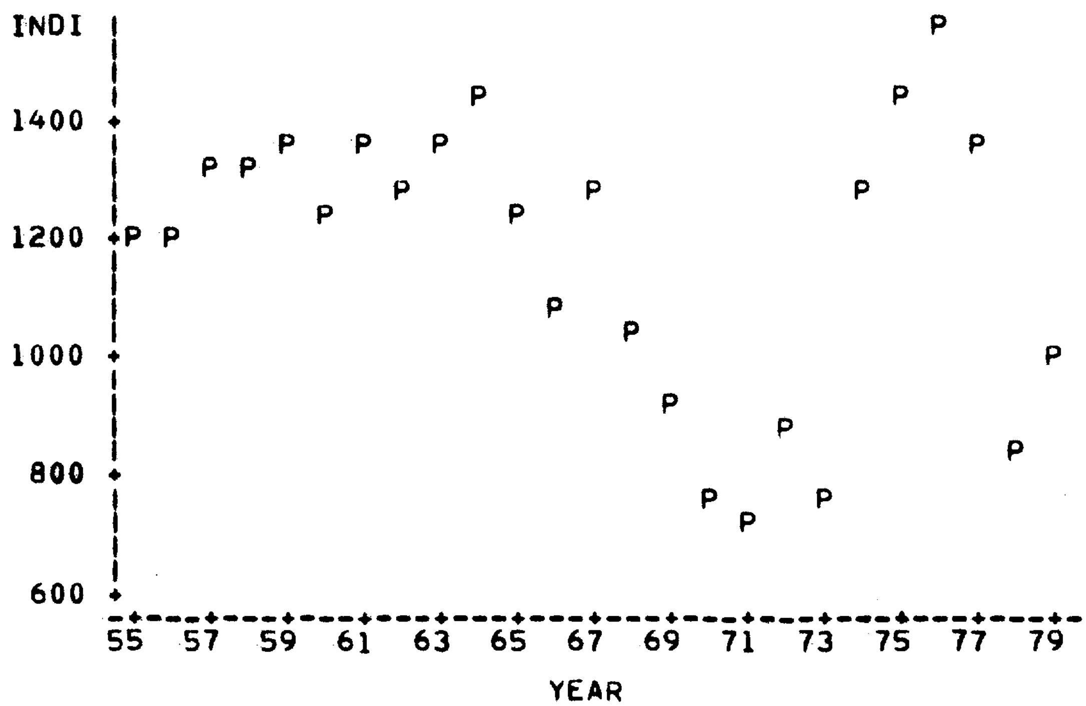


Figure 14. Area planted to winter wheat in Montana (000 acres)

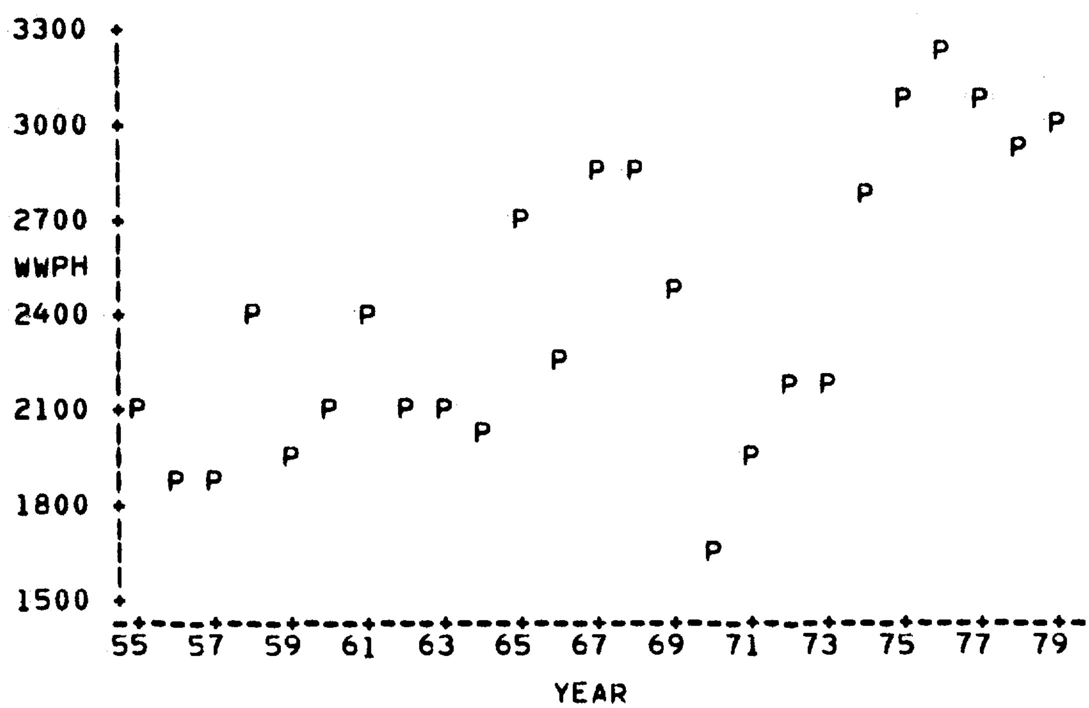


Table 5. Indicators of Yield Reliability
Indiana - Respecified Trend
1970-1979

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	-0.35	-0.19	-0.03	0.10
Relative Bias = RB (%)	-0.8	-0.5	-0.10	0.2
Mean Square Error = MSE $(B/A)^2$	22.80	18.79	23.35	18.77
Root Mean Square Error = RMSE (B/A)	4.78	4.33	4.83	4.33
Relative Root Mean Square Error = RRMSE (%)	11.5	10.4	11.6	10.4
Variance = Var $(B/A)^2$	22.68	18.75	23.35	18.76
Standard Deviation = SD (B/A)	4.76	4.33	4.83	4.33
Relative Standard Deviation = RSD (%)	11.50	10.5	11.6	10.4
Percent of Years $\|rd\| > 10\%$ (%)	50	50	60	40
Largest $\|rd\|$ (%)	18.7	-16.4	18.5	-15.6
Next Largest $\|rd\|$ (%)	-15.3	-13.4	16.6	-13.8
Smallest $\|rd\|$ (%)	-2.8	-3.9	-3.7	-3.0
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	56	67	56	67
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	57	71	57	71
Pearson correlation coefficient between observed and predicted yields	0.22	0.43	0.16	0.41

farmers were slow to seed their wheat in anticipation of some moisture. Moisture conditions did not improve and consequently not as much acreage was seeded.

Bond and Umberger report that the growing of Hard Red Winter (HRW) wheat has been moving northward in the Great Plains for many years. The shift in acreage from Hard Red Spring (HRS) to HRW has been rather dramatic in Montana. Beginning in the fifties, HRW represented approximately thirty percent of all wheat harvested acreage. By the mid to late sixties, that figure had risen to the sixty percent level. The shift in acreage from HRS to HRW resulted in a change in cropping practices. The short amount of time between harvest and winter seeding (for soil water availability) dictates summer fallow precede planting of winter wheat. These factors would certainly contribute to changing yield levels during the fifties and sixties.

Two general types of trends were considered and were composed of piecewise linear components. The first type consisted of two piecewise linear trends: both were positive with a break point ranging from 1963-1971. The second type consisted of three linear pieces: a flat portion followed by a positive segment followed by a flat segment at the end. The break points were allowed to range from 1961-1965 for the first break and 1967-1971 for the second. A total of 29 models were tested for Montana.

The model which produced the lowest MSE was a three-line model with break points at 1961 and 1967. Possible explanations for choosing these points are discussed above. Comparison of the original model with the model incorporating the respecified trend shows (using all data):

	Original	Respecified
MSE	6.8	5.6

Results of the bootstrap test using the respecified trend are presented in Table 6. Comparison with Table 3 will show where improvements occurrred. A reduction in bias was shown for all combinations of defining trend and using (or not using) rust information. The MSEs decreased in all situations (down to 23% for the Extrapolation-Rust model). The percent of years the absolute value of the relative difference is greater than 10 percent demonstrated improvement, particularly when ΔTECH is used, and most of the largest absolute relative differences decreased substantially. The correlation coefficients show some improvement although one combination did decrease. Based on these improvements, a respecification of the trend is recommended.

Use of Denser Weather Station Data in Kansas

The analysis up to this point has been based on the use of WX values supplied by Dr. Feyerherm. The AWX term in the model is the simple average of the station WX values in a state. The weather stations used by Dr. Feyerherm are as follows:

Table 6. Indicators of Yield Reliability
Montana - Respecified Trend
1970-1979

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	-0.10	-0.81	-0.02	-0.73
Relative Bias = RB (%)	-0.30	-2.80	-0.10	-2.50
Mean Square Error = MSE $(B/A)^2$	6.16	5.95	6.49	6.15
Root Mean Square Error = RMSE (B/A)	2.48	2.44	2.55	2.48
Relative Root Mean Square Error = RRMSE (%)	8.5	8.3	8.7	8.5
Variance = Var $(B/A)^2$	6.16	5.29	6.49	5.62
Standard Deviation = SD (B/A)	2.48	2.30	2.55	2.37
Relative Standard Deviation = RSD (%)	8.5	8.1	8.7	8.3
Percent of Years $\|rd\| > 10\%$ (%)	20	10	30	10
Largest $\|rd\|$ (%)	13.7	-15.7	14.1	-16.0
Next Largest $\|rd\|$ (%)	-13.7	-9.4	-14.0	9.4
Smallest $\|rd\|$ (%)	-1.7	1.0	-1.4	1.1
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	78	89	78	89
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	86	86	86	86
Pearson correlation coefficient between observed and predicted yields	0.44	0.56	0.39	0.51

No.	Montana	Kansas	Indiana	Ohio
1	Cutbank	Goodland	South Bend	Toledo
2	Great Falls	Garden City	Fort Wayne	Findlay
3	Havre	Dodge City	Indianapolis	Cleveland
4	Glasgow	Concordia	W. Lafayette	Akron
5	Miles City	Salina	Evansville	Mansfield
6	Lewiston	Russell		Columbus
7	Helena	Wichita		Youngstown
8	Billings	Topeka		Cambridge
9		Chanute		Dayton
10				Cincinnati

The Atmospheric Science Department at the University of Missouri at Columbia, under an agreement with NOAA, has created county level daily weather data from 1940 to 1980 for Kansas. Around 120 stations over the state were used, with the data becoming more complete over recent years. These are the same stations used to compute the monthly climatic division weather values published by the National Climatic Data Center. Daily climatic division values were computed by taking a simple average of the county values within each climatic division in Kansas.

Climatic divisions and crop reporting districts (CRDs) follow the same county boundaries in Kansas. Feyerherm's WRVPGM'82 was used to calculate WX values for each CRD using the daily weather data for input. The state value of AWX was computed for each year 1955-1979 by taking a weighted average of the WX values using the winter wheat harvested area in each CRD as the weight. The state weighted AWX values are compared with the averaged station AWX values in Figure 15. All but five values of the weighted AWX were lower than the station AWX values. The weighted AWX values ranged from 1.6 bushels per acre higher to 6.2 bushels lower than the station AWX results. A paired-sample t-test rejects the hypothesis that the difference between the values is zero ($P < 0.0001$). The average difference is 1.47 bushels per acre. A paired-sample t-test was also performed between the station AWX and a straight average of the CRD values. That test did not reject the hypothesis that the difference between the values is zero ($T = -0.86$, $p > |T| = .3996$). Therefore, using harvested area to weight the WX values, as opposed to equal weighting, contributes to the significant difference from the simple average of the station values (nine stations).

A bootstrap test, utilizing the denser weather station to compute the weighted AWX data, was run and the indicators of yield reliability computed. They are shown in Table 7. A comparison of Tables 2 and 7 shows that use of the denser weather station data has not improved the performance and for some of the indicators, performance has declined.

The use of a denser weather network was also coupled with alternate ways of specifying the phenological stage days. These stage days can be simulated by the WRVPGM'82 or they can be input into the model. The alternate ways of specifying the stage days included the following (they will be referred to as situations here and in subsequent tables):

Situation A: Using a 50% observed planting day for each year/CRD, i.e. when 50% of the crop is reported planted. Winter dormancy is calculated to be planting day plus 60. The rest of the stages are fixed and calculated according to the

Figure 15. Kansas AWX values in bushels/acre, S represents station data and C represents CRD data

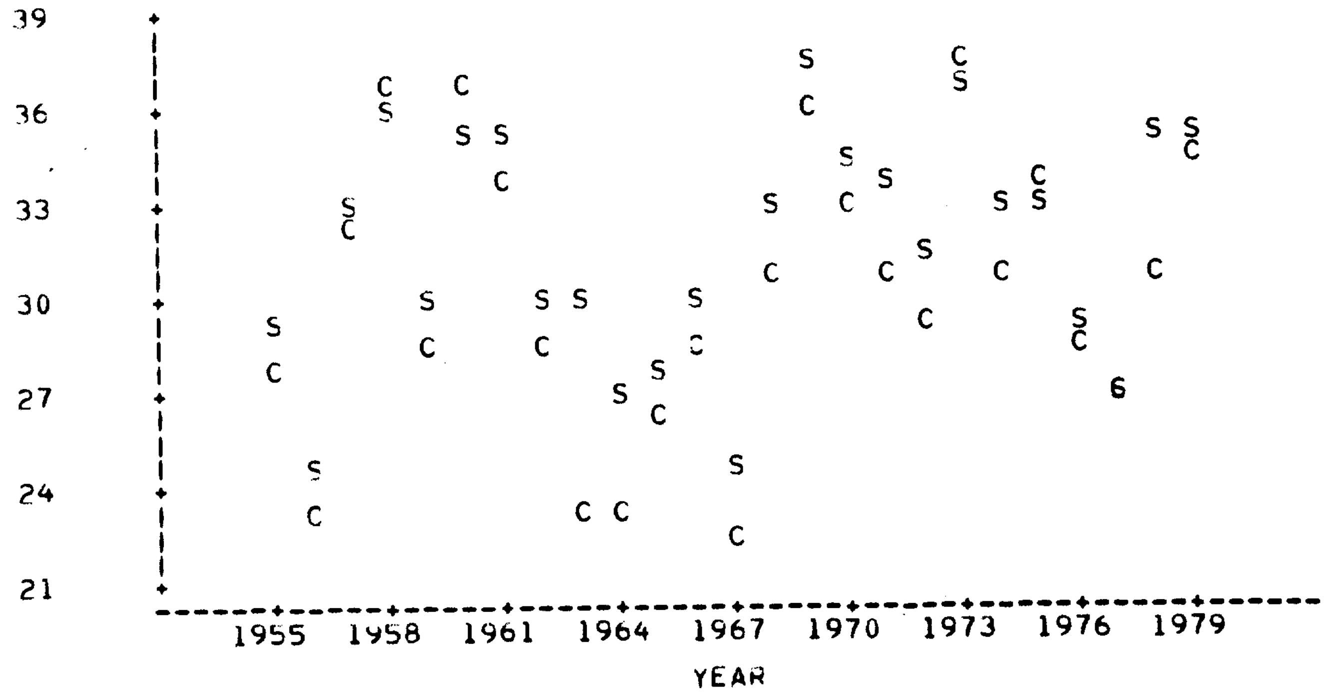


Table 7. Indicators of Yield Reliability
Kansas - Using Denser Weather Network
1970-1979

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	0.49	0.21	0.25	-0.03
Relative Bias = RB (%)	1.5	0.7	0.8	-0.1
Mean Square Error = MSE $(B/A)^2$	14.16	13.37	11.67	11.04
Root Mean Square Error = RMSE (B/A)	3.76	3.66	3.42	3.32
Relative Root Mean Square Error = RRMSE (%)	11.7	11.4	10.6	10.4
Variance = Var $(B/A)^2$	13.92	13.33	11.61	11.04
Standard Deviation = SD (B/A)	3.73	3.65	3.41	3.32
Relative Standard Deviation = RSD (%)	11.5	11.3	10.5	10.4
Percent of Years $\|rd\| > 10\%$ (%)	50	40	40	50
Largest $\|rd\|$ (%)	22.2	19.6	18.6	-17.7
Next Largest $\|rd\|$ (%)	20.7	18.6	-15.4	16.6
Smallest $\|rd\|$ (%)	1.6	2.2	-2.9	-2.9
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	78	67	67	67
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	71	71	86	71
Pearson correlation coefficient between observed and predicted yields	0.29	0.35	0.39	0.45

procedure outlined on pages 1-6 of the Users Manual for Weather Related Variables Program, March 1982. The procedure simulates the heading date with a formula involving temperature. The day for the remaining stages are obtained by adding or subtracting the model specified number of days from the heading day.

Situation B: Using a 50% observed planting day (for each year/CRD) with a variable crop calendar, i.e., starting from the observed planting day, simulate the time of successive stages using the Baier-Robertson method (included in the program). This approach had to be modified as the program did a poor job of estimating the winter dormancy and spring green-up dates. The problem may be because the Baier-Robertson method does not estimate these stage-days and the program had been modified to attempt to estimate for winter dormancy and spring green-up. Winter dormancy was "forced" to be planting day plus 60 and spring green-up was "forced" to be jointing minus 30.

Situation C: Using a 50% observed planting day with an observed crop calendar (for each year/CRD), i.e., determine the time of successive stages from the observed phenological data, interpolating where necessary.

Generally, the stage days used in each of the situations were similar (averages of the same time span) to the fixed values used for the stations (equating the stations to the CRDs in which they are located). The purpose for using these alternate methods was to attempt to incorporate the year to year variability in the growing seasons which in turn might make the WRVs more accurate with respect to the time periods they represent.

A paired-sample t-test rejects the hypothesis that the difference between weighted average AWX with the station average AWX is zero for all three situations (sit. A:$p<.005$; sit. B:$p<.0001$; sit. C:$p<.0001$). The average differences in bushels per acre are 1.47, 2.62 and 6.89 for situations A, B and C, respectively.

Paired-sample t-tests were also performed on the difference between the straight average AWX and the station average AWX. The results showed no significant difference for Situation A ($T=-0.79$, $p>|T|=.4348$). The results did show a significant difference for Situation B ($T=2.2$, $p>|T|=0.0361$) and for Situation C ($T=10.87$, $p>|T|=0.0001$).

Bootstrap tests were run and indicators of yield reliability were computed using each of the three methods of specifying stage days. The results are presented in Tables 8, 9, and 10. Figure 16 presents a plot of observed yields with bootstrap predicted yields for each of the situations. Comparison among the methods and to the original data (Table 2) shows that no improvement occurred. Situation B gave the worst results. One would expect that the use of a denser weather network with observed developmental stage days would result in more accurate results than the original. The results presented here show a degraded effect on the accuracy of the predictions.

Investigation of Alternate Calculation of DYA and AVE_DYA

The importance of winter wheat in Kansas prompted us to examine an alternate way of calculating the DYA and the AVE_DYA.

Table 8. Indicators of Yield Reliability
Kansas - Situation A
1970-1979

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	0.36	0.08	0.10	-0.17
Relative Bias = RB (%)	1.1	0.2	0.3	-0.5
Mean Square Error = MSE $(B/A)^2$	13.77	13.00	11.81	11.53
Root Mean Square Error = RMSE (B/A)	3.71	3.60	3.44	3.40
Relative Root Mean Square Error = RRMSE (%)	11.6	11.2	10.7	10.6
Variance = Var $(B/A)^2$	13.64	12.99	11.80	11.50
Standard Deviation = SD (B/A)	3.69	3.60	3.44	3.39
Relative Standard Deviation = RSD (%)	11.4	11.2	10.7	10.6
Percent of Years $\|rd\| >$ 10% (%)	50	40	50	40
Largest $\|rd\|$ (%)	20.3	18.3	18.3	-18.6
Next Largest $\|rd\|$ (%)	19.3	-18.0	-15.9	15.9
Smallest $\|rd\|$ (%)	1.9	2.4	2.9	0.7
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	67	67	67	67
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	71	86	57	71
Pearson correlation coefficient between observed and predicted yields	0.31	0.37	0.40	0.44

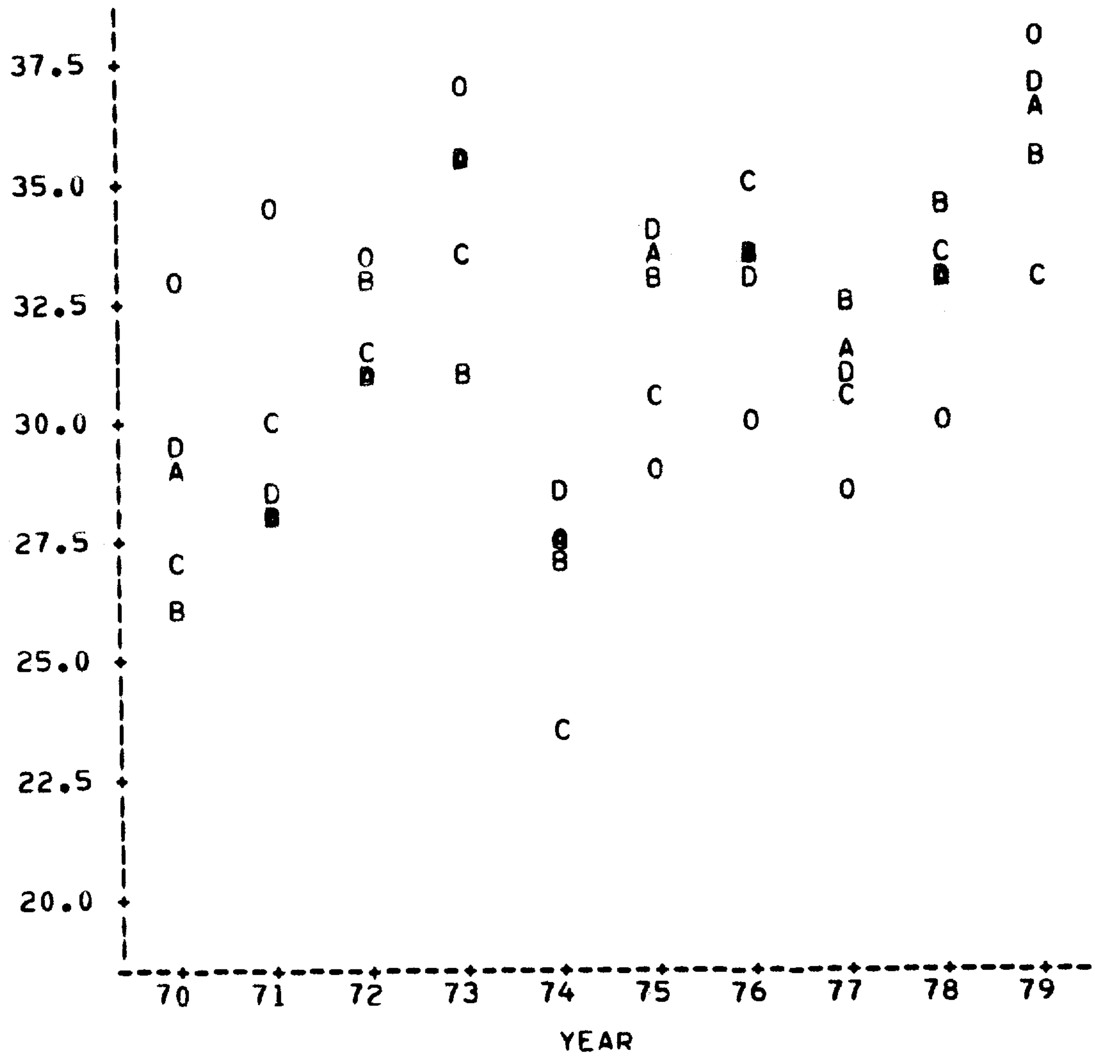
Table 9. Indicators of Yield Reliability
Kansas - Situation B
1970-1979

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	-0.24	-0.44	-0.53	-0.73
Relative Bias = RB (%)	-0.7	-1.4	-1.7	-2.3
Mean Square Error = MSE $(B/A)^2$	18.01	17.65	20.42	20.09
Root Mean Square Error = RMSE (B/A)	4.24	4.20	4.52	4.48
Relative Root Mean Square Error = RRMSE (%)	13.2	13.1	14.1	14.0
Variance = Var $(B/A)^2$	17.95	17.46	20.14	19.56
Standard Deviation = SD (B/A)	4.24	4.18	4.49	4.42
Relative Standard Deviation = RSD (%)	13.3	13.2	14.2	14.1
Percent of Years $\|rd\| >$ 10% (%)	60	50	70	70
Largest $\|rd\|$ (%)	-21.2	-22.4	-20.9	-21.8
Next Largest $\|rd\|$ (%)	18.3	-18.8	-17.1	-19.4
Smallest $\|rd\|$ (%)	-4.5	-2.1	-0.4	-1.2
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	67	78	67	78
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	71	86	57	57
Pearson correlation coefficient between observed and predicted yields	0.03	0.11	0.06	0.13

Table 10. Indicators of Yield Reliability
Kansas - Situation C
1970-1979

Indicator of Yield Reliability (unit)	No Rust Information		Rust Information	
	Extrapolation	ΔTECH	Extrapolation	ΔTECH
Bias = B (B/A)	-0.89	-0.96	-1.21	-1.29
Relative Bias = RB (%)	-2.8	-3.0	-3.8	-4.0
Mean Square Error = MSE $(B/A)^2$	12.15	11.96	15.36	15.45
Root Mean Square Error = RMSE (B/A)	3.49	3.46	3.92	3.93
Relative Root Mean Square Error = RRMSE (%)	10.9	10.8	12.2	12.2
Variance = Var $(B/A)^2$	11.36	11.04	13.90	13.78
Standard Deviation = SD (B/A)	3.37	3.32	3.73	3.71
Relative Standard Deviation = RSD (%)	10.8	10.7	12.1	12.1
Percent of Years $\|rd\| >$ 10% (%)	40	30	70	60
Largest $\|rd\|$ (%)	-18.2	-19.1	-17.3	-17.9
Next Largest $\|rd\|$ (%)	-14.7	-14.2	14.0	16.0
Smallest $\|rd\|$ (%)	-4.1	2.5	7.2	-5.4
Percent of years direction of change from the previous year in the predicted yields agrees with the observed yields (%)	78	78	78	78
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the observed yields (%)	71	86	43	57
Pearson correlation coefficient between observed and predicted yields	0.37	0.41	0.34	0.38

Figure 16. Kansas observed winter wheat yields with bootstrap predictions for each of the methods of specifying stage days utilizing rust and ΔTECH information; D = dense weather station network used with original fixed stage days. Units are bushels per acre. A = situation A, B = situation B, C = situation C, O = observed



The difference in yield levels over time due to the introduction of new varieties is estimated by AVE_DYA. The formula for AVE_DYA is:

$$AVE\_DYA = \frac{\sum_{k=1}^{N} q_k * DYA_k}{\sum_{k=1}^{N} q_k}$$

where q_k = percent of area planted to variety k,

DYA_k = the differential yielding ability of variety k,

N = number of varieties

AVE_DYA, calculated at the state level, is the weighted average of DYA values with the q_k percentages serving as the weights. A variety is included in a specified year if the percentage planted to that variety is 0.6 percent or more of the planted area in Kansas. The q values are not available from standard sources for every year between 1955 and 1969, so linear interpolation of AVE_DYA values is performed between years with known q values. Data for q values were available for every year from 1969-1979.

Differences in yield at the plot level between new varieties and a "standard" variety (yield of new variety minus yield of standard variety) at the same location in the same year are used to calculate DYA. Feyerherm used varietal trial data from agricultural experiment stations and cooperating farmers. The data are described in detail in the "Users Manual for differential Yielding Ability Program (DYAPGM'82)." Commanche is used as the standard variety (DYA=0). Differences from Commanche are computed directly for new varieties during the fifties up to the mid-sixties and DYA is calculated as the mean difference. But Commanche is no longer used in trials past the mid-sixties, so Scout was chosen by Feyerherm as an intermediate variety to link later varieties back to Commanche. Differences in yields between these later varieties and Scout (yield of later variety minus yield of Scout) are calculated for the locations and years the two varieties are both planted and the mean difference is calculated. Also, the mean difference between Scout and Commanche is calculated. The DYA value for the later variety is then the sum of these mean differences. Therefore, it is apparent that the intermediate variety needs to have several common location/years with the standard variety and with the new varieties.

An investigation was conducted on two factors which affect the calculation of the Kansas DYAs. One was the choice of method used for computing mean differences and the other involves the use of alternate standard and intermediate varieties.

Feyerherm calculated the mean differences in yields by the arithmetic average over all location/years for which paired data are available. This method would be sound if values for a given yield difference were available at all locations for each year having an observation at any location. This completeness is not available in the Kansas data. Therefore, the simple average of differences could be biased due to the missing observations.

Another method of estimating the mean differences was considered. Each mean difference in yields was estimated by the intercept of a linear regression model with the observed yield differences as the dependent variable and indicator variables for location and year main effects. Since the intercept is computed as part of a least squares regression, it is called the least squares mean. For a given variety, observations were excluded if a yield difference was available at only one location for that year. Estimates were not made for varieties with fewer than 5 total observations. DYA values based on these least squares mean yield differences were computed using data from 1945 through 1979.

Table 11 presents data on varieties which accounted for 0.6% or more of the total planted area and had plot data at two or more locations during the 1945-1979 period. Years for which these conditions are met and the highest percentage planted during the period are also shown. Figure 17 graphically displays the range of data availability for two or more locations. Using this information, one can determine alternate varieties to use as standard and intermediate varieties.

Several candidates for an alternate standard variety were available including Triumph, Pawnee, and Wichita. The range of years that these varieties accounted for 0.6% or more of the total planted area planted was longer for these varieties than for Commanche with the exception of Pawnee (1 year shorter). In addition, the highest percent planted figures (for the years in which data were reported) were all greater than Commanche for these three varieties.

Since data for two or more locations for Commanche ends in 1966, an intermediate variety is needed to compute DYA values for varieties introduced in later years. Several overlapping years between the standard and the intermediate are required. As previously mentioned, Scout was chosen by Feyerherm as the only intermediate. Scout has a three year overlap with Commanche and its highest percent planted was 48.1 percent. Studying Figure 17, no other single variety provides such a strong intermediate link.

In an attempt to make use of a longer overlap period, an alternate intermediate was sought which would allow a greater overlap with the standard, and a greater overlap with Scout (to be used as a second intermediate). In addition, this variety or varieties should have a strong percent planted. Bison is the only variety which satisfies these conditions. Data for two or more locations for Bison begin in 1954 and end in 1974. Bison also attained an 18.8% highest planted. Bison, along with a standard, provides another estimate of the DYA for Kaw, Ottawa, Scout, Gage, Triumph 64, Parker, and Chanute.

Three varieties were investigated as alternative standard varieties to Commanche. They are Triumph, Wichita, and Pawnee. The use of varieties Scout and Bison was also investigated for use as intermediates, each by themselves and together. All of these combinations will now be discussed.

DYA values for the direct comparison to Commanche along with Scout and Bison as intermediates are presented in Table 12. The error degrees of freedom are from the least squares regression model which provided the mean difference between the variety and Commanche, for the direct comparison, or between the variety and the first (or only) intermediate variety. The choice of intermediate(s) can result in DYA values which differ from .3 to 3.8 bushels per acre (see Chanute and Buckskin, Table 12).

Table 11. Kansas winter wheat varieties planted 0.6% or more 1954, 1959, 1964, 1969-1979, when data were available for 2 or more locations and highest percent planted

Variety	Years: 0.6% or more planted	Years: Data for 2 or more locations	Highest percent planted
Commanche	54-69	45-66	11.1
Tenmarq	54-59	45-55	2.2
Cheyenne	54-59	-	1.3
Triumph	54-64	45-69	14.8
Red Chief	54	55-56	6.1
Pawnee	54-64	45-65	29.0
Wichita	54-76	45-68	24.3
Kiowa	54-72	45-68	13.8
Ponca	54-64	46-66	11.6
Bison	59-76	54-74	18.8
Kaw	64-73	60-67	12.7
Ottawa	64-71	60-68	8.2
Scout	69-69	63-78	48.1
Gage	69-79	63-79	3.7
Triumph 64	69-79	65-79	11.7
Parker	70-79	66-79	9.3
Chanute	71-79	70-76	2.7
Eagle	72-79	70-79	23.0
Centurk	73-79	71-79	11.9
Danne	75-78	75	1.1
Tamu 101	77-79	76-79	4.9
Sage	75-79	73-79	14.7
Trison	76-79	73-79	2.0
Buckskin	76-79	75-79	2.7
Homestead	76-79	75-78	1.9
Lancota	78-79	76-78	1.1
Larned	78-79	76-79	8.4
Vona	79	77-79	0.8
Newton	79	77-79	2.8

Figure 17. Range of varietal data for two or more locations and highest percent planted for winter wheat in Kansas

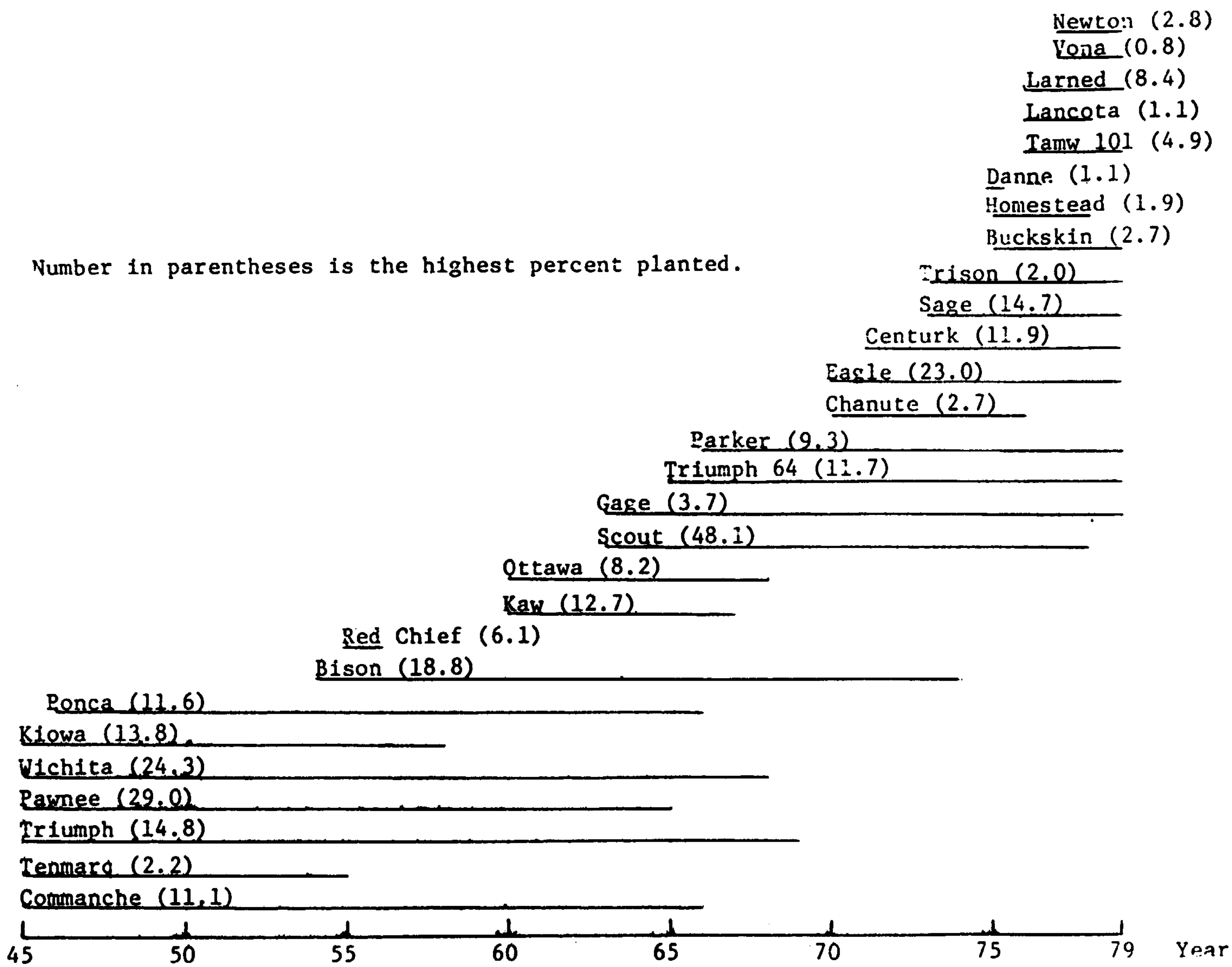


Table 12. DYA values computed using Commanche as a standard, either directly or with Scout and Bison as single or multiple intermediates. Number in parentheses is the error degrees of freedom. Units are bushels per acre.

Variety	Direct to Commanche	Single Intermediate		Multiple Intermediates1/
		Scout	Bison	
Commanche	0			
Tenmarq	-2.4(41)			
Cheyenne	*			
Triumph	-0.4(130)			
Red Chief	1.1(2)			
Pawnee	0(123)			
Wichita	-0.4(153)			
Kiowa	1.5(64)			
Ponca	-0.3(119)			
Bison	1.1(81)			
Kaw	2.3(45)		1.6(48)	
Ottawa	2.8(45)		2.3(63)	
Scout	3.8(21)		4.6(69)	
Gage	2.2(22)	3.7(92)	2.6(60)	4.5(92)
Triumph 64	1.9(4)	1.6(79)	0.4(40)	2.4(79)
Parker		3.0(83)	1.6(32)	3.8(83)
Chanute		1.5(31)	2.6(8)	2.3(31)
Eagle		4.6(72)		5.4(72)
Centurk		4.6(66)		5.4(66)
Danne		*		*
Tamw 101		4.7(11)		5.5(11)
Sage		6.6(46)		7.4(46)
Trison		3.0(35)		3.8(35)
Buckskin		6.1(28)		2.3(28)
Homestead		5.4(20)		6.2(20)
Lancota		4.6(17)		5.4(17)
Larned		6.6(17)		7.4(17
Vona		6.1(6)		6.9(6)
Newton		8.6(10)		9.4(10)

*insufficient data to compute DYA
1/ First intermediate is Scout, second intermediate is Bison.

DYA values computed by using Wichita as a standard with Scout and Bison as intermediates are presented in Table 13. The largest difference in DYA values occurs for Buckskin (3.7 bushels). DYA values computed by using Triumph as a standard with the same intermediates are shown in Table 14. The largest difference occurs for Parker (3.2 bushels). Table 15 shows DYA values obtained using Pawnee as a standard and again using Scout and Bison as intermediates. Scout was not used as a single intermediate because Pawnee and Scout overlap for only two years. Again the largest difference occurs with Parker (2.2 bushels).

Table 16 summarizes the data contained in Tables 12-15. Each entry is a DYA value which is computed from a weighted average of the DYA values in Tables 12-15, using the error degrees of freedom for weights. The following rules were used to obtain the weighted average DYA. When there are multiple DYA values to be weighted together, each must have at least 15 degrees of freedom to receive any weight. The exception to this comes when each of the DYA values has less than 15 df but each has the same number. In this case they are weighted together equally. When there is only one DYA value for a variety, that value is carried forward as the weighted DYA. Fifteen is a reasonable cutoff since when there are multiple DYAs to be weighted together, usually there is only one value excluded while the remaining DYAs have a proportionally large number of error degrees of freedom.

Also included in Table 16 for comparison is the DYA obtained by using the method outlined by Feyerherm which used Commanche as the standard and Scout as the intermediate variety. As can be seen in Table 16, the DYA value can vary depending upon the method of calculation and the choice of standard and intermediate varieties.

The average DYA values for Kansas using the least squares means for four standard varieties along with Feyerherm's values are shown in Table 17. Each column of values was smoothed over time and plotted in Figure 18. It can be seen that the values were higher using Triumph and Pawnee as standard varieties. The values for Commanche, Wichita and the average defined by Feyerherm are quite similar over the time period.

Bootstrap test results utilizing ΔTECH information obtained from DYA values using Triumph as a standard variety with Scout and Bison as intermediates are presented in Table 18. DYA values, calculated using Triumph as a base, were used for computing ΔTECH because it differed the most from the values provided by Feyerherm. Feyerherm's nine station straight average AWX was used making it possible to directly compare Table 2, columns utilizing ΔTECH, with the values in Table 18.

This comparison reveals that improvement has been made for nearly every criteria. The root mean square error decreased slightly from 3.36 bushels/acre to 3.32 bushels/acre.

Other Criteria for Model Evaluation

Eight model characteristics to be emphasized in model evaluation are discussed in Wilson, et al. (1980) and Wilson and Sebaugh (1981). They are yield indication reliability, objectivity, consistency with scientific knowledge, adequacy, timeliness, minimum costs, simplicity, and accurate current measure of modeled

Tablê 13. DYA values computed using Wichita as a standard, either directly or with Scout and Bison as single or multiple intermediates. Number in parentheses is the error degrees of freedom. Units are bushels per acre.

Variety	Direct to Wichita	Single Intermediate		Multiple Intermediates 1/
		Scout	Bison	
Commanche	0.4(153)			
Tenmarq	-1.7(39)			
Cheyenne	*			
Triumph	-0.1(147)			
Red Chief	2.8(3)			
Pawnee	0(127)			
Wichita	0			
Kiowa	2.5(67)			
Ponca	0.2(124)			
Bison	1.1(95)			
Kaw	0.8(48)		1.6(48)	
Ottawa	1.8(57)		2.3(63)	
Scout	3.7(33)		4.6(69)	
Gage	2.4(34)	3.6(92)	2.6(60)	4.5(92)
Triumph 64	1.9(14)	1.5(79)	0.4(40)	2.4(79)
Parker	4.0(3)	2.9(83)	1.6(32)	3.8(83)
Chanute		1.4(31)	2.6(8)	2.3(31)
Eagle		4.5(72)	4.6(6)	5.4(72)
Centurk		4.5(66)	5.6(4)	5.4(66)
Danne		*		*
Tamw 101		4.6(11)		5.5(11)
Sage		6.5(46)		7.4(46)
Trison		2.9(35)		3.8(35)
Buckskin		6.0(28)		2.3(28)
Homestead		5.3(20)		6.2(20)
Lancota		4.5(17)		5.4(17)
Larned		6.5(17)		7.4(17)
Vona		6.0(6)		6.9(6)
Newton		8.5(10)		9.4(10)

*insufficient data to compute DYA
1/ First intermediate is Scout, second intermediate is Bison.

Table 14. DYA values computed using Triumph as a standard, either directly or with Scout and Bison as single or multiple intermediates. Number in parentheses is the error degrees of freedom. Units are bushels per acre.

Variety	Direct to Triumph	Single Intermediate		Multiple Intermediates1/
		Scout	Bison	
Commanche	0.4(130)			
Tenmarq	-1.8(33)			
Cheyenne	*			
Triumph	0			
Red Chief	3.7(2)			
Pawnee	0.4(105)			
Wichita	0.1(147)			
Kiowa	1.4(57)			
Ponca	0.4(111)			
Bison	2.3(98)			
Kaw	3.8(48)		2.8(48)	
Ottawa	3.8(63)		3.5(63)	
Scout	4.8(50)		5.8(69)	
Gage	3.5(50)	4.7(92)	3.8(60)	5.7(92)
Triumph 64	2.2(30)	2.6(79)	1.6(40)	3.6(79)
Parker	3.0(20)	4.0(83)	1.8(32)	5.0(83)
Chanute		2.5(31)	1.5(8)	3.5(31)
Eagle		5.6(72)	3.5(6)	6.6(72)
Centurk		5.6(66)	4.5(4)	6.6(66)
Danne		*		*
Tamw 101		5.7(11)		6.7(11)
Sage		7.6(46)		8.6(46)
Trison		4.0(35)		5.0(35)
Buckskin		7.1(28)		8.1(28)
Homestead		6.4(20)		7.4(20)
Lancota		5.6(17)		6.6(17)
Larned		7.6(17)		8.6(17)
Vona		7.1(6)		8.1(6)
Newton		9.6(10)		10.6(10)

*insufficient data to compute DYA
1/ First intermediate is Scout, second intermediate is Bison.

Table 15. DYA values computed using Pawnee as a standard, either directly or with Bison as a single intermediate and with Scout and Bison as multiple intermediates. Number in parentheses is the error degrees of freedom. Units are bushels per acre.

Variety	Direct to Pawnee	Single intermediate Bison	Multiple Intermediates[1/]
Commanche	0(123)		
Tenmarq	-2.8(41)		
Cheyenne	*		
Triumph	-0.4(105)		
Red Chief	1.2(3)		
Pawnee	0		
Wichita	-0.5(127)		
Kiowa	1.0(69)		
Ponca	.4(105)		
Bison	1.7(52)		
Kaw	3.6(18)	2.2(48)	
Ottawa	4.3(18)	2.9(63)	
Scout	3.2(2)	5.2(69)	
Gage	3.9(2)	3.2(60)	5.1(92)
Triumph 64		1.0(40)	3.0(79)
Parker		2.2(32)	4.4(83)
Chanute		2.2(8)	2.9(31)
Eagle		5.2(6)	6.0(72)
Centurk		6.2(4)	6.0(66)
Danne			*
Tamw 101			6.1(11)
Sage			8.0(46)
Trison			4.4(35)
Buckskin			7.5(28)
Homestead			6.8(20)
Lancota			6.0(17)
Larned			8.0(17)
Vona			7.5(6)
Newton			10.0(10)

*insufficient data to compute DYA

1/ First intermediate is Scout, second intermediate is Bison.

Table 16. DYA values obtained using Commanche, Wichita, Triumph and Pawnee as standard varieties. Scout and Bison were used as intermediate varieties. Units are bushels per acre.

	Standard Variety				Feyerherm Method
	Commanche	Wichita	Triumph	Pawnee	
Commanche	0	0.4	0.4	0	0
Tenmarq	-2.4	-1.7	-1.8	-2.8	-2.2
Cheyenne	*	*	*	*	*
Triumph	-0.4	-0.1	0	-0.4	-0.4
Red Chief	1.1	2.8	3.7	1.2	0.6
Pawnee	0	0.5	0.4	0	0.3
Wichita	-0.4	0	0.1	-0.5	0
Kiowa	1.5	2.5	1.4	1.0	1.4
Ponca	-0.3	0.2	0.4	0.4	-0.3
Bison	1.1	1.1	2.3	1.7	0.9
Kaw	1.9	1.3	3.3	2.6	2.6
Ottawa	2.5	2.1	3.7	3.2	3.0
Scout	4.4	4.3	5.4	5.2	3.9
Gage	3.6	3.5	4.6	4.4	3.6
Triumph 64	1.7	1.6	2.7	2.3	2.3
Parker	3.1	3.1	4.0	3.8	3.9
Chanute	1.9	1.9	3.0	2.9	2.0
Eagle	5.0	5.0	6.1	6.0	4.9
Centurk	5.0	5.0	6.1	6.0	6.2
Danne	*	*	*	*	6.4
Tamw 101	5.1	5.1	6.2	6.1	6.9
Sage	7.0	7.0	8.1	8.0	6.8
Trison	3.4	3.4	4.5	4.4	3.9
Buckskin	4.2	4.2	7.6	7.5	6.5
Homestead	5.8	5.8	6.9	6.8	5.4
Lancota	5.0	5.0	6.1	6.0	4.4
Larned	7.0	7.0	8.1	8.0	6.8
Vona	6.6	6.5	7.6	7.5	8.2
Newton	9.0	9.0	10.1	10.0	8.4

*insufficient data to compute DYA

Table 17. Average differential yielding abilities for Kansas from 1955 to 1979 using different standards and intermediates; i signifies a year whose value is interpolated

Year	Average Differential Yielding Ability (bu/acre)				Average Feyerherm
	Least Squares Means Method				
	Commanche	Wichita	Triumph	Pawnee	
1954	0.0	0.6	0.5	0.0	0.1
1955i	0.0	0.6	0.5	0.0	0.1
1956i	0.0	0.6	0.5	0.0	0.1
1957i	0.1	0.6	0.6	0.1	0.2
1958i	0.1	0.6	0.6	0.1	0.2
1959	0.1	0.6	0.6	0.2	0.2
1960i	0.3	0.7	0.8	0.4	0.4
1961i	0.4	0.7	1.0	0.5	0.5
1962i	0.6	0.8	1.3	0.8	0.7
1963i	0.7	0.8	1.5	1.0	0.8
1964	0.9	0.9	1.7	1.2	1.0
1965i	1.3	1.3	2.2	1.7	1.4
1966i	1.8	1.5	2.7	2.2	1.7
1967i	2.2	2.2	3.1	2.7	2.1
1968i	2.7	2.6	3.6	3.2	2.4
1969	3.1	3.0	4.1	3.7	2.8
1970	3.2	3.2	4.2	3.9	2.9
1971	3.3	3.3	4.3	4.0	2.8
1972	3.5	3.4	4.5	4.3	3.1
1973	3.8	3.7	4.8	4.6	3.6
1974	4.0	3.9	5.0	4.8	3.9
1975	4.2	4.1	5.2	5.0	4.1
1976	4.4	4.4	5.5	5.3	4.6
1977	4.8	4.7	5.9	5.7	4.9
1978	4.9	4.9	6.0	5.9	5.1
1979	5.2	5.1	6.3	6.1	5.3

Figure 18. Average differential yielding abilities in bushels per acre for Kansas after smoothing. Letter represents the variety used as the standard: C = Commanche, W = Wichita, T = Triumph, P = Pawnee, and A = Average (Feyerherm method).

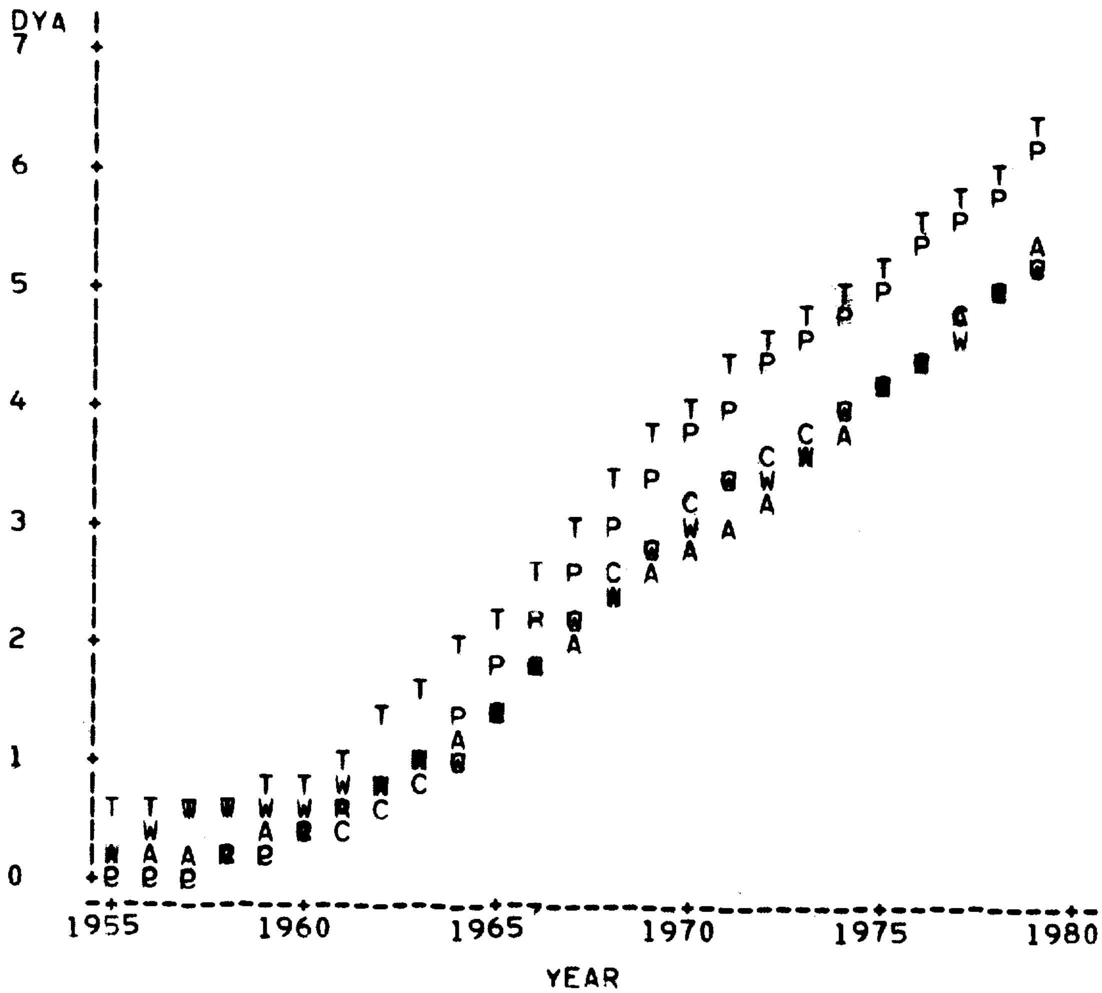


Table 18. Indicators of Yield Reliability for model estimates utilizing ΔTECH information. DYA values computed using Triumph as a standard variety with Scout and Bison used as intermediate varieties.

Indicator of Yield Reliability (unit)	No Rust Information	Rust Information
Bias = B (B/A)	-0.50	-0.81
Relative Bias = RB (%)	-1.6	-2.5
Mean Square Error = MSE $(B/A)^2$	11.89	11.04
Root Mean Square Error = RMSE (B/A)	3.45	3.32
Relative Root Mean Square Error = RRMSE (%)	10.7	10.3
Variance = Var $(B/A)^2$	11.64	10.38
Standard Deviation = SD (B/A)	3.41	3.22
Relative Standard Deviation = RSD (%)	10.8	10.3
Percent of Years $\|rd\| > 10\%$ (%)	50	40
Largest $\|rd\|$ (%)	17.1	20:3
Next Largest $\|rd\|$ (%)	16.3	-15.4
Smallest $\|rd\|$ (%)	-2.0	-0.7
Percent of years direction of change from the previous year in the predicted yields agrees with the actual yields (%)	67	67
Percent of years direction of change from the average of the previous three years in the predicted yields agrees with the actual yields (%)	86	71
Pearson correlation coefficient between actual and predicted yields	0.43	0.50

yield reliability. This evaluation so far has mainly been concerned with yield indication reliability. In the course of making improvements, some current features of the model may be changed, which would alter the evaluation concerning the other seven characteristics. Therefore, only a brief discussion of these areas will be presented.

Model inputs are objective and the use of a daily soil moisture budget and crop calendar lends credibility to the scientific aspect of the model. The inclusion of genetic improvement and technological information in the prediction equation adds to this credibility. Other than rust loss, information concerning episodal events is not used in the model.

The use of daily weather data (as opposed to monthly) make the model more costly and complex. Feyerherm's model requires daily weather variables as input to the WRV program which calculates the terms in the weather index.

This report has not addressed the forecasting ability of the Feyerherm model. However, the acquisition of daily weather data on a daily or weekly basis would permit timely forecasts. Some preliminary work on forecasting the Kansas winter wheat crop was conducted by Feyerherm during the 1982-83 crop year. The results were encouraging and more work in the area was conducted during the 1983-84 crop year.

CONCLUSION

In order to warrant the added complexity of the Feyerherm model as compared to monthly weather data models, one needs to provide evidence of an advantage in one or more of the other model characteristics, such as accuracy of yield predictions, timeliness of forecasts, or adaptability to other geographic areas. Although the effort required in providing daily weather values for each station (or CRD) exceeds that required to calculate the terms for a monthly weather data model, the use of an independently derived weather index should promote the adaptability to other geographic areas.

Accuracy of the weather index has been demonstrated in Kansas. A comparison was made with the LACIE monthly weather data models which coincided with two of the four states in which Feyerherm tested his model. A bootstrap test was performed using 1970-79 as the test years. Trend was specified in the same way for each model (trend = year minus 1955). The dependent variable for both models was yield adjusted for loss due to rust. The results were as follows:

	RMSE (B/A)	
	Kansas	Montana
LACIE monthly weather	5.07	2.53
Feyerherm (using rust information with trend extrapolated)	3.49	2.90

Since the improvement found for Kansas was not shown for Montana, improved performance would need to be demonstrated to justify the argument of adaptability to other areas.

The following recommendations are offered:

- Expand the plot-level data base by including years after 1973 for which yield and weather data are available;

- Consider improved methods for adjusting plot yields to a standard;

- Investigate the use of additional regression diagnostics and variable selection techniques to improve the prediction ability of the model;

- Consider the use of 50% observed dates for the phenological stage days for use in WRVPGM'82.

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APPENDIX - STATISTICAL FORMULAS

Selected Measures of Model Performance

Definition of Terms:

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

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

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

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

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

$\bar{Y} = 1/n\ \Sigma\ Y_i$ = average actual yield.

Measures:

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

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

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

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

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

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

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

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

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

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

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

APPENDIX - WEATHER INDEX

The winter wheat weather index (WX) computed for each year for each weather location is the following function of weather-related variables (WRVS):

$$WX = 72.6 + ET + XPR + TEMP$$

where

ET = measure of effects of evapotranspiration,

$$= 1.29 * AE\_PW + 8.26 * AE+JF - 1.65\ (AE\_JF)^2 + 6.23 * AE\_FH - 1.18\ (AE\_FH)^2 + 2.35 * AE\_MD,$$ and

XPR = measure of effects of excessive precipitation,

$$= -1.44 * XPR6\_PW - 0.84 * XPR5\_WS - 1.29 * XPR3\_HD,$$ and

$TEMP$ = measure of effects of excessively high temperature,

$$= -0.63 * RNG\_PW - 0.0021\ (ATX\_WS)^2 - 0.47 * ATN\_SH - 0.35 * T50PR\_JF - 0.46 * T77\_HM - 0.25 * ATX\_MD,$$

where the WRVs are defined in the following appendix.

APPENDIX

DEFINITION OF WEATHER RELATED VARIABLES

The letters following the underline in the WRV name denote crop stages. They are P = planting, W = winter, S = spring, J = jointing, F = flag leaf, H = heading, M = milk, D = dough, R = ripe. There are eight phenological periods: PW, WS, SJ, JF, FH, HM, MD, DR. The following is a description of each WRV.

WRV Name	Definition
PR_PW through PR_DR	Total precipitation in each phenological period starting with the period PW and ending with the period DR
TN_PW through TN_DR	Average daily minimum temperature during each of the 8 phenological periods
TX_PW through TX_DR	Average daily maximum temperature during each of the 8 phenological periods
T50_JF	Average number of degree-days by which daily minimum temperatures exceeded 50° F during period JF
T50_FH	Same as preceding except period is FH
T56_HM	Average number of degree-days by which daily minimum temperatures exceeded 56° F during period HM
T56_MD	Same as preceding except period is MD
T77_ab	Average number of degree-days by which daily maximum temperatures exceeded 77° F during period (ab) where (ab) = FH, HM, MD, DR, respectively
CN_P through CN_R	Contents (plant-available water) of all six zones in the Baier-Robertson soil moisture budget at the specified stage of development for the 9 stages P through R
CPR_P through CPR_R	Cumulative precipitation from planting (P) up to the specified stage of development for the 9 stages P through R
AE_PW through AE_DR	"Actual" evapotranspiration during the specified phenological period, as computed in the Baier-Robertson VSMB or the 8 periods from PW to DR
PE_PW through PE_DR	"Potential" evapotranspiration during a specified phenological period, as computed in the Baier-Robertson VSMB for the 8 periods from PW to DR

APPENDIX
Data Values Supplied by Feyerherm with Corrections
Unit of measure is bushels/acre.

INDIANA

YEAR	YIELD	AWX	AVE_DYA	TECH	NI	LOSS	ADTYIELD
1955	29.0	30.1	0.8	3.4	2.6	1.2	30.2
1956	30.5	30.5	1.3	4.1	2.8	0.0	30.5
1957	25.5	26.6	1.9	4.9	3.0	0.8	26.3
1958	32.0	32.5	2.4	5.5	3.1	0.0	32.0
1959	26.0	29.5	2.9	6.1	3.2	0.0	26.0
1960	33.0	34.5	3.3	6.7	3.4	0.0	33.0
1961	34.0	37.1	3.7	7.2	3.5	0.0	34.0
1962	34.0	32.9	4.0	7.7	3.7	0.0	34.0
1963	40.0	37.1	4.4	8.3	3.9	0.0	40.0
1964	34.0	26.2	4.8	8.9	4.1	0.3	34.3
1965	32.5	28.0	4.8	9.1	4.3	0.0	32.5
1966	44.0	36.4	4.8	9.6	4.8	0.0	44.0
1967	37.0	33.1	4.8	9.6	4.8	0.0	37.0
1968	35.0	32.0	4.8	10.1	5.3	1.8	36.8
1969	40.0	35.4	4.8	9.2	4.4	1.2	41.2
1970	38.5	32.3	7.0	11.7	4.7	0.4	38.9
1971	46.0	37.6	10.5	16.1	5.6	0.9	46.9
1972	48.0	34.2	12.0	17.6	5.6	0.0	48.0
1973	35.0	30.0	11.4	17.7	6.3	0.0	35.0
1974	37.5	32.3	11.8	17.6	5.8	0.0	37.5
1975	44.0	33.6	12.6	19.1	6.5	0.0	44.0
1976	36.0	29.7	12.5	19.1	6.6	0.0	36.0
1977	45.0	29.9	12.7	19.4	6.7	0.0	45.0
1978	39.0	38.1	12.6	18.0	5.4	0.4	39.4
1979	47.0	32.0	12.4	19.1	6.7	0.5	47.5

KANSAS

YEAR	YIELD	AWX	AVE_DYA	TECH	NI	LOSS	ADTYIELD
1955	15.0	29.0	0.1	0.5	0.4	0.6	15.6
1956	15.5	24.6	0.1	0.5	0.4	0.0	15.5
1957	19.0	32.7	0.2	0.8	0.6	2.8	21.8
1958	27.5	36.1	0.2	0.8	0.6	0.0	27.5
1959	20.0	29.8	0.2	0.9	0.7	2.2	22.2
1960	28.0	35.4	0.4	1.2	0.8	0.9	28.9
1961	26.5	34.9	0.5	1.4	0.9	2.3	28.8
1962	23.5	29.8	0.7	1.7	1.0	1.0	24.5
1963	21.5	29.6	0.8	1.8	1.0	0.0	21.5
1964	22.5	27.1	1.0	2.1	1.1	0.2	22.7
1965	24.0	27.6	1.4	2.6	1.2	1.0	25.0
1966	19.5	30.2	1.7	3.6	1.9	0.0	19.5
1967	20.0	24.6	2.1	4.1	2.0	0.0	20.0
1968	25.0	33.2	2.4	5.2	2.8	2.2	27.2
1969	31.0	37.7	2.8	5.6	2.8	0.0	31.0
1970	33.0	34.8	2.9	5.5	2.6	0.3	33.3
1971	34.5	33.8	2.8	5.2	2.4	0.7	35.2
1972	33.5	31.8	3.1	6.5	3.4	0.3	33.8
1973	37.0	37.0	3.6	7.5	3.9	3.2	40.2
1974	27.5	32.7	3.9	7.5	3.6	5.2	32.7
1975	29.0	32.8	4.1	7.6	3.5	2.5	31.5
1976	30.0	29.0	4.6	8.8	4.2	0.0	30.0
1977	28.5	27.1	4.9	8.8	3.9	0.3	28.8
1978	30.0	34.9	5.1	8.6	3.5	0.6	30.6
1979	38.0	35.0	5.3	9.2	3.9	0.8	38.8

APPENDIX: Continued
Data Values Supplied by Feyerherm with Corrections
Unit of measure is bushels per acre.

MONTANA

YEAR	YIELD	AWX	AVE_DYA	TECH	NI	LOSS	ADTYIELD
1955	27.0	35.1	-2.2	-2.2	0.0	0.0	27.0
1956	20.5	28.3	-1.9	-1.9	0.0	0.0	20.5
1957	25.0	28.8	-1.7	-1.7	0.0	0.0	25.0
1958	27.5	33.6	-1.4	-1.4	0.0	0.0	27.5
1959	25.5	27.8	-1.2	-1.2	0.0	0.0	25.5
1960	23.0	28.1	-1.0	-1.0	0.0	0.0	23.0
1961	19.0	19.4	-0.8	-0.8	0.0	0.0	19.0
1962	22.0	34.0	-0.6	-0.6	0.0	1.2	23.2
1963	26.0	29.1	-0.4	-0.4	0.0	0.0	26.0
1964	28.5	28.8	-0.2	-0.2	0.0	0.0	28.5
1965	29.0	31.4	-0.2	0.0	0.2	1.5	30.5
1966	30.0	30.4	-0.3	-0.1	0.2	0.0	30.0
1967	30.0	30.6	-0.3	-0.1	0.2	0.0	30.0
1968	31.5	31.2	-0.4	-0.1	0.3	0.0	31.5
1969	26.0	31.9	-0.4	-0.2	0.2	0.0	26.0
1970	27.0	28.0	-0.6	-0.3	0.3	0.0	27.0
1971	30.0	28.2	-0.6	-0.1	0.6	0.0	30.0
1972	27.0	31.0	-0.5	0.2	0.7	0.0	27.0
1973	26.5	27.0	-0.7	-0.2	0.6	0.0	26.5
1974	29.5	30.4	-0.6	-0.1	0.6	0.0	29.5
1975	35.0	33.5	-0.6	-0.1	0.6	0.4	35.4
1976	32.0	29.8	-0.3	0.6	0.9	0.0	32.0
1977	29.0	25.2	0.1	1.2	1.1	0.0	29.0
1978	31.0	35.6	0.2	1.4	1.2	0.0	31.0
1979	25.5	28.5	0.0	1.1	1.1	0.0	25.5

OHIO

YEAR	YIELD	AWX	AVE_DYA	TECH	NI	LOSS	ADTYIELD
1955	29.0	30.8	2.5	4.3	1.8	0.9	29.9
1956	26.0	31.7	2.6	4.4	1.8	0.8	26.8
1957	22.0	32.8	2.8	4.7	1.9	0.7	22.7
1958	31.0	37.0	2.9	4.8	1.9	0.3	31.3
1959	24.5	29.2	3.0	5.0	2.0	0.5	25.0
1960	35.0	36.2	3.2	5.3	2.1	0.0	35.0
1961	31.0	37.8	3.4	5.7	2.3	0.3	31.3
1962	32.0	34.2	3.5	5.9	2.4	0.0	32.0
1963	38.0	38.4	3.7	6.3	2.6	0.0	38.0
1964	32.0	27.6	3.9	6.7	2.8	0.0	32.0
1965	32.0	28.6	4.1	7.8	3.7	0.0	32.0
1966	39.0	36.9	4.4	8.0	3.6	0.0	39.0
1967	34.0	34.0	4.6	9.2	4.6	0.0	34.0
1968	37.5	38.3	4.9	9.0	4.1	0.0	37.5
1969	38.0	37.8	5.1	9.1	4.0	0.0	38.0
1970	38.0	33.4	6.3	10.3	4.0	0.0	38.0
1971	44.0	36.5	7.6	12.2	4.6	0.0	44.0
1972	45.0	38.1	8.8	13.4	4.6	0.0	45.0
1973	32.0	31.5	10.1	14.5	4.4	0.0	32.0
1974	41.0	34.2	11.3	15.6	4.3	0.0	41.0
1975	42.0	33.7	11.8	17.2	5.4	0.0	42.0
1976	40.0	34.9	12.3	18.4	6.1	0.0	40.0
1977	47.0	34.8	12.9	19.5	6.6	0.0	47.0
1978	39.0	37.2	13.4	18.2	4.8	0.0	39.0
1979	48.0	35.3	13.9	20.0	6.1	0.0	48.0