79-10062
TM-79927

LACIE-00472
JSC-13740

NASA NOAA USDA

FY78-79 LACIE TRANSITION PROJECT

"Made available under NASA sponsorship in the interest of early and wide dissemination of Earth Resources Survey Program information and without liability for any use made thereof."

REANALYSIS OF CCEA I U.S. GREAT PLAINS WHEAT YIELD MODELS

(E79-10062) LACIE TRANSITION PROJECT, FY 1978-1979: REANALYSIS OF CCEA 1 US GREAT PLAINS WHEAT YIELD MODELS (NASA) 107 p HC A06/MF A01 CSCL 02C
N79-13469
Unclas
G3/43 00062

NASA
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

JUNE 1978

CENTER FOR CLIMATIC AND

ENVIRONMENTAL ASSESSMENT

Technical Note 78-3

Reanalysis of CCEA I U.S. Great Plains Wheat Yield Models

Authorized for release by

Jerry D. Hill for

Dr. Norton D. Strommen, Director

Center for Climatic and
Environmental Assessment
Federal Building, Room 116
Columbia, Missouri 65201

April 1978

CCEA TECHNICAL REPORT 78-3

Reanalysis of CCEA I U.S. Great Plains Wheat Yield Models

Clarence M. Sakamoto[1]

INTRODUCTION

A first generation wheat model (CCEA I) was developed by the Center for Climatic and Environmental Assessment for operational use in Phases I, II, and III of the Large Area Crop Inventory Experiment (LACIE). These CCEA I models are multiple regression equations which utilize monthly climatic data as direct or as derived independent variables (Technical Note 75-1, Wheat Yield Models for the United States, 1975; CCEA Staff). Since their development in 1975 two modifications have been implemented into the U.S. Great Plains models during the 1976 and 1977 crop seasons. The first restricted the range of the new data used in the model. If the values of the climatic variables were outside a selected probability level, these were censored to the value of the preselected threshold percentile. The rationale for this procedure was simply to prevent extreme values from producing unrealistic model output (yield) values. Another reason for this flagging procedure is the assumption that excessive precipitation outside of the 90th percentile is not all available to the crops, being lost in runoff. The second modification was a trend adjustment for selected areas. Two general trend changes were instituted. The first included the Texas and Oklahoma area while the other altered the trend in Colorado, Kansas, North Dakota, South Dakota, Minnesota, Nebraska, Montana, the "Badlands," and the Red

---

[1]Research Meteorologist, Center for Climatic and Environmental Assessment, NOAA/EDS, 116 Federal Building, Columbia, Missouri, April 1978.

River Valley. The results of these changes simulated for the 11-year period, 1965 through 1975, have been previously reported (The Effect of Flagging and Trend Adjustments to Wheat Yield Estimates with CCEA Great Plains Models, March 1976; CCEA Staff). Other than these two changes, the equations in the U.S. Great Plains have not been reevaluated with regard to their candidate variables.

It should be reemphasized that the use of monthly climatic data assumes a normal crop calendar and is acknowledged as a limitation. However, the experience in LACIE has revealed that much information can be gained even with these simple models. It is the intent of this review to determine whether the information content from these simple models can be improved.

This review is considered the first attempt at an in-depth reanalysis of the operational model (LACIE-CCEA I). The objectives of this revision are to: 1) review candidate variables that may provide a more responsive index of the variability of weather to wheat yield in the U.S. Great Plains, 2) assess the linear trend specification of all U.S. Great Plains models with respect to known management changes that may be associated with factors affecting trend (Technical and Economic Causes of Changes in U.S. Wheat Production, 1949-1976; J. Bond and D. Umberger, USDA/FAS, to be published in 1978), 3) compare by graphical plot the 12-year test, 1965-1976, of the CCEA I and results of the revised model, if any, and 4) document the candidate variables that were attempted but may not have been included in the final model. In this report, revisions of CCEA I will be referred to as CCEA IA models.

PROCEDURE

Figure 1 is a flow diagram showing the process of reviewing and selecting the candidate variables for the revised CCEA I wheat yield models

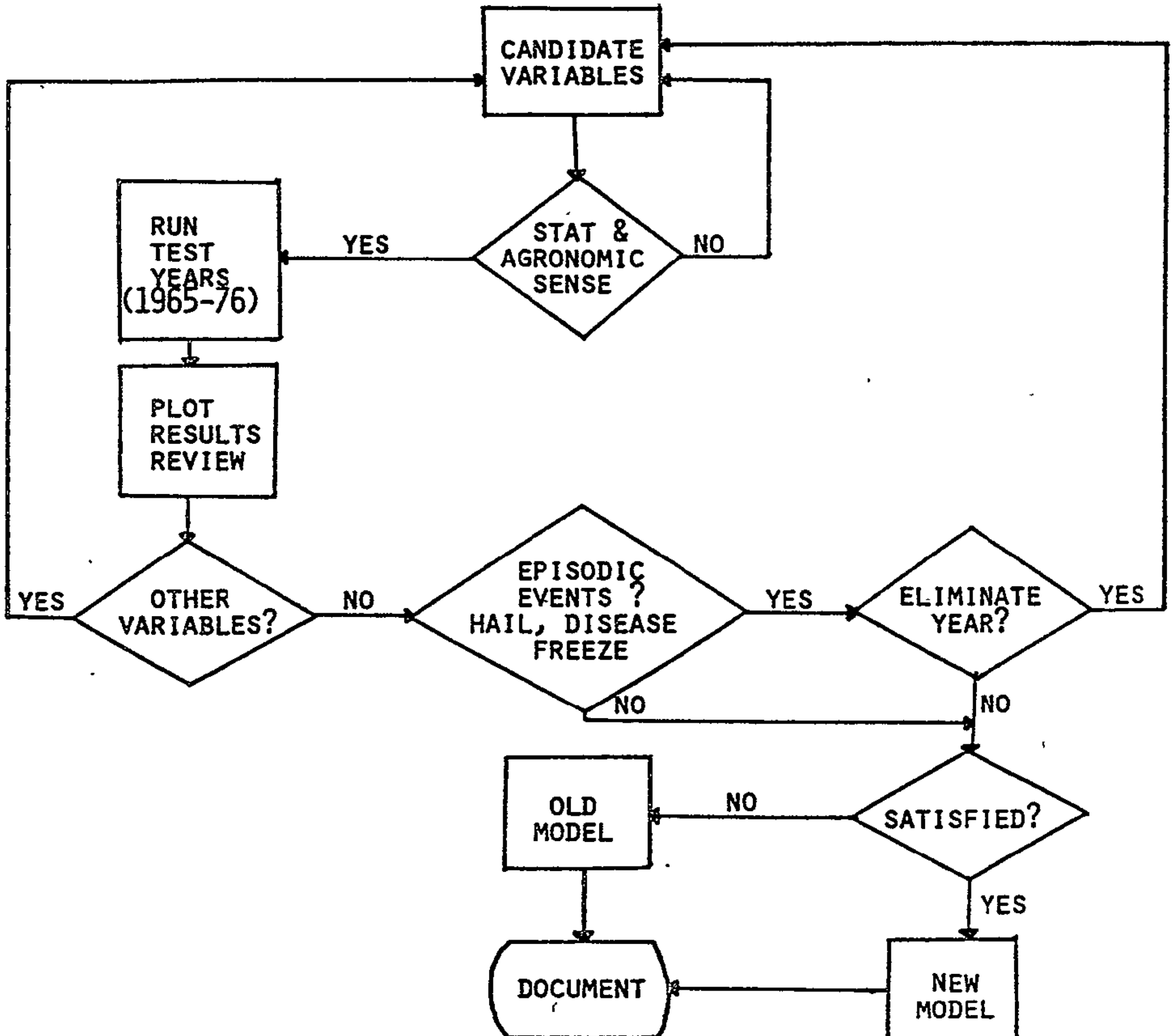

CANDIDATE VARIABLES
STAT & AGRONOMIC SENSE
YES
NO
RUN TEST YEARS (1965-76)
PLOT RESULTS REVIEW
OTHER VARIABLES?
YES
NO
EPISODIC EVENTS ? HAIL, DISEASE FREEZE
YES
NO
ELIMINATE YEAR?
YES
NO
SATISFIED?
NO
YES
OLD MODEL
NEW MODEL
DOCUMENT

Figure 1

(CCEA IA). Initially, two changes were considered: 1) respecification of trend, and 2) replacement of the degree day variable, a step-function, with a continuous variable; i.e., the number of days above 90°F (32°C). Table 1 is a list of stations and weights used in assessing the value of this variable. Figure 2 shows the locations on a map. As with any multiple regression model, a change of one variable will affect the coefficients of those remaining. Since all of the possible combinations of variables were too numerous, the approach in this study was one of a selective process which utilized a priori knowledge of the response of the wheat crop to weather in a given area. In addition, information was gleaned from the Weekly Weather and Crop Bulletin (NOAA) to help explain the large year-to-year variability. From this, other variables were analyzed. Information on the mean phenological stages for winter and spring was also considered to determine if the candidate variable made sense. The ultimate goal was to have the remaining variables be both statistically and agronomically meaningful, the coefficients sufficiently stable to estimate year-to-year wheat yield variability with a high degree of precision. The general form and discussion of weather indices for these models are shown in Appendix A.

The variables that were considered were bounded by certain constraints, namely: 1) other than the variable "number of days above 32°C," the derived variables used the basic monthly temperature and precipitation data as in CCEA I models, and 2) the revision was limited by the program that was operationally used in Phases I, II, and III. This meant that the data base, at the time of the revisions, could not utilize other systems such as SAS (Statistical Analysis System). Consequently, the number of candidate variables for the models was limited. SAS is a powerful tool that can permit quick and easy analysis of the candidate variables. The reassessment of

TABLE 1

Stations Utilized in the Aggregation of the

"Number of Days Above 90°F" Model Variable

Winter Wheat

Model	Station Number	Name	Weight	Months Used
Badlands (61)	72566	Scotts Bluff, NE	.50	June
	73565	Chadron, ND	.10	
	72662	Rapid City, SD	.20	
	73668	Pierre, SD	.10	
	72659	Aberdeen, SD	.03	
	72654	Huron, SD	.04	
	72651	Sioux Falls, SD	.03	
Colorado (08)	73218	Akron, CO	.45	May
	72465	Goodland, KS	.30	
	LIC	Limon, CO	.15	
	LHX	La Junta, CO	.10	
Kansas (20)	72465	Goodland, KS	.15	May
	73465	Hill City, KS	.15	
	73720	Garden City, KS	.15	
	HUT	Hutchinson, KS	.20	
	72451	Dodge City, KS	.15	
	72458	Concordia, KS	.10	
	72456	Topeka, KS	.05	
	EMP	Emporia, KS	.05	
Montana (30)	72777	Moore, MT	.55	June
	72768	Glasgow, MT	.20	
	73677	Lewiston, MT	.15	
	73667	Miles City, MT	.10	
Nebraska (31)	72562	North Platte, NE	.70	June
	72552	Grand Isle, NE	.10	
	LNK	Lincoln, NE	.20	
Oklahoma (40)	73354	Punca City, OK	.25	May
	73350	Gage, OK	.20	
	73352	Hobart, OK	.15	
	72353	Oklahoma City, OK	.10	
	72351	Wichita Fall, TX	.15	
	72356	Tulsa, OK	.15	
Texas Low Plains (48)	72351	Wichita Falls, TX	.50	May
	72266	Abilene, TX	.25	
	72256	Waco, TX	.15	
	72259	Fort Worth, TX	.10	

Winter Wheat (Continued)

Model	Station Number	Name	Weight	Months Used
TX Edwards Plateau (48-70)	JCT	Junction, TX	1.00	April, May
TX South Central (48-81)	72254	Austin, TX	1.00	April, May
TX/OK Panhandle (62)	73350	Gage, OK	.25	May
	72363	Amarillo, TX	.60	
	72267	Lubbock, TX	.15	

Spring Wheat

Model	Station Number	Name	Weight	Months Used
Minnesota (27)	72655	St. Cloud, MN	.60	June, July
	MKT	Mankato, MN	.40	
Montana (30)	72777	Havre, MT	.30	June
	72768	Glasgow, MT	.45	
	73677	Lewiston, MT	.10	
	72767	Williston, ND	.10	
	73667	Miles City, MT	.05	
North Dakota (38)	73767	Minot, ND	20	June, July
	72767	Williston, ND	.15	
	73764	Dickinson, ND	.15	
	72764	Bismarck, ND	.15	
	73752	Jamestown, ND	.15	
	72753	Fargo, ND	.20	
South Dakota (46)	72659	Aberdeen, SD	.40	June
	73668	Pierre, SD	.10	
	72654	Huron, SD	.10	
	ATY	Watertown, SD	.25	
	72662	Rapid City, SD	.10	
	72651	Sioux Falls, SD	.05	
Red River Valley (63)	73758	Grand Forks, ND	.35	June, July
	72753	Fargo, ND	.30	
	72655	St. Cloud, MN	.15	
	73752	Jamestown, ND	.20	

Location of stations that " number of days above 90 deg F " data is collected for.

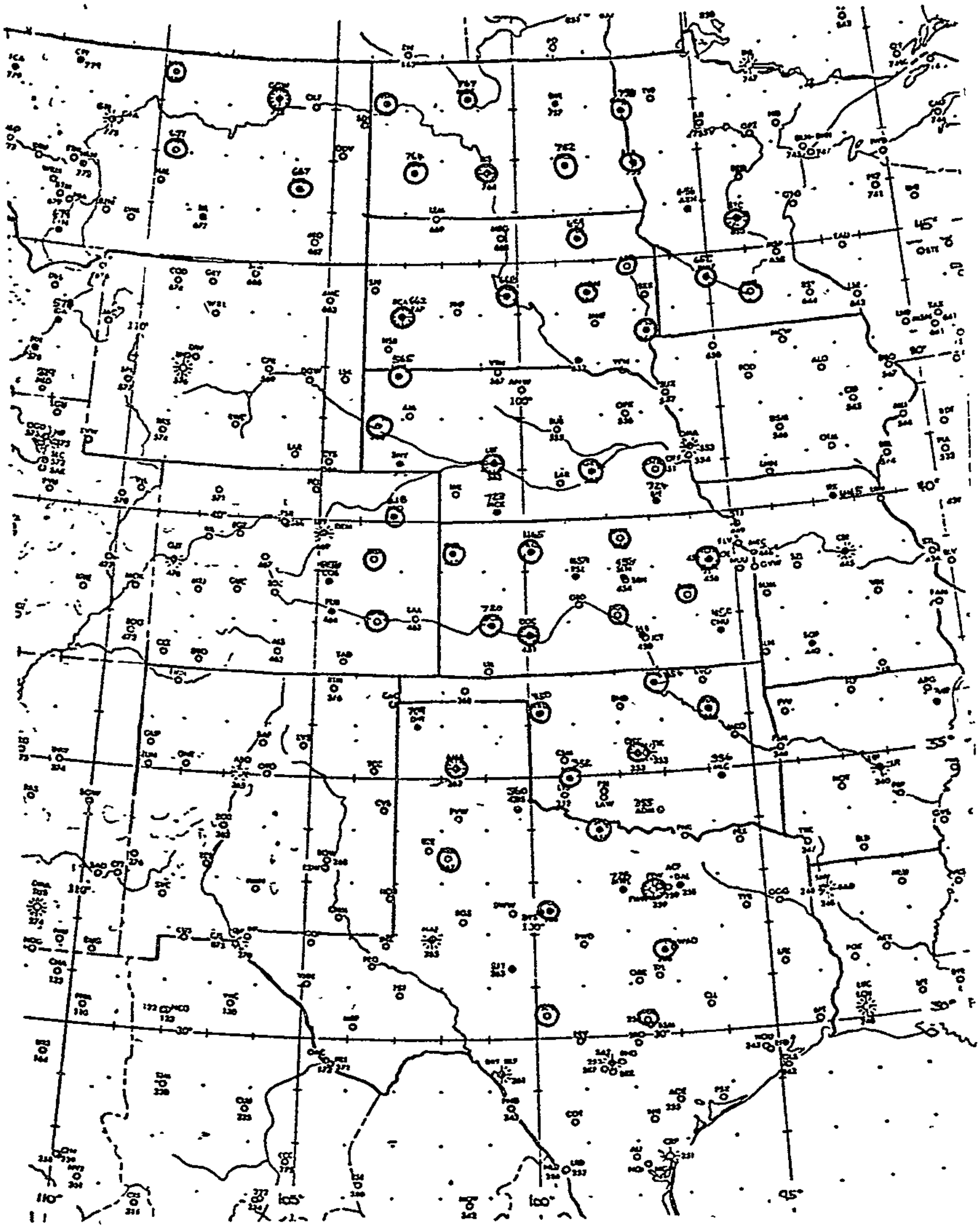


Figure 2

CCEA I was well into the revision process with the operational program before SAS became available and the decision was made to not use it. However, in any future reevaluation of the model, it is recommended that this tool be used for detailed variable analysis and to produce other kinds of indices that may be responsive to the variability in yield.

As indicated in Figure 1, if the models made sense and showed stability in the coefficients, a 12-year (1965-1976) "bootstrap" test was initiated. This is a test wherein the data years prior to a prediction year are used to develop the coefficients of the model with the same variables. Each advancing prediction year would then have an additional data year for coefficient estimation. When the yield estimates are plotted with the "observed yield," the data serve to indicate disparities that might suggest a need for further analysis or inclusion of new variables not otherwise considered. In some cases, review of the crop year may suggest the effects of an episodic event such as freeze, disease, hail, etc. A decision is then made as to whether that data year should be eliminated. If it is eliminated, the model is rerun without the inclusion of the episodic year. An episodic year is defined as a year in which the yield is affected by a relatively rare event, natural as well as social occurrence, and is not modeled by the selected set of independent variables. Examples include frost, hail, rust outbreak, flood, cattle trampling the crop, etc. (Yield Advisory Group Report, LACIE-00466, JSC-13730, February 1978, NASA, Johnson Space Center, Houston, Texas). This systematic trial and error procedure is selective with regard to the candidate variables. If after several iterations one finds that the model does not improve the model performance, the original CCEA I effort is retained.

"Which model is better?" is a question of much controversy. If one is given the task to select the "better" of two models, the one that most often estimates the "observed" value is considered the more suitable candidate. Unfortunately, this criterion alone is insufficient and objective methods of comparing models need to be addressed and developed. Another criterion might be the ability of the model to detect large fluctuations or variability in the data series. The standard error of the model as well as the coefficient of determination, R^2, and bias could also be used as a criteria for model selection. In this report, the criteria used were: 1) select the model that could best detect the swings in the 12-year test with respect to the base Statistical Reporting Service (SRS) yield estimate, 2) reduce standard error and increase the coefficient of determination tempered by the number of variables, and 3) select a model that might provide an estimate closer to 1977 estimates. No set values were used to determine statistical significance.

Since documentation is one of the objectives of this study, the following section will address each model with a discussion of the candidate variables and factors that may be associated with trend specification. It is understood that trend specification is highly qualitative in these models and objective estimates must wait until better quantitative studies on this subject are initiated.

MODEL DISCUSSION

Spring Wheat

Figure 3 is a map indicating the areal coverage of the spring (durum and other spring) wheat areas. Five areas are included: North Dakota (crop reporting districts (CRDs) 10, 20, 40, 50, 70, 80, and 90), Red River Valley (CRDs 30 and 60 for North Dakota and CRDs 10 and 40 for Minnesota), Minnesota (CRDs 50, 70, and 80), Montana (CRDs 20, 30, and 90), and South Dakota (CRDs 10, 20, 30, 50, 60, and 90).

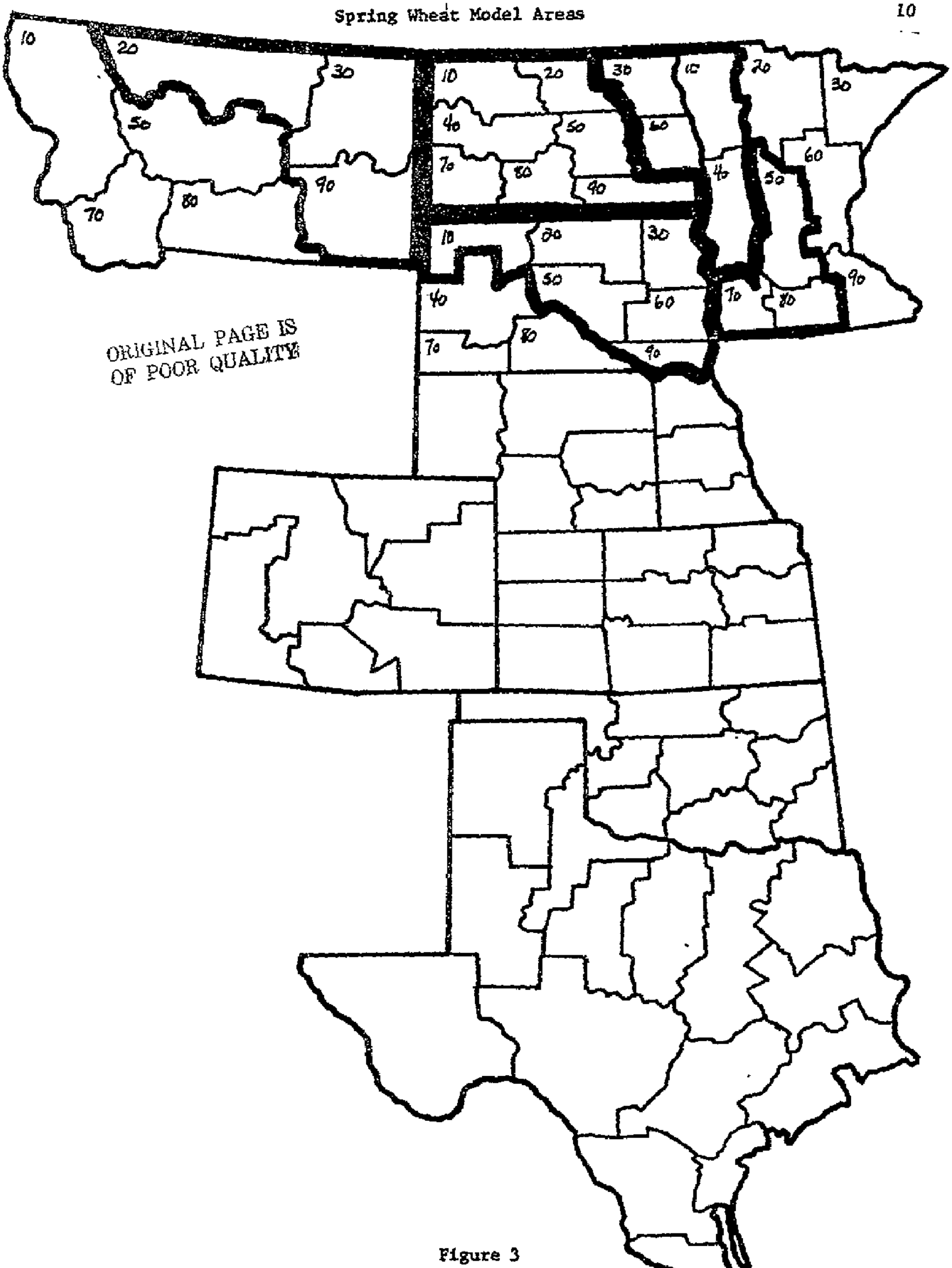

10
20
30
50
70
80
90
10
20
40
50
70
80
90
30
10
60
40
20
30
60
50
90
70
80
10
20
30
40
50
60
70
80
90

Figure 3

1. North Dakota spring wheat

The initial CCEA I North Dakota spring wheat model included three trend terms: 1932-1955, 1955-1965, and 1965-1972. Specification of trend in a data series should be rationally defined with respect to the causes of the trend shifts. This is easier said than done, since many factors are often involved. Bond and Umberger (1978), for example, identified seven nonweather factors associated with variations in wheat yield. In North Dakota, a plot of the yield series (Figure 4) shows that yield trend decreased from 1879 until the drought period of the 1930's. This decreasing trend is partially attributed to soil fertility deterioration with time as well as to the expansion of the wheat acreage from the more humid eastern sections of the state to the less humid western areas. Following World War II fertilizer application also increased, while during the 1950's the major impact was the introduction of new varieties that lead to higher yields. The 1950 years were also drier. Furthermore, the drought of the 1930's is a known event associated with deteriorating yields. If trend was started in the 1930's, the effect of the dry period would be masked by this trend term. Therefore, the linear trend 1932-1955 was eliminated. Inspection of the data also shows that the rate of trend increase has slowed since the early to mid-1960's. Consequently, a second trend, ending about 1972, was added. The leveling of trend in 1972 is in accord with the work reported by several investigators including Bond and Umberger (1978) and Haigh (1977).

It is impractical and difficult to specify the exact beginning and ending year of the trend term at this time. An example of this can be shown by comparing the results of the 12-year "bootstrap" of two models in Figure 5. In both models, the variables are identical with the exception of trend. Note that for the 1955-1965, 1965-1972 trend the model appears to capture the

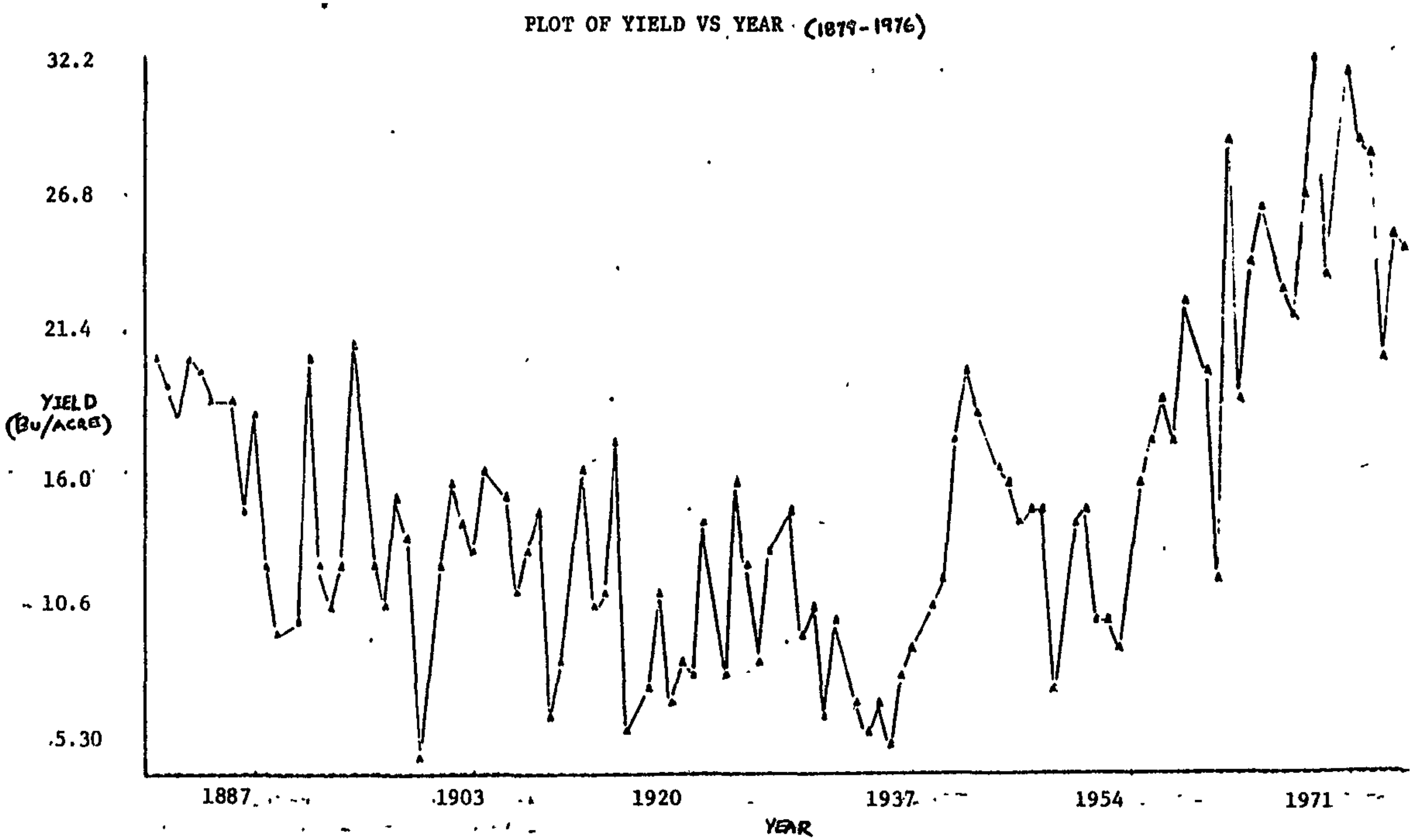

PLOT OF YIELD VS YEAR (1879-1976)
32.2
26.8
21.4
YIELD (Bu/ACRE)
16.0
10.6
5.30
1887
1903
1920
1937
1954
1971
YEAR

Figure 4

COMPARATIVE YIELD TESTS, NORTH DAKOTA SW

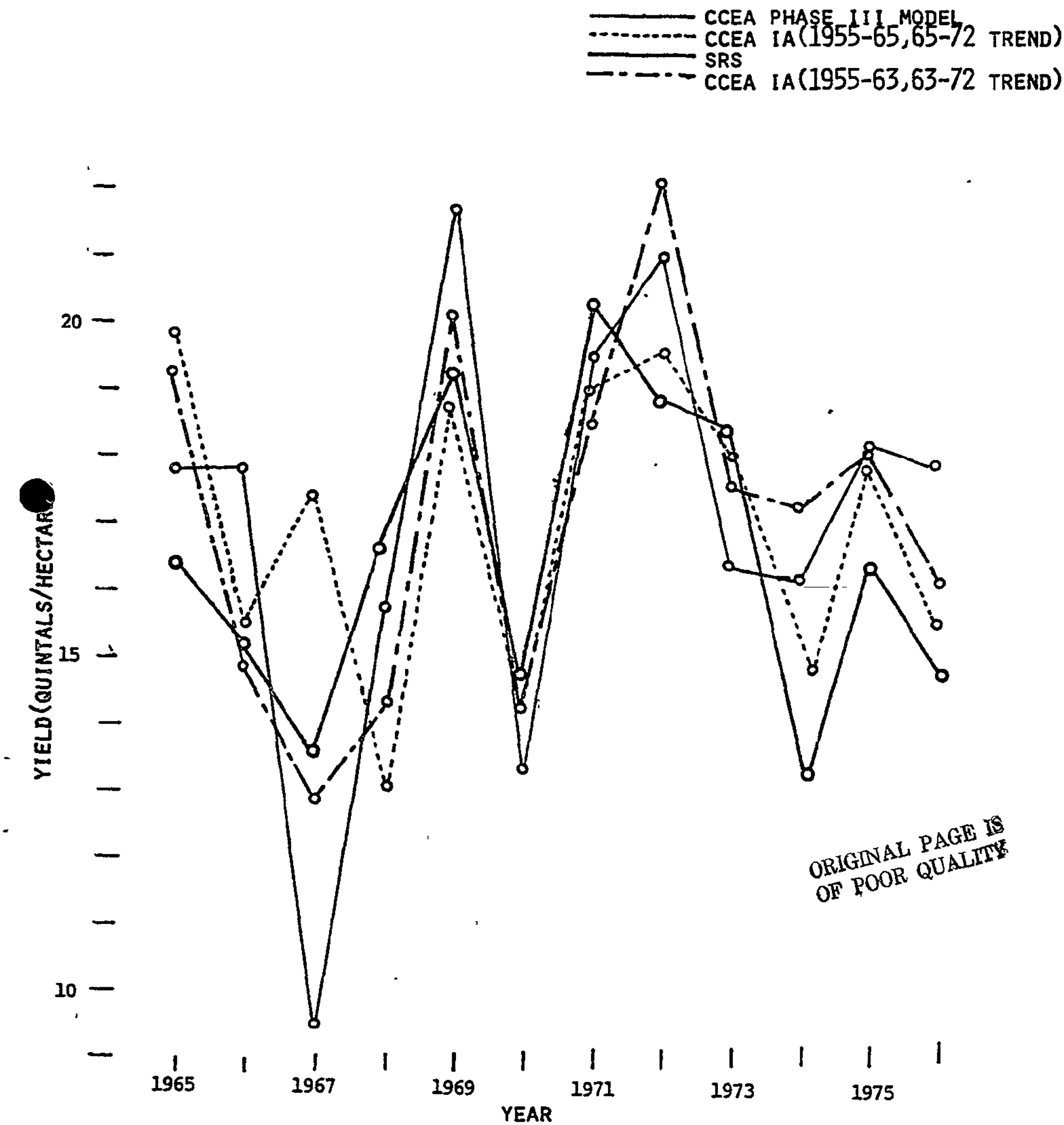


Figure 5

variability from 1971 through 1975 better than the model that included the 1955-1963, 1963-1972 trend. The larger difference in model estimates for 1967 and 1968 is associated with the so-called "two-year rule" in the "bootstrap" test which restricts a change of trend in the test until two years after the break period. However, in an operational mode, it is likely that a change will be subjectively made for each forecast year. The principal guides for determining where trend should be broken with a particular trend specification are how much of the yield variation the meteorological variables "explain" and do the trend components agree with nonweather considerations influencing yield.

Two other trend terms, 1943-1972 and 1955-1972, were also tried in separate models. As expected, these trend variables were statistically significant in both cases; however, when both of the two trend terms, 1955-1965 and 1965-1972, were included, the model explained a greater portion of the variability with a corresponding decrease in the standard error.

Instead of the preseason variable August-March precipitation as defined in the CCEA I model, the period August-November was selected because it was both more statistically significant, and also because this shorter period is the period generally associated with non-freezing temperatures. With frozen soil, additional winter precipitation does not effectively add to the soil profile, and a large portion of this precipitation is considered potential runoff. The detrimental effect of April precipitation on yield is reasonable and is associated with a delay in planting resulting from excessive precipitation.

Another variable, the deviation of number of weeks from the average planting date for the period 1950-1976, was also examined. This value ranged from zero to four, zero if planted before the average date and 1 through 4 for each week delay from the average date. This variable was no better than April precipitation alone and therefore was discarded as a candidate variable.

Since new varieties have entered into the yield series since the 1950's, it was decided to run the model with only the period 1950-1976. When this was done, neither the preseason precipitation August-March nor August-November were statistically significant. In fact, with two trend terms, 1955-1965 and 1965-1972, the only weather variables to show significance were April departures from normal precipitation ($t = -2.389$, $df = 21$) and number of days above 90°F (32°C) in June ($t = -5.906$) and July ($t = -3.128$). The model with these five variables produced a coefficient of determination of 91 percent with a standard error of 1.47 quintals/hectare. When the same variables were tried with the longer 1932-1970 data period, April precipitation showed a negative coefficient, but was not statistically significant ($t = -0.631$).

It is clear that June and July temperatures expressed by the number of days above 90°F (32°C) highly affect spring wheat yield in North Dakota, the higher the temperature the lower the yield. The phenological stages linked with these two months include both the heading and the ripening stages.

The selected model for North Dakota is shown in Appendix B. Appendix C includes the t-statistics for the final truncation for all models. Note that the second trend for North Dakota is not considered statistically significant. However, this term was retained to account for the decreasing rate of change in yield during this period relative to the period 1955-1965. The revised North Dakota model (CCEA IA) contains nine variables as opposed to the 12 in the original one (CCEA I).

2. Red River Valley spring wheat

As in the North Dakota spring wheat model, the 1932-1955 trend for the Red River Valley was eliminated. The second trend term in CCEA I, 1955-1972, was extended through 1977. This was done to consider the increasing acreage of the new semi-dwarf variety, Era, released in 1970 by the University of Minnesota plus the increasing rate of nitrogen application since 1975 (Figure 6). In 1977, it has been estimated that Era occupied 70 to 75 percent of the spring wheat acreage (Seeley, personal communication to Dr. V. Whitehead on March 9, 1978, Subject: Large Positive Trend in Acreage and Yield of Spring Wheat in Minnesota). As of 1976, approximately 80 percent of Minnesota spring wheat was grown in the Red River Valley. It is also noted that in 1977 harvested spring wheat (excluding durum) acreage was down 12 percent from 1976, and durum wheat harvested acreage down 34 percent from 1976 (Minnesota Annual Crop Summary, December 1977, Minnesota Crop and Livestock Reporting Service, USDA, and Minnesota Department of Agriculture). These three factors, increased fertilizer, varietal changes, and reduced acreage, should contribute to increasing the yield trend rather than stabilizing the trend after 1972. However, it has been estimated that nitrogen fertilization for wheat has stabilized between 40 to 80 pounds per acre and that acreage planted to Era has leveled off at 70 to 80 percent of total acreage (Seely, 1978). This suggests that trend due to these factors should be level after 1978. Another factor that may have contributed to the record 39.9 bushels per acre (spring and durum wheat) in Minnesota yield was the relatively dry 1976 crop year with the consequence that residual 1976 fertilizer becoming available in 1977.

The trend terms for the Red River Valley could also have been separated into two variables, 1955-1965 and 1965-1977. These, plus the four other

RATE OF FERTILIZER APPLICATION
FOR WHEAT IN MINNESOTA

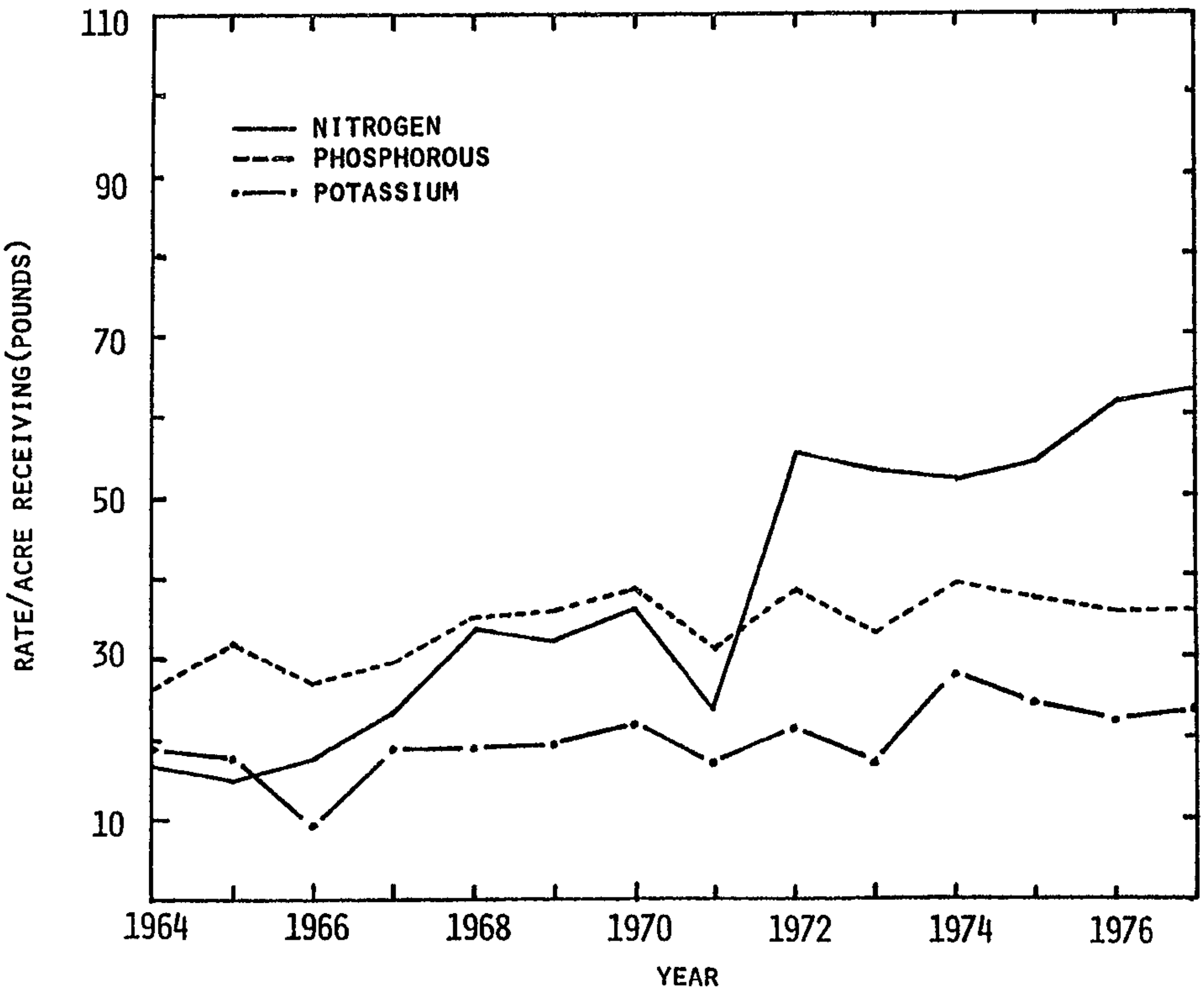


Figure 6

ORIGINAL PAGE IS
OF POOR QUALITY

variables selected in the final truncation, provided a coefficient of determination (R^2) of 90 percent and a standard error of 1.81 quintals. The estimated yield for 1977 was only 21.5 quintals per hectare. This compares with the selected model with an R^2 of 87 percent and a standard error of 2.04 quintals (Appendix C). Figure 7 shows the plot of the 12-year "bootstrap" test for both of these. In the case of the model with two trends, the CCEA IA estimate approximates the SRS series better after 1971 than the CCEA IA model with only one trend. The model with one trend was selected because of its closer estimate to the 1977 yield and the rationale for this increase based on the discussion above. In both cases, however, note the decreasing yields from 1971 through 1976 even though the trend variable was extended through 1977. This indicates that the model appears to be sensitive to meteorological change experienced during this period. These two models need to be monitored and have been included in Appendix C. If indeed the hypothesis of residual fertilizer lag effect is a dominant factor, this would suggest that this effect needs to be considered in future crop model development.

As with the North Dakota model, preseason precipitation candidate variables, August-October, August-November, August-March, September-April, September-November, and August-December were tried. Again the best variable in terms of its statistical significance was the September-November total precipitation which effectively measures moisture going into the soil before the ground is frozen.

April temperature, departure from normal, was retained in the model to reflect the planting problems during this month. Lower April temperature is highly correlated with higher precipitation; this could delay planting and subsequently lead to reduction in yield. The positive temperature

COMPARATIVE YIELD TESTS, RED RIVER VALLEY SW

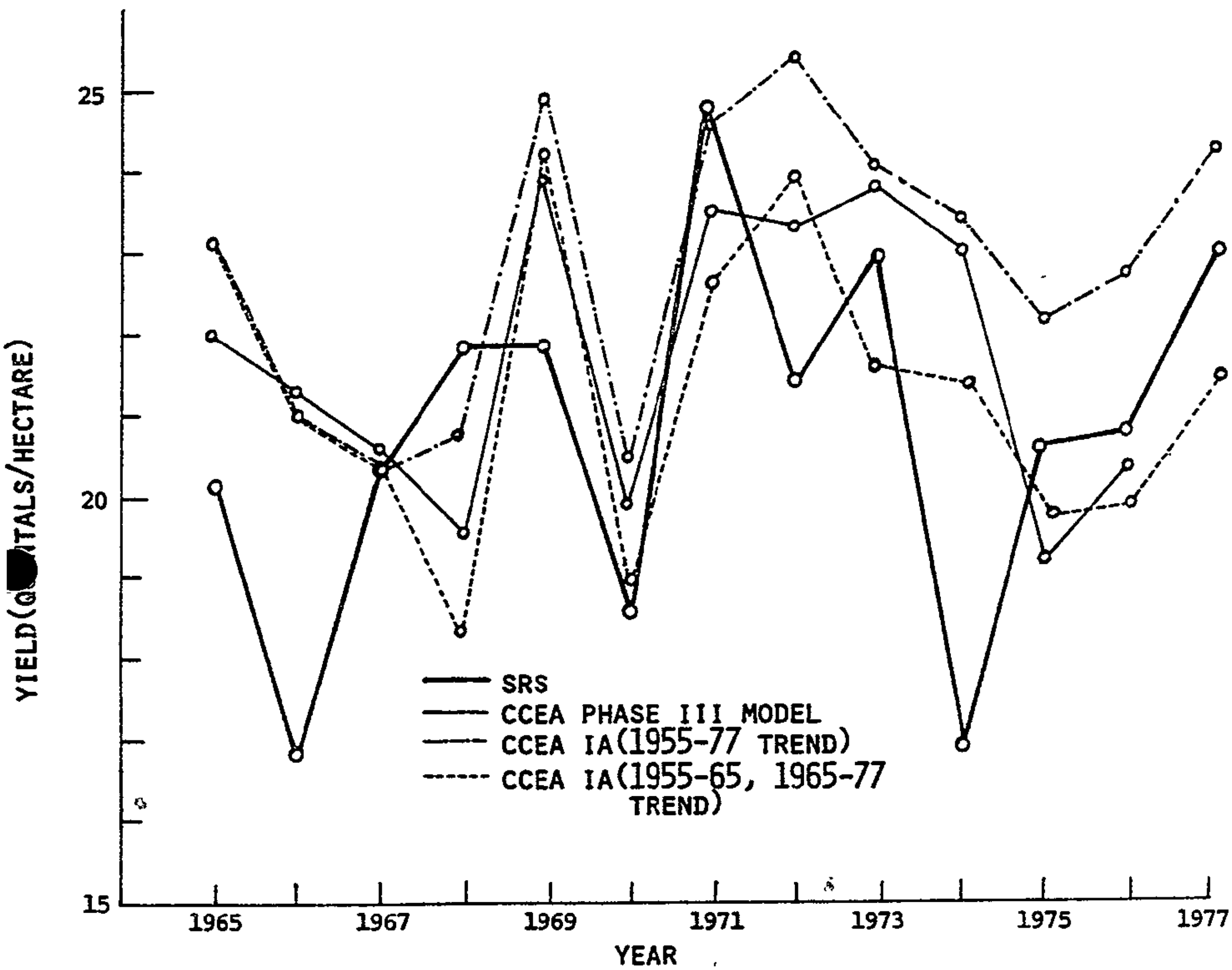


Figure 7

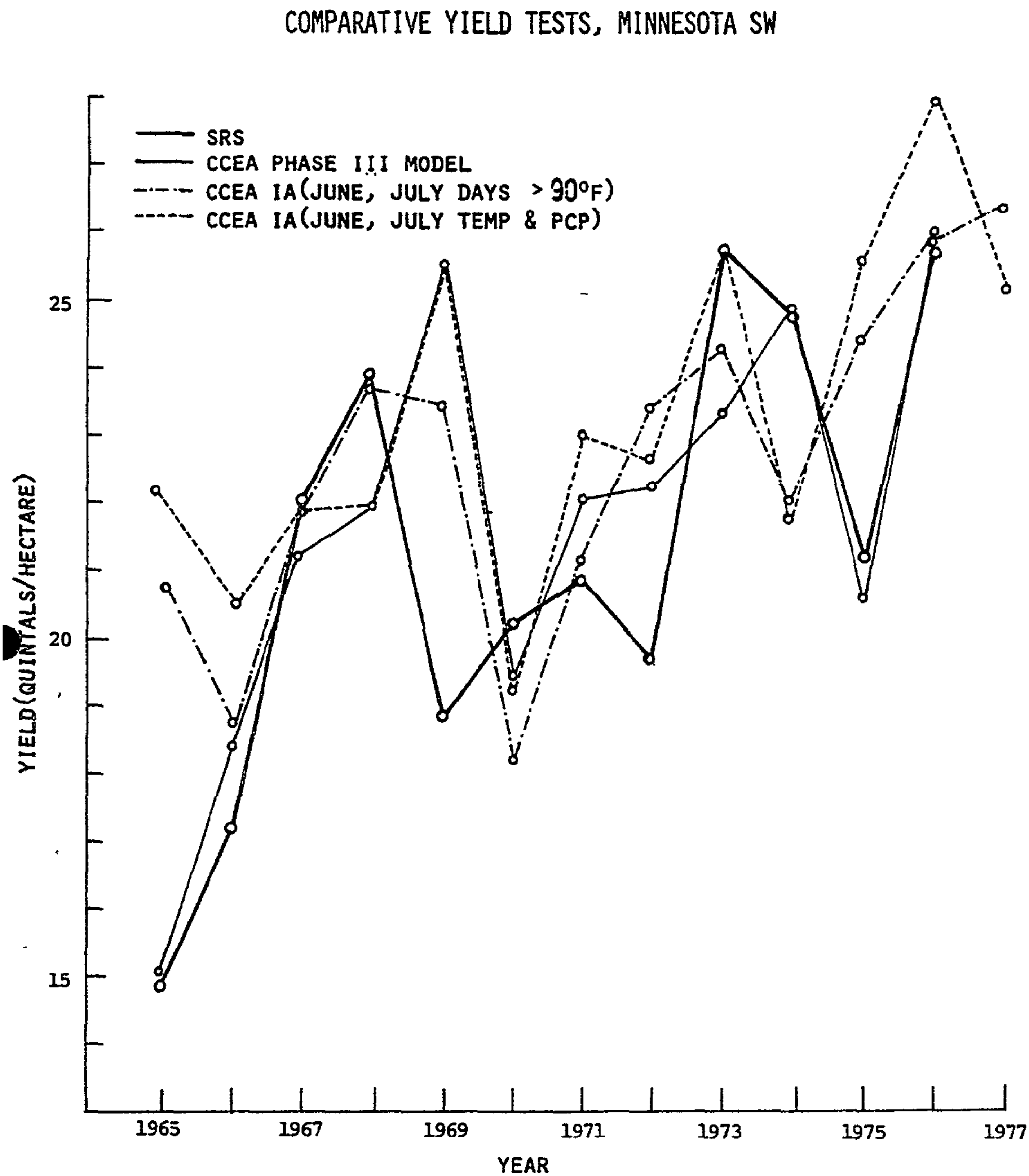
coefficient is also associated with plant emergence in this area. April precipitation was also examined, but did poorly in terms of its statistical significance which was considered unstable in its coefficient and sign. Other variables tried but not included in the model for the Red River Valley were May temperature, and June and July precipitation. Although statistically significant, June and July precipitation are highly correlated with June and July number of days greater than 90°F (32°C). The exclusion of a May variable does not imply that this month is not critical to the growth and development of wheat. The results suggest that climatically, May weather conditions are favorable in the Red River Valley.

3. Minnesota spring wheat

Approximately 20 percent of the Minnesota spring wheat area is accounted for by this model while the remaining 80 percent is contributed by the model for Red River Valley (see Figure 3). In reviewing the original CCEA I model, two variables were considered controversial: the May and August temperature variables as the squared departure from their long-term averages. The interpretation of these variables is that any positive or negative departure from the optimum (mean) is beneficial or detrimental depending on the signs of the coefficients. Agronomically, this interpretation is not reasonable. Climatically, for that area, this kind of variable may be reasonable.

The CCEA IA revised model basically contains the same variables that were employed in the original model, but includes only eight as opposed to ten.

When the 12-year "bootstrap" test was run on the selected model (Appendix B) and plotted as in Figure 8, it was evident that the estimates for 1965, 1969, 1972, and 1975 missed the SRS estimates by a wide margin. On reviewing



COMPARATIVE YIELD TESTS, MINNESOTA SW
SRS
CCEA PHASE III MODEL
CCEA IA(JUNE, JULY DAYS > 90°F)
CCEA IA(JUNE, JULY TEMP & PCP)
YIELD(QUINTALS/HECTARE)
25
20
15
1965
1967
1969
1971
1973
1975
1977
YEAR

Figure 8

the Weekly Weather and Crop Bulletin (issues for 1965, 1969, 1972, and 1975) the following abnormalities were noted. In 1965, planting was not completed until mid-June. Furthermore, hail and rust problems were also reported. In 1969, the month of May was very cold and hampered growth of seedlings. In both 1972 and 1975, excessive rain in June and July was deterrent to favorable yields. Heavy downpour from thunderstorms plus gusty surface winds do not favor the crop and subsequently decrease crop yield.

After examination of the weather events in years where the yields fluctuated greatly, it was thought that inclusion of precipitation in both June and July could produce a more sensitive response of yield to weather. However, plots of the 12-year "bootstrap" test show that the inclusion of precipitation for June and July did not improve the performance of the model when compared with the selected model.

In 1977, the CCEA I model underestimated the Statistical Reporting Service (SRS, USDA) estimate for Minnesota by a large margin. The question has been raised as to whether high temperatures in May, June, and July in the model were tempered by the rainfall that occurred during this period. The interaction of May temperature and precipitation was attempted as the difference between precipitation and potential evapotranspiration, which is a function of temperature (Thornthwaite, 1948). This variable did not show as large a sensitivity to yield as precipitation alone. It should also be recognized that temperature and precipitation for the same month are highly correlated. Nevertheless, a candidate model including both temperature and precipitation for May, June, and July was attempted. The coefficient signs for all of these variables were negative, although not statistically strong when compared to the inclusion of only May precipitation and June and July temperature into the model.

Instead of June and July number of days above 90°F (32°C), the temperature departure from normal was attempted. The result, in the case of June and July temperature (all other variables were identical), was that the 1977 estimate was 25.3 quintals with an R^2 of .876 and the standard error of 2.05. With the variable number of days greater than 32°C, the 1977 estimate was 26.4 quintals with an R^2 of .855 and a standard error of 2.23 quintals.

Except for 1969, the original CCEA I model, in terms of meeting the swings of yields in the 12 years, did remarkably well. However, for 1977, this model did poorly - only 22.8 versus the "observed" 26.2 quintals per hectare.

Various combinations of preseason precipitation were attempted: October-March, October-November, August-March. October-March was highly significant and had a negative effect on yield. The explanation perhaps is that the heavy winter precipitation may be associated with heavy snowmelt during spring and hence a delay in planting.

One other candidate model that needs to be monitored uses June and July temperature instead of the number of days greater than 32°C. In addition to a slightly higher R^2 (.878 versus .854) and a lower standard error (2.05 versus 2.23), the model estimate was about two bushels below that derived from the selected model in Appendix B. This could suggest that in Minnesota a mean temperature, possibly the mean maximum, may be a better temperature stress factor for the months of June and July than the number of days above 90°F (32°C).

4. Montana spring wheat

Two major changes were implemented in the revised CCEA Montana spring wheat model. First, the 1932-1955 trend was eliminated. The rationale for this has been discussed above. Secondly, the second trend term beginning 1955 was extended through the current prediction year rather than stabilizing it at 1972. The plot of fertilizer (NPK) used since 1964 suggests that this trend assumption may not be too far wrong (Figure 9). Other variables that were attempted included using only a 1943-1977 trend while retaining the original variables. The estimated yield for 1977 was 19.7 bushels, only one bushel above the original model.

The variable July temperature was used rather than July precipitation minus potential evapotranspiration (prec-PET). Either one of these variables could have been used. Similarly, May precipitation was used in lieu of May precipitation minus potential evapotranspiration, but it made little difference. Excessive precipitation in June in the form of a quadratic term was tested, but this squared deviation from normal term was not considered sufficiently stable to be retained in the final model. A temperature factor, June days above 90°F, was included to consider the damping effect of temperature on yield.

From the several combinations of candidate variables attempted, it is apparent that more than one candidate model could be used. The question of which to choose in the case of Montana was guided by the ability of the model to detect the swings of the "observed" yield since 1971 as well as the ability to pick up the higher yield in 1977 to reflect the fertilizer increase since 1975 (Figure 9). The estimated yield for 1967 was close to the "observed" yield in the original model, in spite of the very late planting (95 percent completed by June 5) as reported by the Weekly Weather and Crop Bulletin. One of the major weaknesses of monthly data and regression is the inability to consider other than a normal crop calendar.

RATE OF FERTILIZER APPLICATION FOR WHEAT

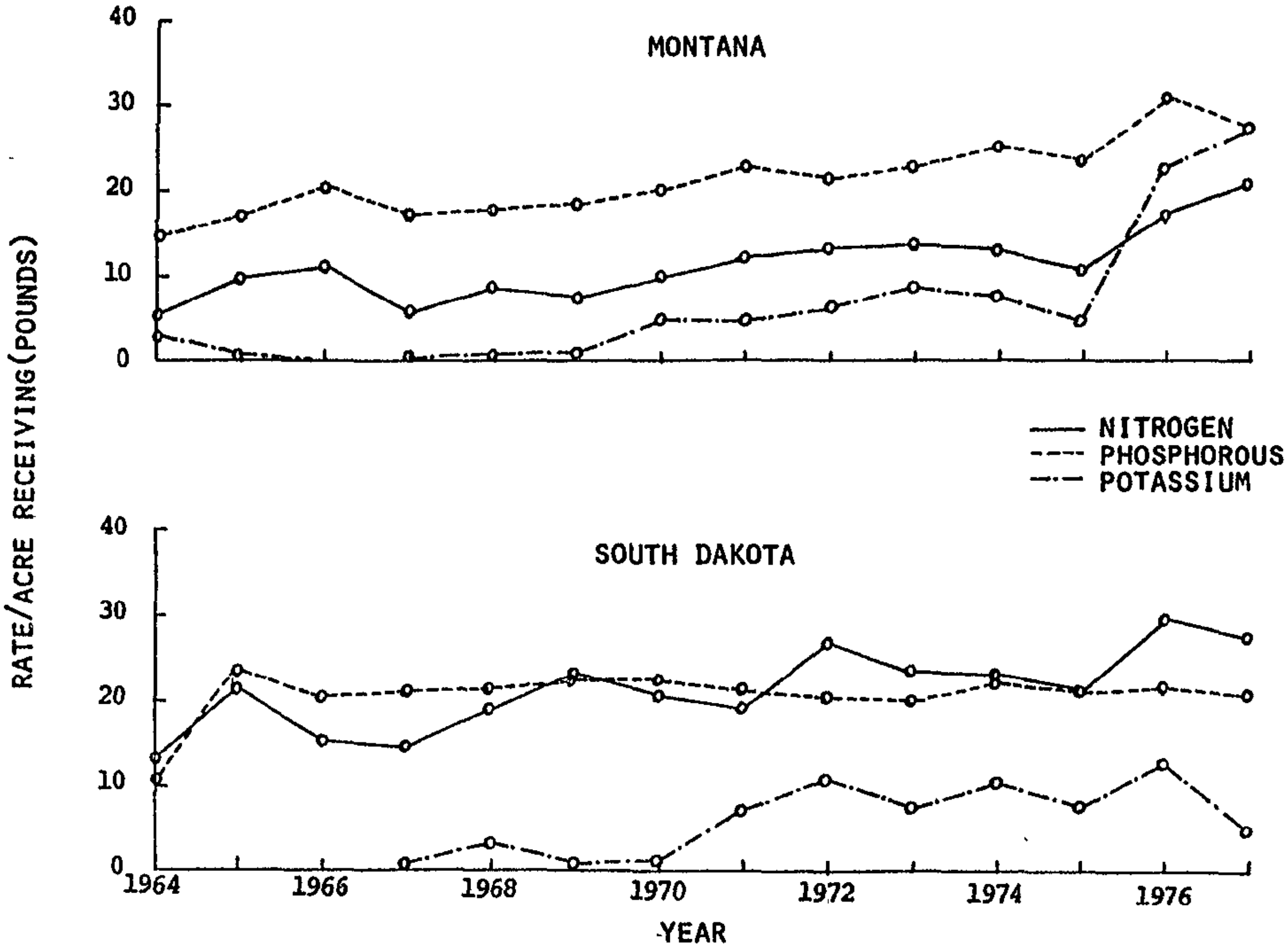


Figure 9

The fact that both the "observed" and the estimated yield for 1967 were close may have been serendipity.

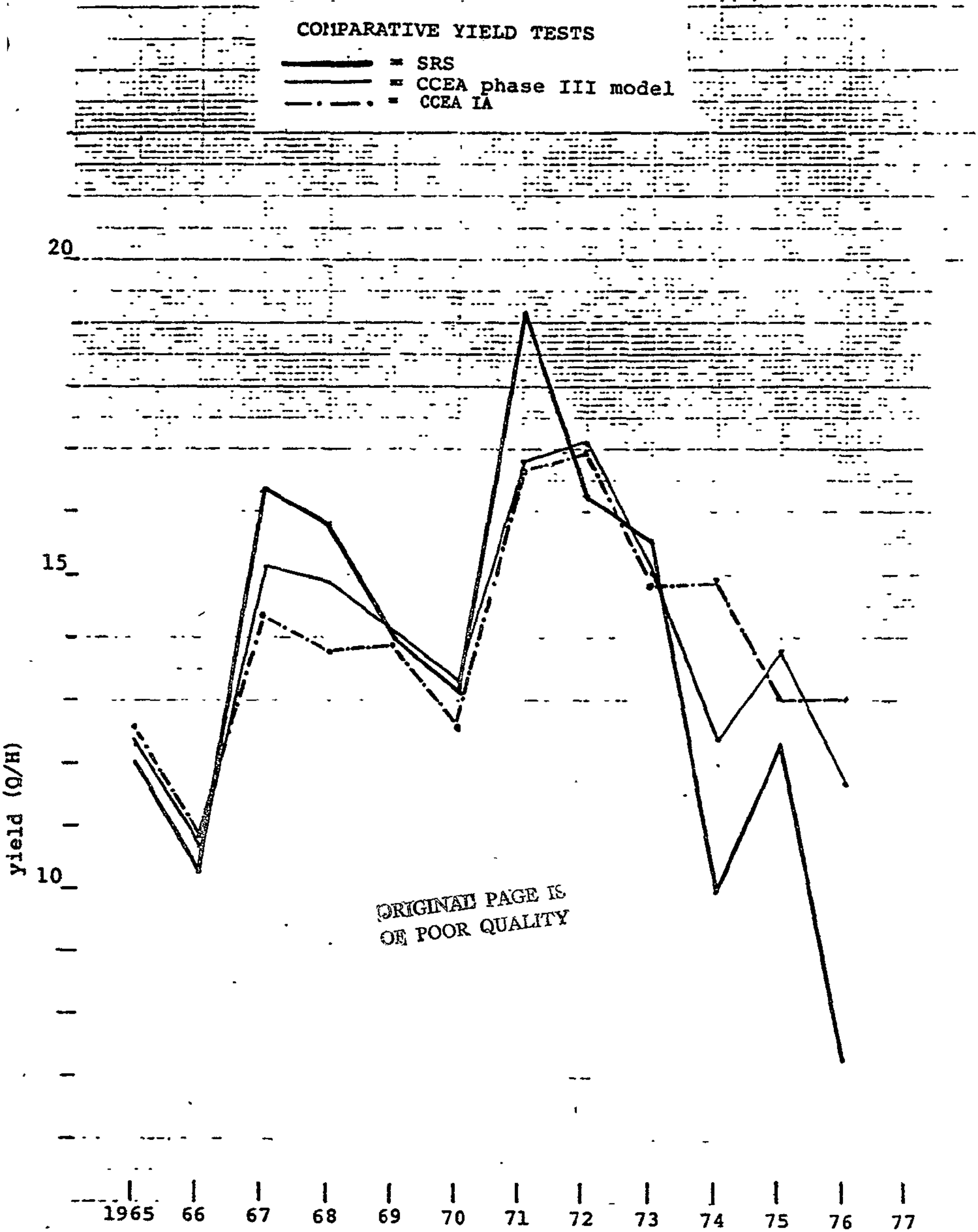
5. South Dakota spring wheat

As with the other spring wheat models, the first trend variable 1932-1955 was dropped, leaving only the 1955-1977 years for a linear trend. The variable June degree days was also eliminated and in its place the number of days above 90°F (32°C) was included in the candidate models. When these two changes were implemented and the other variables from the original model retained, the estimate of 1977 dropped to about 18 bushels. Attempts to add a May variable represented by May precipitation or May prec-PET revealed that statistically this month was not significant. The squared deviation from normal (SDFN) June precipitation also did not contribute to the improvement of the reduction in the yield variability. Furthermore, the preseason variable August to March showed poor correlation with yield. Various combinations led to September to November precipitation as the best indicator of preseason moisture. The interaction of September and June was made to reflect moisture at emergence and root development, while the period of June is associated with the critical heading stage in South Dakota. The interpretation of this variable showed low September precipitation with high June precipitation to have the same effect as a high September precipitation and low June precipitation. Unfortunately, the limitation of the operational computer program did not permit the assessment of interactions involving more than one month. The overall performance of the revised model, as viewed from the results of the 12-year test (Figure 10), suggests very little improvement, if any.

May variables such as May temperature, May precipitation, and May prec-PET were not included since the t-statistics showed a value of about

Figure 10

SOUTH DAKOTA SW



.33. Attempts to replace the April variable precipitation/PET with prec-PET or precipitation were unsuccessful since the original variable, the ratio of precipitation and PET, was more statistically significant.

Winter Wheat

Figure 11 shows the winter wheat modeled areas of the U.S. Great Plains. Ten areas are indicated: Montana (CRDs 20, 30, 50, 70, 80, and 90), Badlands (CRDs 40, 50, 70, and 80 for South Dakota and CRD 10 for Nebraska), Nebraska (CRDs 50, 60, 70, 80, and 90), Colorado (CRDs 20, 60, and 90), Kansas (all nine CRDs), Oklahoma (CRDs 20, 30, 40, 50, 60, and 70), Texas-Oklahoma Panhandle (CRD 10 for Oklahoma and CRDS 11 and 12 for Texas), Texas Low Plains (CRDs 21, 22, 30, and 40), Edwards Plateau (CRD 70), and Texas South Central (CRDs 81 and 82).

1. Badlands winter wheat

The Badlands winter wheat model covers four crop districts in South Dakota and one in Nebraska (see Figure 11). It is one of the more illusive areas with regard to associating monthly climatic data with yield. In many respects, it is similar to the eastern Colorado area where major problems are associated with winter damage from temperature and/or wind. Numerous variations of candidate models were attempted to capture this winter effect. For example, interactions of temperature and precipitation in January were attempted, but the results, based on the restrictions of data manipulation in the program, proved meaningless because of both positive and negative winter temperatures and the difficulty in interpretation of the interaction effects on yield. The effect of February temperature showed that the higher the temperature during the month, the lower the yield; however, in the

Winter Wheat Model Areas

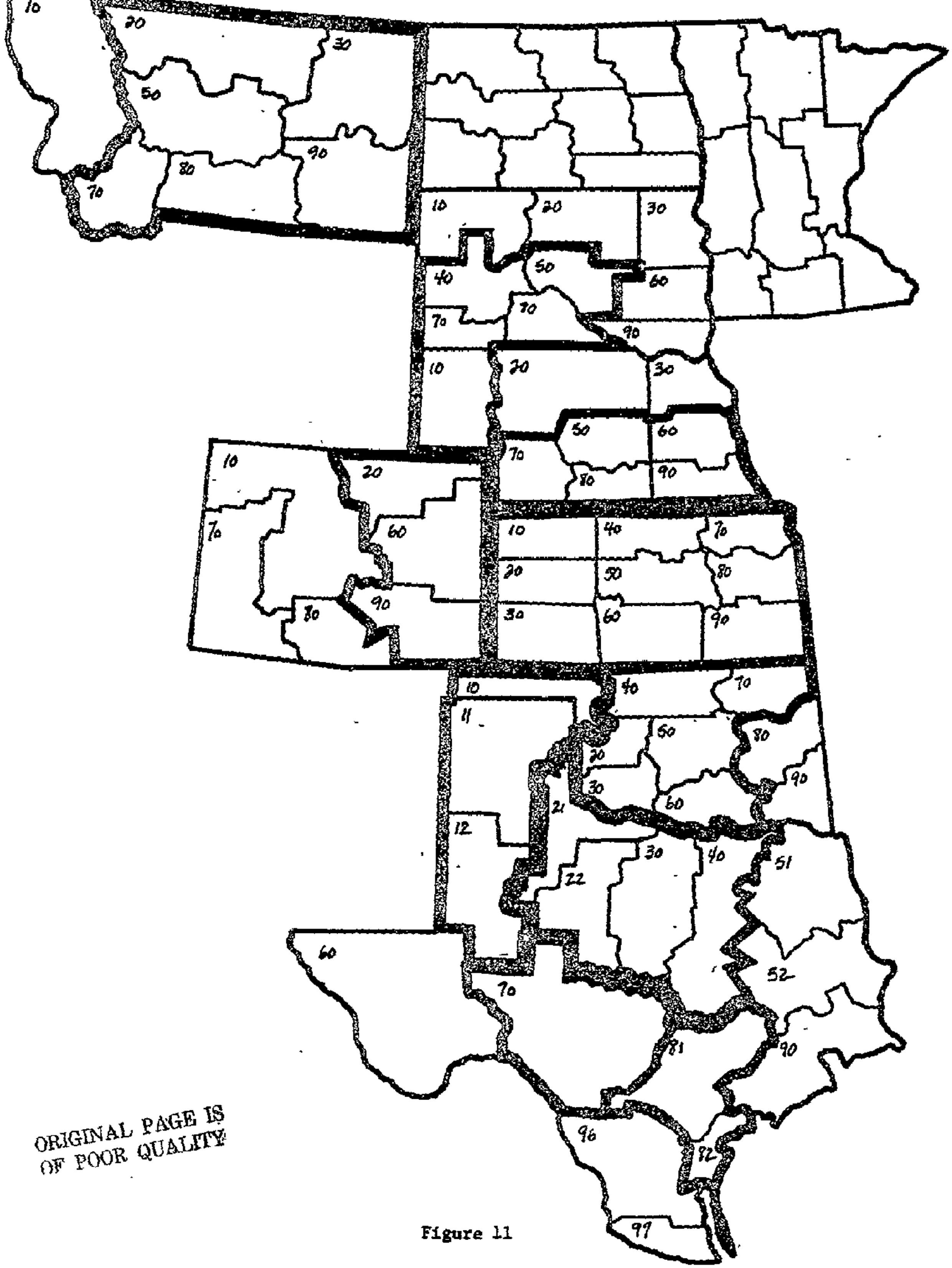


Figure 11

overall model, the deletion of a February variable did not measurably affect the remaining variables.

The squared departure from normal for June precipitation as a variable was not totally satisfactory in CCEA I. A linear positive coefficient, although not statistically significant, was retained for the revised CCEA IA model. June degree days were dropped as was its candidate replacement, the number of days above 90°F. The latter variable was not an improvement over June degree days. In addition, the model indicates that higher June precipitation leads to higher yield up to a point. This is consistent with the effects of excessive precipitation during heading. The July precipitation variable is associated with the ripening and harvesting effect where higher than normal precipitation can detract from yield.

One major difficulty in applying the least squares procedures for the Badlands in the model revision has been the failure of this procedure to capture the effects of the 1930's drought without having to begin a trend in those years. When an attempt was made to start and end the trend years other than the 1930's, the effects of the remaining variables that were known to be important were diminished. Therefore, the trend variables were retained in the revised model to include the 1932-1955 and 1955-1972 years.

A model which contained the trend years 1932-1947 and 1955-1972 was attempted with the same variables as those in the model included in Appendix B. Comparison of these two provided an estimated yield of 26.3 bushels with a trend 1932-1947 included in the model as compared with 24.7 bushels when the trend included the 1932-1955 period. Although the 26.2 bushels compares favorably with the 27.0 bushels for South Dakota winter wheat for

1977, the selected model provided slightly higher t-statistics for the selected variables (Appendix C).

One encouraging observation of the Badlands winter wheat model is yield estimates from the model have been dropping since about 1971-1972 in spite of the fact that trend was allowed to stabilize (Figure 12). This suggests that even this model is capturing the yield decline of the 1970's, although not in an entirely satisfactory direction.

Unusual years included 1974 and 1976, when light snow cover associated with very low temperatures reduced yield substantially. The effect seems much greater with a soil moisture shortage, as in 1976. With warmer winter temperatures and light snow cover, the wind effects may not be as detracting especially when soil moisture supply is adequate (<u>Weekly Weather and Crop Bulletin</u> for the years concerned).

2. <u>Colorado winter wheat</u>

Several changes were implemented in the original CCEA I Colorado winter wheat model. First, the 1932-1955 trend was eliminated. Second, the 1955-1972 trend was extended to the current forecast year. This was based on the analysis of the yield series with time as well as the indication that the use of nitrogen fertilizer and improved varieties has been on the upswing since that time. Nitrogen application rates decreased in 1973, 1974, and 1975 from 60 pounds per acre in 1972, but the rates in 1976 and 1977 have since reached the 55 to 60 pound range. The early dry 1970's have been partially responsible for this lower fertilizer application, although 1974 was a year of a fertilizer shortage throughout the nation. Under limited moisture conditions, fertilization may cause plants to deplete soil moisture to a critical level (Poostchi <u>et al.</u>, 1972). This may lead to a negative

COMPARATIVE YIELD TESTS, BADLANDS WW

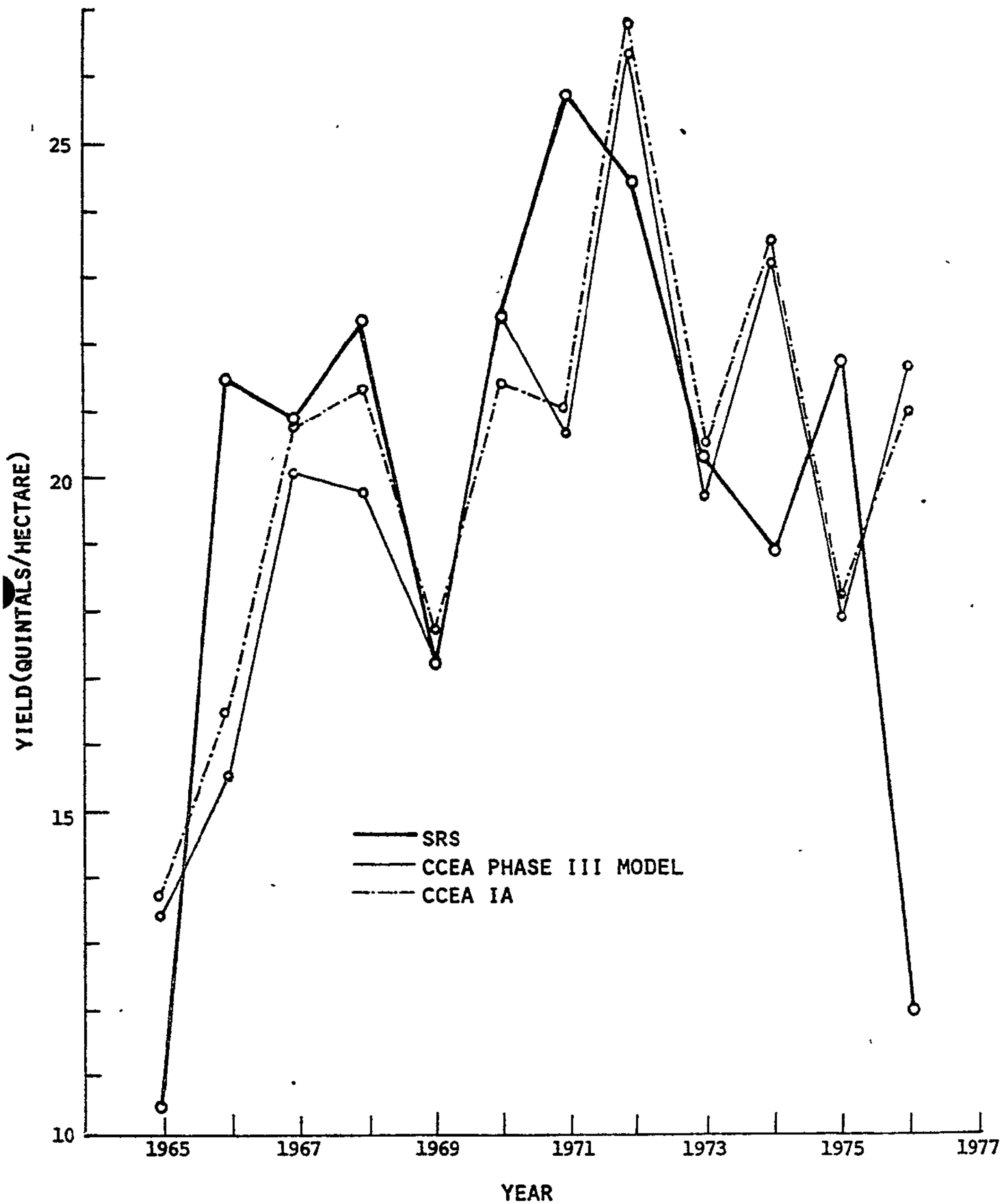


Figure 12

correlation between winter wheat grain yield and fertility level, as found by these scientists. Third, the preseason moisture term was changed from the August to March period to the October to February period. This period was selected after several trial combinations provided a stable and highly significant coefficient for this variable.

One of the major problems with winter wheat production in eastern Colorado is the potential damage due to winds, particularly during the early spring months of March and April. With limited snow cover, these winds can contribute to winterkill and cause abrasive damage of the tender tissues. With fall and winter moisture shortage, these strong early spring winds produce blowing dust. The dry, lighter soils can be blown across the field to produce damage to the wheat crop. The variable March precipitation times April precipitation, an interaction variable, was selected to provide an index for this yield reducing factor, the assumption being that added moisture during either or both of these months reduces the likelihood of this type of physical damage. The interaction of temperature and precipitation for March and April was considered. This variable was a problem in interpretation of the signs of the resulting coefficient; e.g., when the interaction value was negative because the temperature for the month was below 0°C. The limitation of the operational computer program precluded the derivation of only positive indices. Ideally, it would be desirable to obtain a positive coefficient sign. This did not develop in the case of March and the variable was dropped. The April prec-PET variable was replaced by the interaction of March and April precipitation, the intent being to include a March variable because of its apparent climatological significance with winter wheat in Colorado (Weekly Weather and Crop Bulletin).

Two years were characterized by episodic events, which included hail (1973) and freeze (1968) at critical growth periods. The year 1973 was subsequently excluded from the computation of the model coefficients.

Sakamoto (1978) had found in his wheat models for Australia that the Z-index appeared to provide a reasonable index of soil moisture in the semi-arid areas. However, based on computational difficulty of the Z-index, it was decided to simplify the procedure by obtaining the difference between evapotranspiration (ET) and the "climatically appropriate" evapotranspiration ($\hat{ET}$). Both ET and $\hat{ET}$ are products of the Z-index algorithm. After testing this variable for May and June, it was found that May ET-$\hat{ET}$ was a meangingful and significant variable for Colorado. The interpretation of this variable is that the larger the negative value of ET-$\hat{ET}$, the greater the moisture stress; i.e., moisture is insufficient to meet the average demand of the area. The candidate model that includes ET-$\hat{ET}$ is shown in Tables 2a and 2b; however, it has not been used operationally. In Figure 13 the 12-year test indicates that the model with the variable ET-$\hat{ET}$ for May may be slightly more sensitive to the yield fluctuations than with the model that includes May precipitation and the number of days greater than 32°C. This latter model needs to be monitored for its potential use in future years.

3. Kansas winter wheat

Starting with the trend variables, the trend 1932-1955 was eliminated in favor of the period 1943-1955. This was done after inspecting the data set (see Figure 14). Two factors entered into the decision to change this term. First, fertilizer production and application began to increase after World War II, and second, the drought of the 1930's would bias the meteorological effects by starting with the year 1932. The introduction of new hybrid varieties in the 1950's coupled with increased fertilizer use led to breaking

TABLE 2A

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78108

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 COLORADO (0008)
FOR TRUNCATION JULY

COLORADO WINTER WHEAT

THIS PREDICTION FOR WINTER WHEAT CROP YEAR 1977
BASED ON DATA THRU JULY 1976

VARIABLES USED IN THIS MODEL

VARIABLE	DEVIATION	VALUE	COEFFICIENT	CONTRIBUTION
OVERALL CONSTANT		1.00000	10.90110	10.90110
LINEAR TREND 1955-1978		23.00000	0.28730	6.60780
OCT-FEB PRECIP	(DFN)	-28.90140	0.07355	-2.12563
MAY ET-ETHAT		11.55316	0.05675	0.65564
JUNE PRECIP DFN	(DFN)	-15.10246	0.02236	-0.33770
JUNE PRECIP SDFN	(SDFN)	228.08438	-0.00080	-0.18321
JULY TEMP DFN	(DFN)	0.25824	-0.82714	-0.21360

YIELD IN QUINTALS PER HECTARE 15.3
YIELD IN BUSHELS PER ACRE 22.8
PERCENT DEVIATION FROM A TREND YIELD OF 14.5 IS 5.55%

R SQUARED 0.81647
STANDARD ERROR 1.79375 QUINTALS/HECTARE
STANDARD VARIANCE 3.21754 QUINTALS/HECTARE SQUARED
STANDARD DEVIATION OF YIELDS 3.88392 QUINTALS/HECTARE

VARIANCE OF PREDICTION 0.85502 QUINTALS/HECTARE SQUARED
VARIANCE OF PREDICTION 1.89062 BUSHELS/ACRE SQUARED
PREDICTION ERROR SQUARED 4.07256 QUINTALS/HECTARE SQUARED
PREDICTION ERROR SQUARED 9.00523 BUSHELS/ACRE SQUARED

		------- RESULT 1 -------			------- RESULT 2 -------			
------- VARIABLE NAME -------	NORMALS	ACTUAL	CENSORED	%	ACTUAL	CENSORED	%	AC
OVERALL CONSTANT	1.000	1.0000	0.0000	0	0.0000	0.0000	0	0.(
LINEAR TREND 1955-1978	22.000	23.0000	0.0000	0	0.0000	0.0000	0	0.(
OCT-FEB PRECIP	72.935	44.0336	0.0000	0	0.0000	0.0000	0	0.(
MAY ET-ETHAT	0.000	82.0053	0.0000	0	70.4522	0.0000	0	11.
JUNE PRECIP DFN	51.821	36.7183	0.0000	0	0.0000	0.0000	0	0.(
JUNE PRECIP SDFN	51.821	36.7183	0.0000	0	0.0000	0.0000	0	0.(
JULY TEMP DFN	22.088	22.3465	0.0000	0	0.0000	0.0000	0	0.(

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 2B

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78108

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 COLORADO (0008)
FOR TRUNCATION JULY

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	529.64453	7	75.66350	23.51790	0.00000013
RESIDUAL	119.03906	37	3.21727		
TOTALS	6974.31250	44	158.50710		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	37	26.67351	0.00000000	10.90110
LINEAR TREND 1955-1978	37	6.76375	0.00000486	0.28730
OCT-FEB PRECIP	37	6.66733	0.00000553	0.07355
MAY ET-ETHAT	37	3.13133	0.00378217	0.05675
JUNE PRECIP DFN	37	1.67933	0.09945667	0.02236
JUNE PRECIP SDFN	37	-2.86607	0.00704455	-0.00080
JULY TEMP DFN	37	-2.64678	0.01179366	-0.82714

R SQUARED	0.81647
ADJUSTED R SQUARE	0.78670
STANDARD ERROR	1.79375
STANDARD DEVITATION OF YIELDS	3.88392

ORIGINAL PAGE IS OF POOR QUALITY

COMPARATIVE YIELD TESTS, COLORADO WW

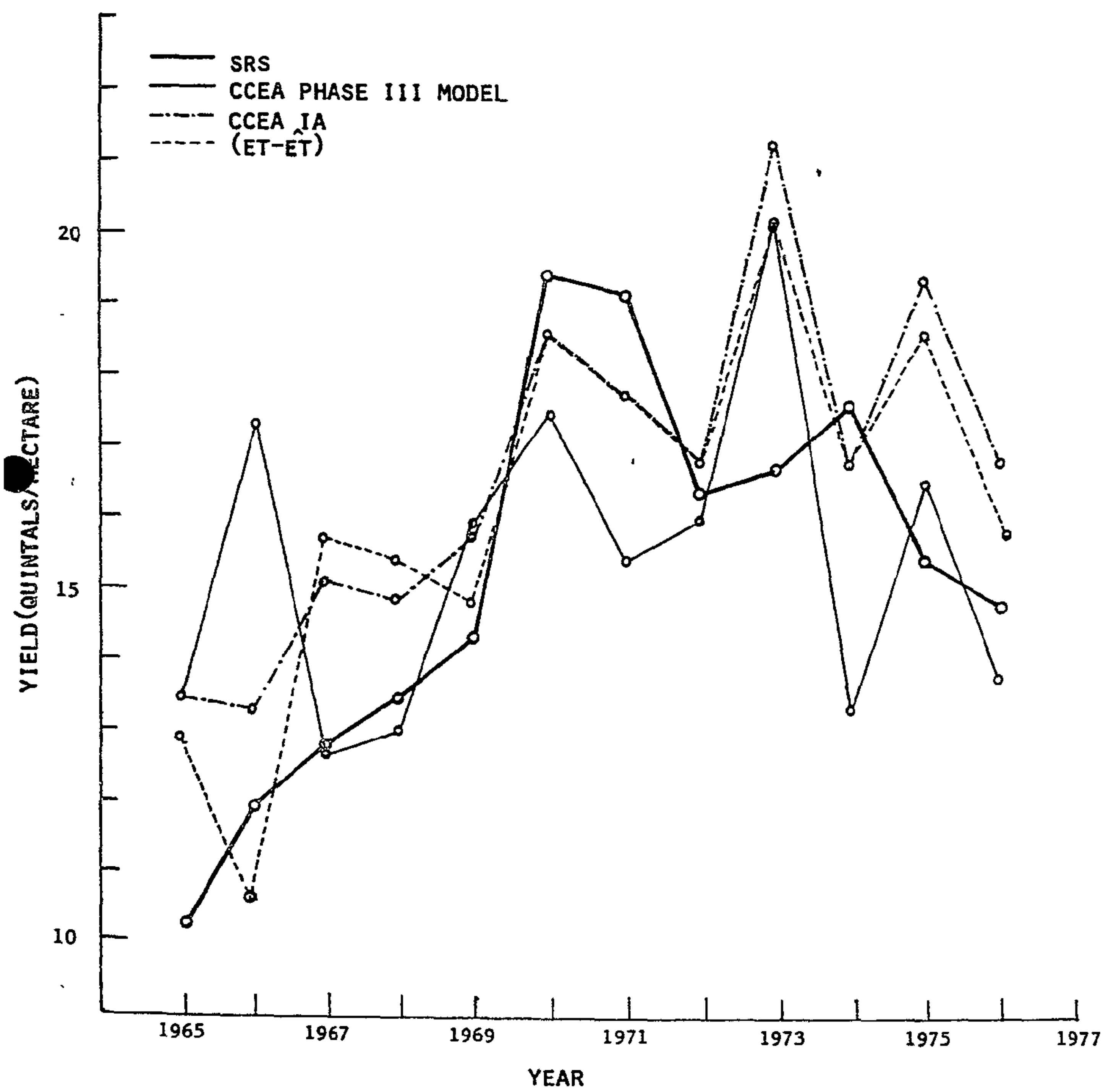
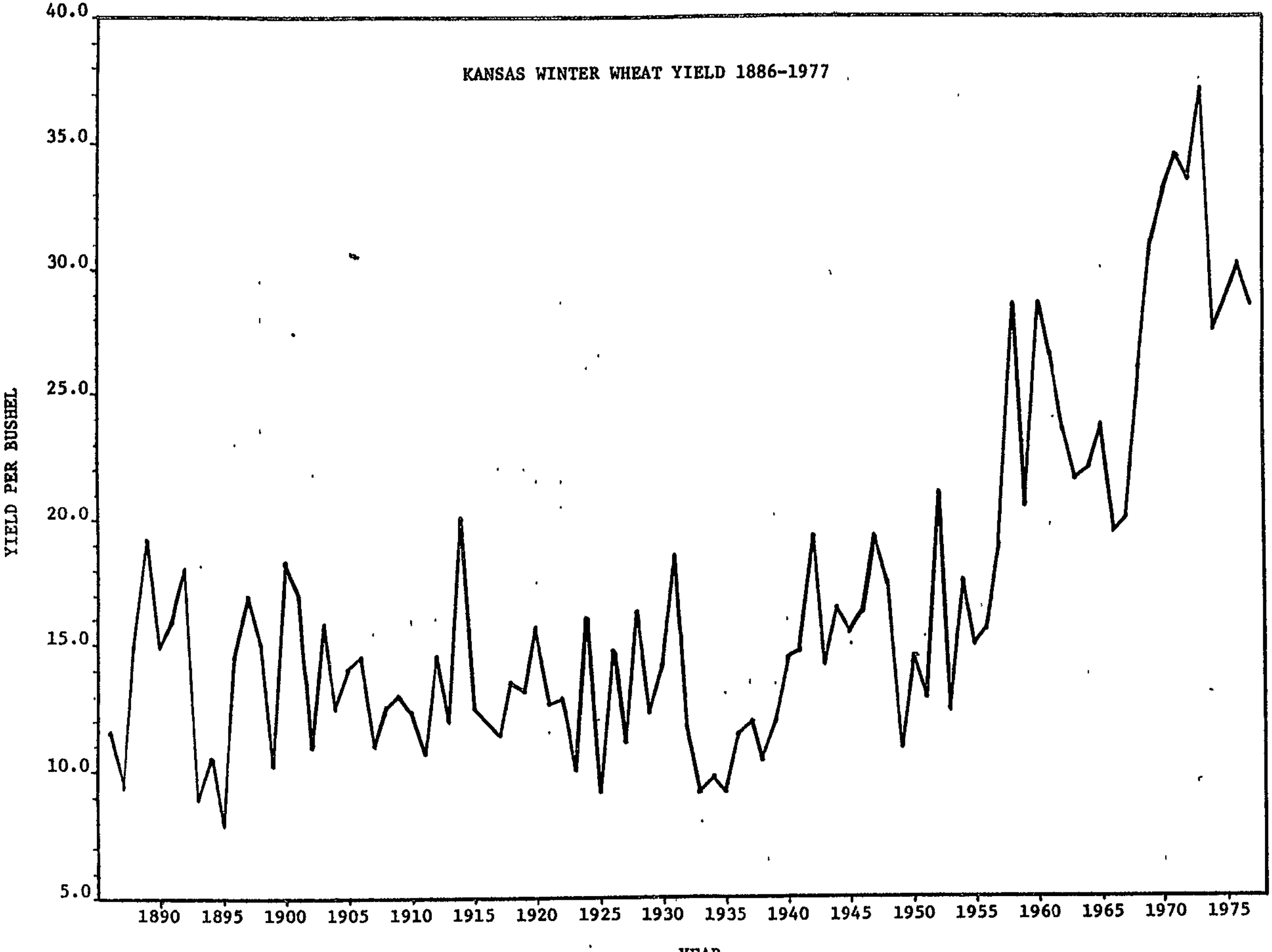


Figure 13


KANSAS WINTER WHEAT YIELD 1886-1977
YIELD PER BUSHEL
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
1890
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
YEAR
Figure 14

the trend at 1955. Stabilizing trend after 1972 is also in accord with stabilizing of nitrogen fertilizer use since about 1969 to 50 pounds per acre (Figure 15). Phosphorous as well as potassium applications have also remained relatively stable since 1969. The Kansas Crop and Livestock Reporting Service (The Kansas City Star, March 19, 1978) reported that for 1978 the new wheat variety Eagle (23 percent) has replaced Scout (20 percent) as the leading hard red winter wheat in Kansas, followed by Sage (14 percent) and Centurk (10 percent). In northwest Kansas, about a third of the area was planted to Eagle in the winter of 1977. In addition, planted acreage was reported 13 percent below that of the 1977 crop (Kansas Crop and Livestock, 1978). This change suggests the possibility of increasing trend in 1978.

Another variable in the CCEA I model that was changed was the preseason moisture variable, August to February precipitation. The August to November precipitation was included because the non-snow precipitation contributes more to the recharge of the soil profile. In the case of Kansas, August to February was considered too lengthy a period. Finally, the t-statistics for the August to November variable were 4.54 versus 2.03 for the months of August through February.

April temperature was tried, but this variable did not contribute to the increased precision of the model. Similarly, the squared deviation from normal March prec-PET did not reduce the standard error nor increase the coefficient of determination.

In the original CCEA I model, the May precipitation effect was indicated by only the squared deviation from normal. In the revised CCEA IA, the variable for the month has been indicated by a linear and quadratic effect,

RATE OF FERTILIZER APPLICATION FOR WHEAT

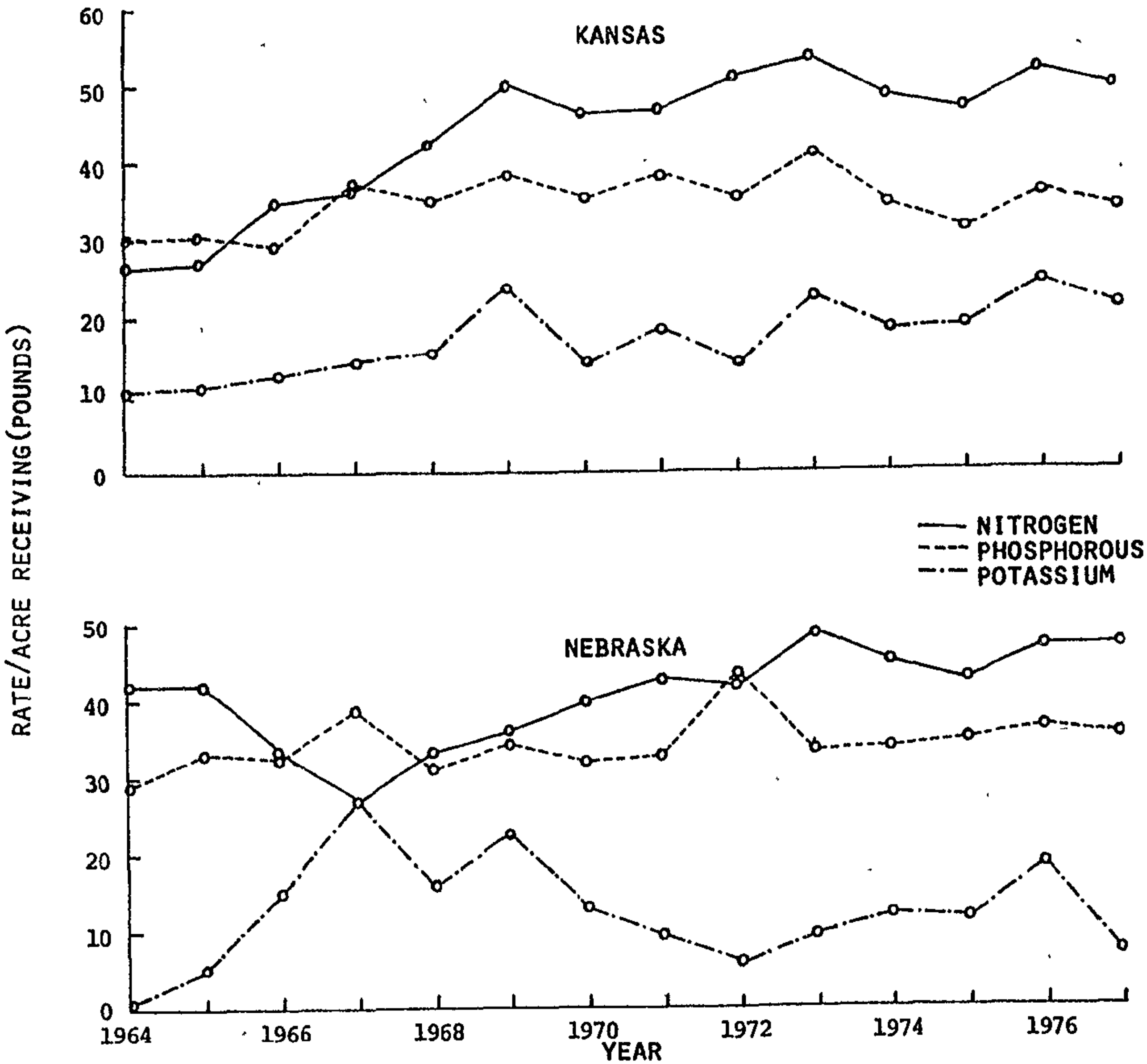


Figure 15

prec-PET. Both coefficients are negative, which is interpreted to mean that as precipitation exceeds potential evapotranspiration, the rate of decline accelerates. The model, of course, is limited by the range of the data set and should not be extended beyond these data. The variable number of days above 90°F was significantly better than the use of the "degree day" variable.

In terms of episodic events, the years 1966 (freeze at heading) and 1973 (rust) were dropped from the calculation. The results of the 12-year test (Figure 16) indicate that the difference between the two (CCEA versus CCEA IA) is small; however, agronomically it is easier to explain the sign of the coefficient of the variables in CCEA IA than in CCEA I.

4. Montana winter wheat

The CCEA IA model for Montana winter wheat (Appendix B) consists of six variables compared with nine in the original model. However, based on the 12-year test, it is apparent that the revised model is better able to capture the fluctuations of the observed yield, particularly in 1974, 1975, and 1976 (see Figure 17). In 1977, the estimated yield from the new model was calculated as 26.5 bushels compared to the Statistical Reporting Service estimate of 28.0 bushels. The major changes in the revised model involved deleting the 1932-1955 trend and 1955-1972 trend and replacing these with a trend 1943-1977. This is to reflect the gradual increase in yield since that time in association with a gradual increase in fertilizer use since post World War II (see Figure 18).

One criticism of the original model involved the use of the square of the April prec-PET deviation from normal term only. To alleviate this situation, the precipitation effect in April was included as a fall-winter-

Figure 16

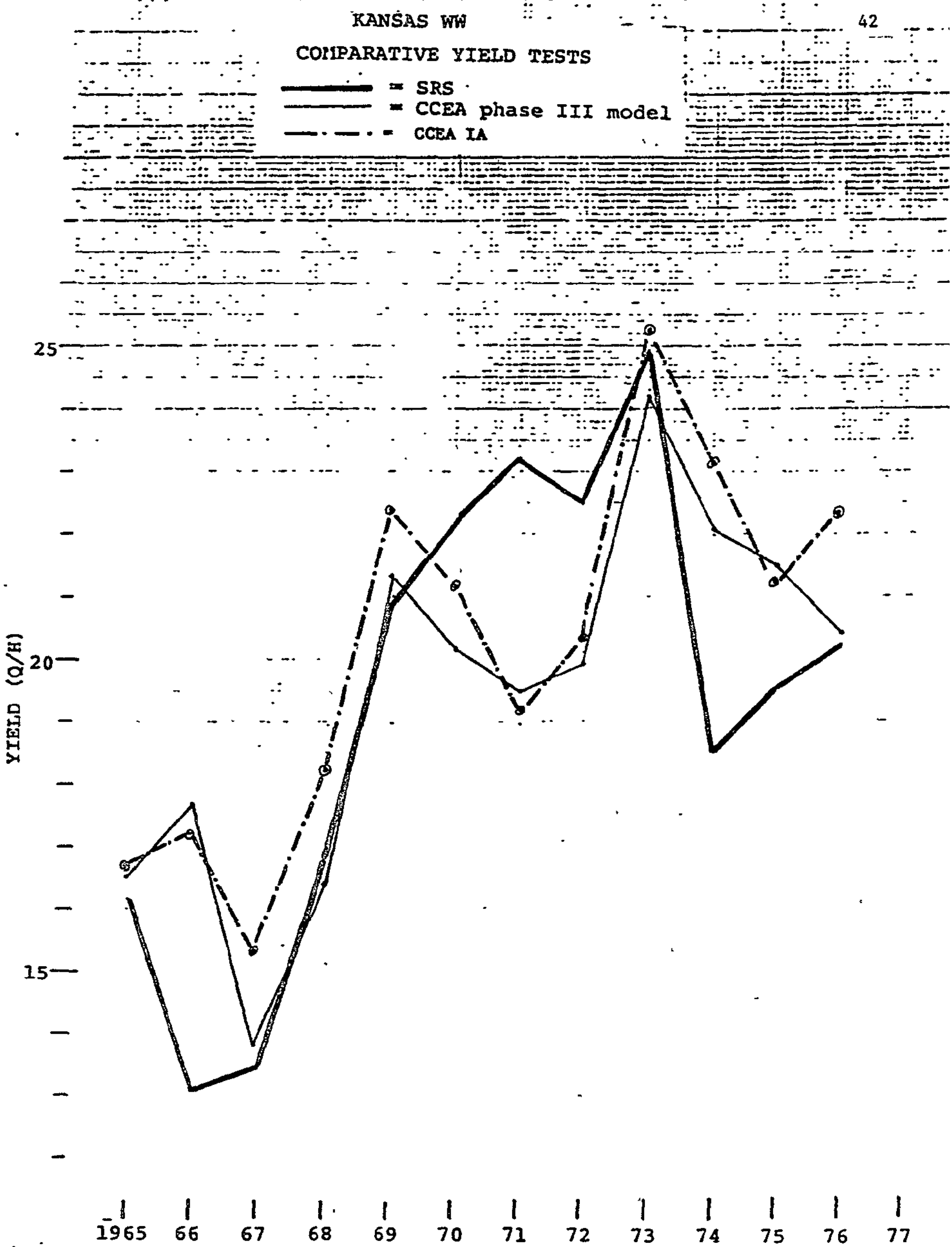
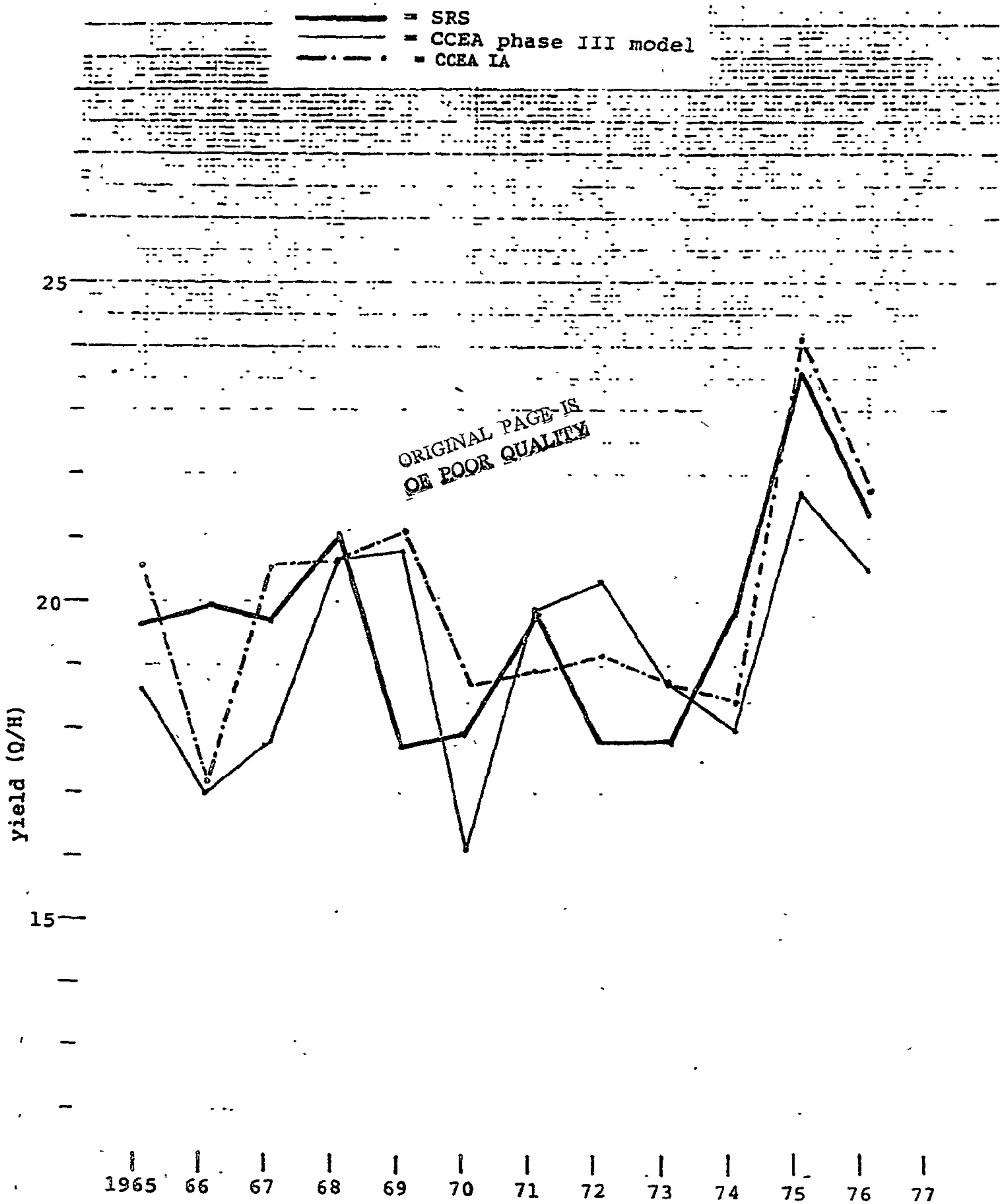

KANSAS WW
COMPARATIVE YIELD TESTS
= SRS
= CCEA phase III model
CCEA IA
YIELD (Q/H)
25
20
15
1965
66
67
68
69
70
71
72
73
74
75
76
77

Figure 17

MONTANA WW

COMPARATIVE YIELD TESTS



RATE OF FERTILIZER APPLICATION FOR WHEAT

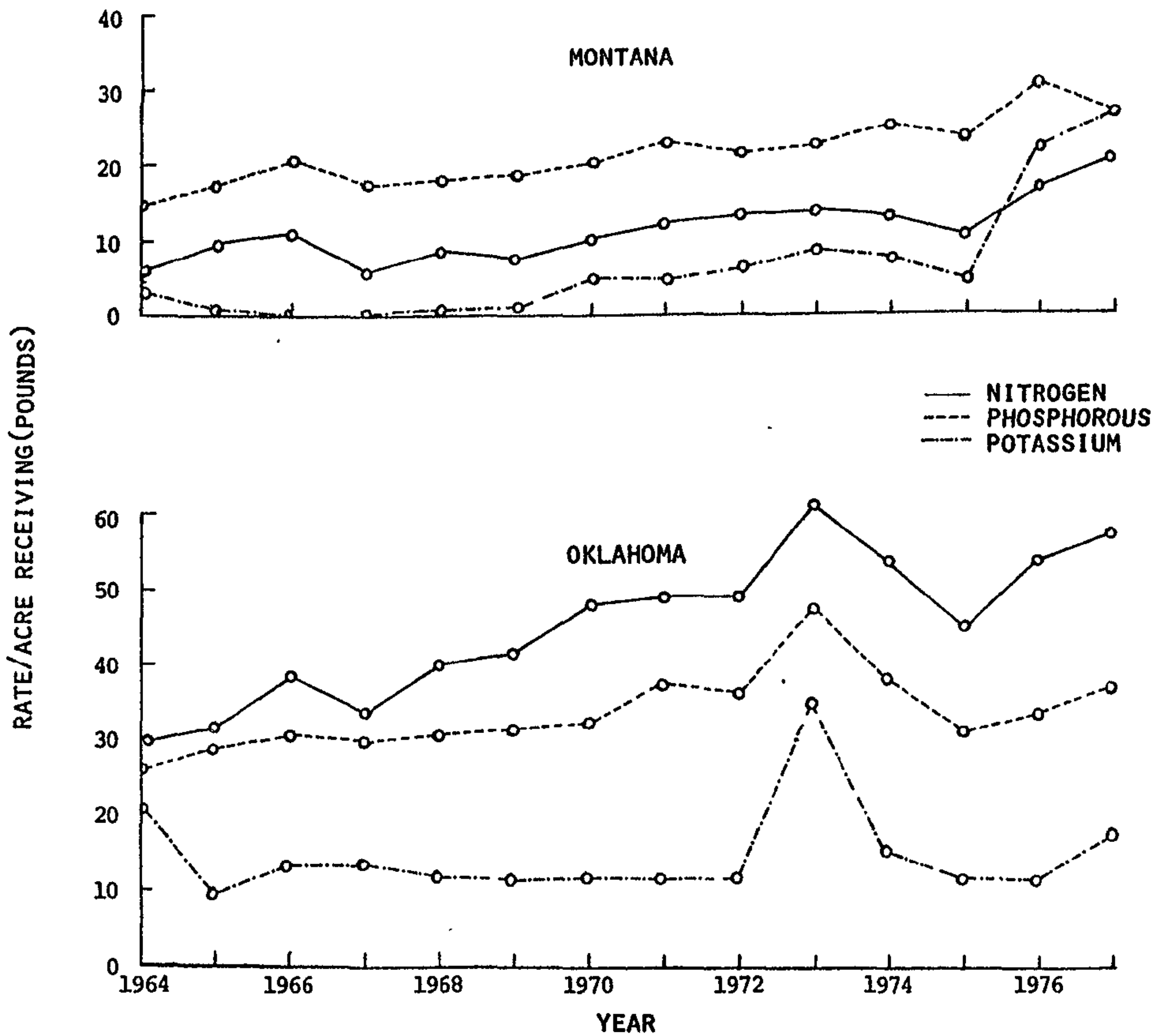


Figure 18

spring precipitation moisture index. It was also believed that the detrimental effect of moisture during this period would occur primarily at planting time; consequently, the quadratic term was eliminated. Furthermore, the quadratic term was not strong enough statistically to warrant retaining this variable.

Instead of using a 1943-1977 trend, the period 1955-1977 was attempted. The analysis pointed to a much lower coefficient of determination ($R^2 = .73$) and a larger standard error ($s = 2.34$). These suggest that this trend 1955-1977 was a misspecification of the variable and that larger variability, possibly due to climatic variability, was accounted for by the variables. By changing the trend from 1955-1977 to 1943-1977, the R^2 increased to .82 (Appendix B).

5. Nebraska winter wheat

Four major questions were associated with the first generation CCEA I Nebraska model. First, as with other models in the U.S. Great Plains, the question was whether the two trends, 1932-1955 and 1955-1972, should remain in the revised model. Second, in CCEA I, moisture for only the month of October was included as a variable to reflect moisture supply at planting. Should the other fall months, September and November, be included? Third, it is difficult to interpret the squared ratio of April precipitation and potential evapotranspiration, and fourth, the discontinuous variable June degree days above 90°F should be replaced with a continuous variable, number of days above 90°F (32°C).

With respect to the trend terms, several other candidate trends were considered: 1943-1955 and 1955-1977 as two separate variables in a model, and 1932-1955 and 1955-1977 also as two separate variables in a model.

Other trends included 1943-1977 and 1955-1977 in different runs of the model.

In terms of the contribution to the final yield, the model with the trends 1943-1955 together with 1955-1977, and the model with trends 1932-1955 together with 1955-1977, contributed identical amounts, 25.3 bushels to the 1977 estimate when the other meteorological variables remain the same. However, the model with trend beginning in 1943 provided an R^2 of .865 and a standard error of 2.39 quintals/hectare as compared with an R^2 of .884. The difference between the two in the 12-year "bootstrap" test is a slight increase of the estimated yield from 1972 through 1977 for the model with trend 1943-1955 and 1955-1977.

In the 12-year test, the model with trend ending in 1972 seemed to have estimated the "observed" yield much better than the extension of the trend through 1977 (Figure 19). The difference in the 1977 estimate was 2 bushels. However, a tentative selection for the model with trend through 1977 was made. It is possible that the dry 1976 year combined with 1976 and 1977 fertilizer had a delayed and additive effect with yield response. As with other yield models, the trend effects need to be reevaluated each year.

Since fall moisture contribution is important to root development and moisture reserve, a longer period, September through November, was considered a more realistic period to include in the model rather than the single month of October. As seen in the Appendix, the September through November precipitation contribution is highly significant.

The t-statistics for ratio precipitation/PET as well as the variable prec-PET were not sufficiently high to retain. These were t = -0.632 and

COMPARATIVE YIELD TESTS, NEBRASKA WW

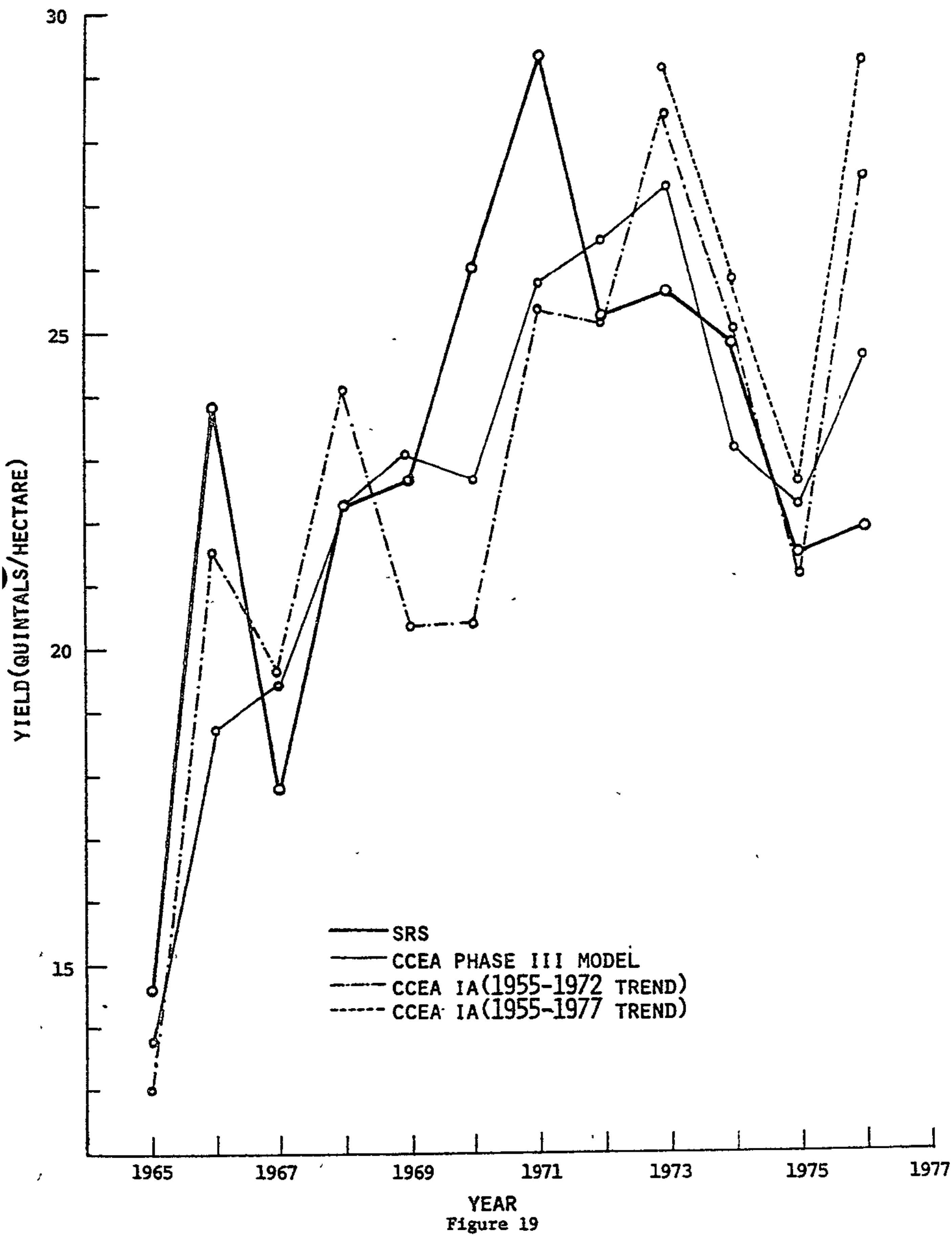


Figure 19

t = -0.614, respectively. The May precipitation, however, came in very strong (t = -2.11) and was retained. This variable is not in the CCEA I model and indicates that excessive precipitation over normal in May during the period of jointing to heading stages is detrimental to yield. Further, very high temperatures during this period are also not conducive to high yields.

Another climatic problem with regard to winter wheat production in Nebraska is related to the snow cover. When snow cover is short, low temperatures and high winds can produce desiccation with subsequent "leaf burn" and reduction in yield. Poor yields in 1967 and 1976 were associated with low snow cover and wind conditions. On the other hand, in 1966, 1970, and 1971, favorable precipitation in the winter months of January, February, and March contributed to the high yields for these years. Consequently, a variable total precipitation for January through March was added, but its statistical significance was very poor (t = 0.231). These were separated into January to February and March precipitation. March precipitation did not show indications of its effectiveness. January and February precipitation showed a weak positive association with yield; however, January to February temperature departure from normal showed a stronger, but negative, coefficient. This is interpreted to mean that higher than normal temperature is conducive to snowmelt, hence poor snow cover and potential exposure of the crop to subsequent hazards.

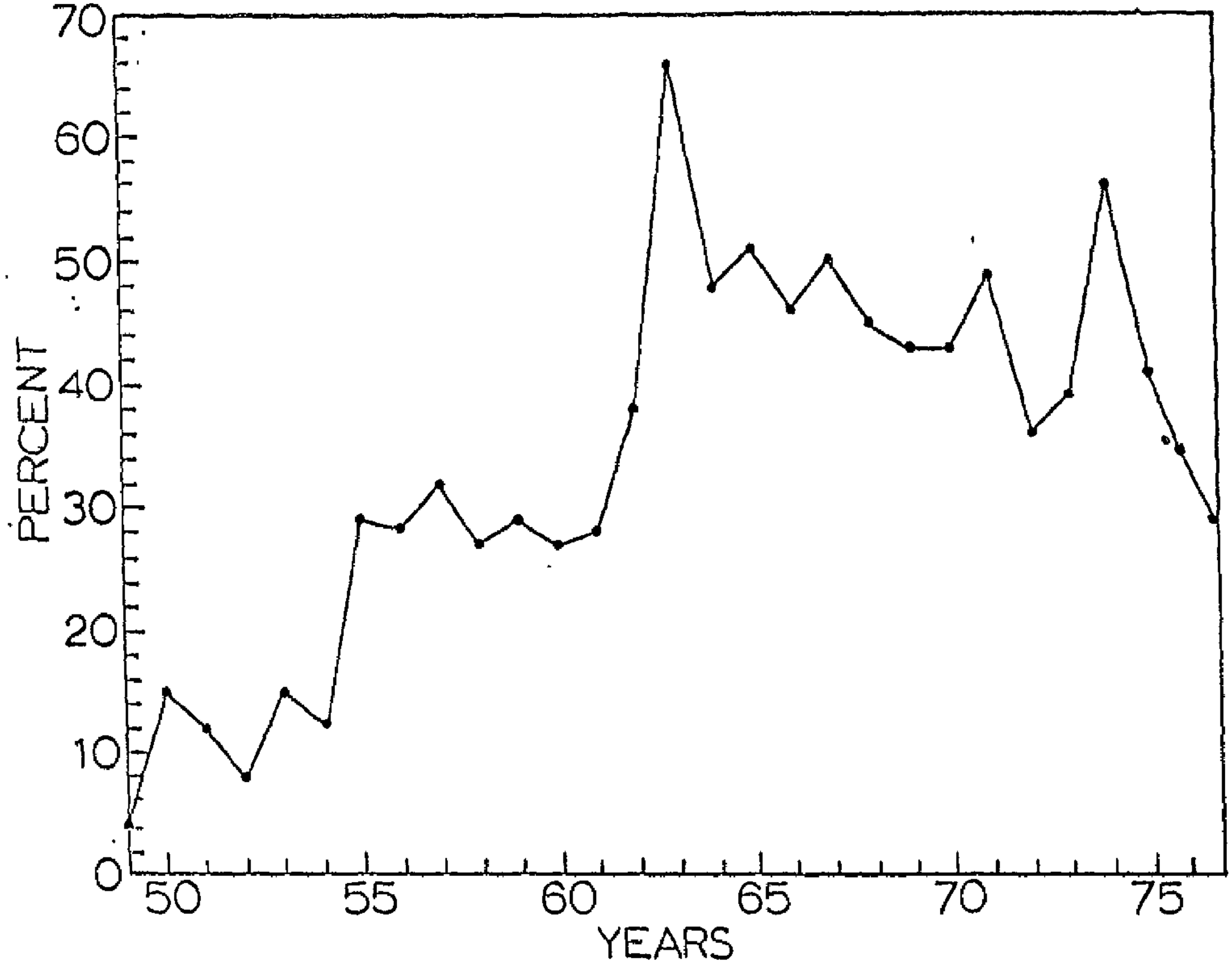
The inclusion of April precipitation as a departure from normal and squared departure from normal as well as prec-PET was not successful as neither of these variables showed to be critical in the model.

In the case of May, both temperature and precipitation show negative influence. This is reasonable as excessive precipitation and high temperatures, particularly at jointing to heading phases, can be detrimental to yield. Average heading dates in southern Nebraska are from late May to mid-June. The variables for June, both precipitation and number of days greater than 90°F (32°C), are also important heading period factors.

6. Oklahoma winter wheat

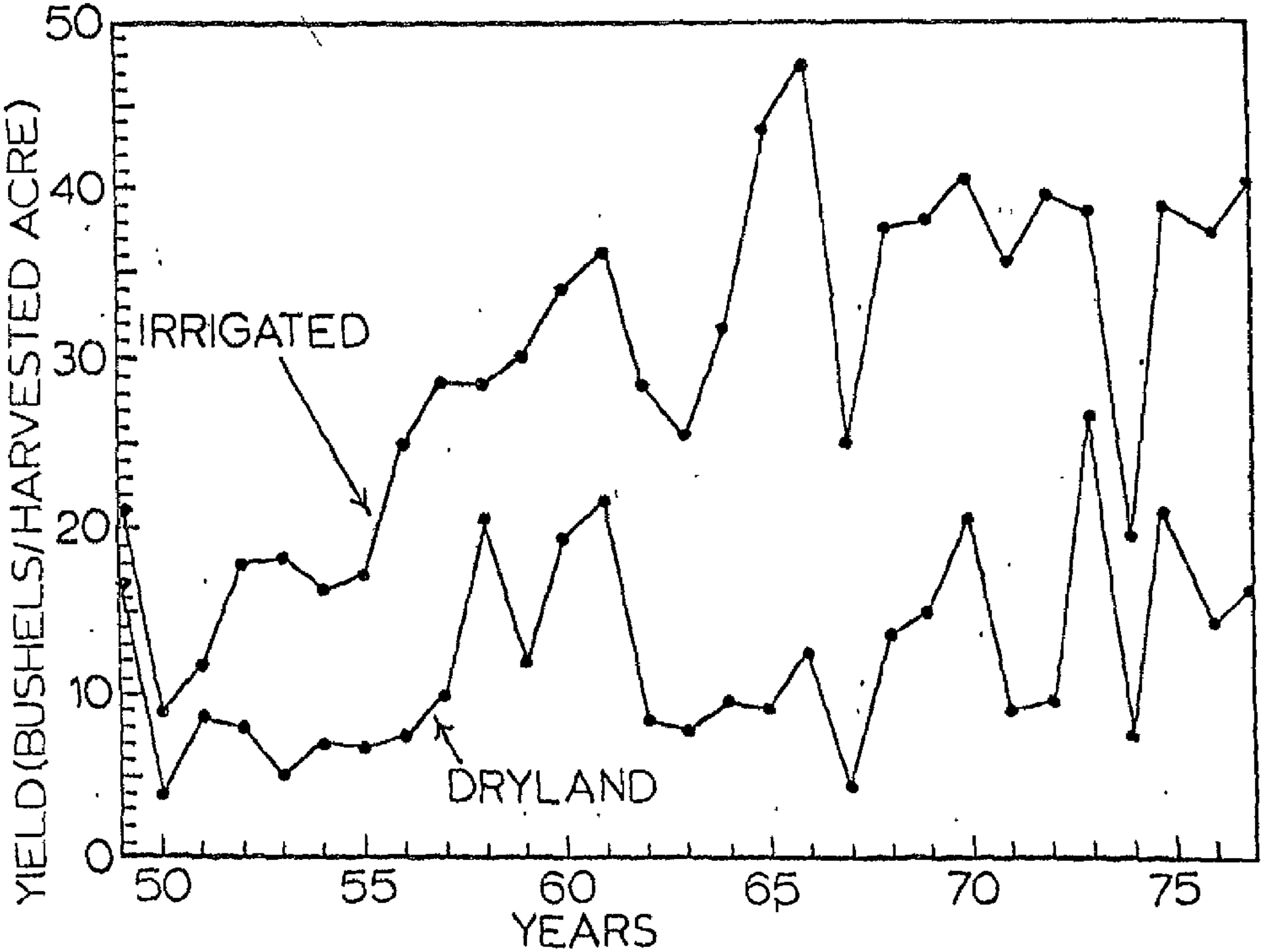
A major issue concerned with the Oklahoma wheat model, as with other areas, is the specification of trend. Other than weather, two of the major factors that affect yield in that area are irrigation and fertilizer application. Figure 18 shows the application rate of fertilizer for Oklahoma in recent years. The data show that fertilizer rates increased steadily up to about 1973, but have decreased since. If one uses crop district 1-N in Texas as an indicator of the irrigation activity in the Oklahoma Panhandle, it is observed that the percent of harvested acreage has been decreasing since 1963 from a level of 66 percent to about 30 percent in 1977 (Figure 20). Irrigated, as well as dry land yield, has also been stabilized since about 1965 (Figure 21). Visual inspection of the yield data series for Oklahoma also suggests that the trend of yield since the 1960's has remained fairly stable. In fact, if one considers a trend from 1962-1973 or 1962-1976, the coefficient for this second trend becomes negative. Consequently, the 1943-1962 period was the only trend term included in the model. The question of where trend should terminate, in 1960 or 1972, is one that could be argued with no solution when this statistical approach is used to define technology changes.

The variable January-February precipitation was separated from the September-December precipitation to serve as an indicator of whether the wheat fields will be put to pasture. During these two months, grazing of livestocks in wheat fields becomes an important activity. When fields are too muddy,



Percent of harvested acres of all wheat that were irrigated in Crop Reporting District 1-N of Texas since 1949. USDA-SRS data. (After Bond and Umberger, 1978)

Figure 20



Yield of irrigated and dryland wheat in Crop Reporting District 1-N of Texas since 1949. (Yields are an average for seven counties: Briscoe, Castro, Deaf Smith, Floyd, Hale, Parmer, and Swisher.) USDA-SRS data. (After Bond and Umberger, 1978)

Figure 21

this activity is limited. This in turn minimizes the potential damage of the crop by livestock and permits the crop to better respond to the favorable moisture condition. A review of the Weekly Weather and Crop Bulletin indicated that 1960, 1965, and 1973 were very wet and that limited grazing activity took place during January and February.

The possibility of extending yield trend from 1943 to 1973 was considered, and based on this trend the estimate for 1977 was 21.7 bushels per acre; however, the model in Appendix B was selected since very little difference was discernible between the models. Extending trend from 1943 to 1977 and using the identical remaining variables as in Appendix B produced a yield estimate of 23.0 bushels for 1977. In this case, however, the coefficient of determination was reduced to 82 percent with a corresponding increase in the standard error.

The average January and February temperature departure from normal was also attempted in lieu of January-February precipitation departure from normal. The coefficient sign was negative, which is reasonable; however, the statistical significance was not sufficient to retain this variable.

In 1977 timely precipitation in May led to favorable yields which the CCEA I model was not able to estimate adequately. In both CCEA I and CCEA IA, May precipitation was highly correlated negatively with yield. It is suggested that climatologically, the rains in May occur chiefly as thundershowers and the associated strong winds may produce lodging. In 1977 it is also possible that the sequence of weather associated with the critical heading and maturation period may have been ideal and that the absence of a crop calendar and the use of monthly data in the model may not have been able to capture these events adequately. Another plausible theory includes that of selective harvesting of irrigated wheat combined with the lag effect of residual fertilizer from the previous year. This lag effect needs to be investigated in future modeling efforts.

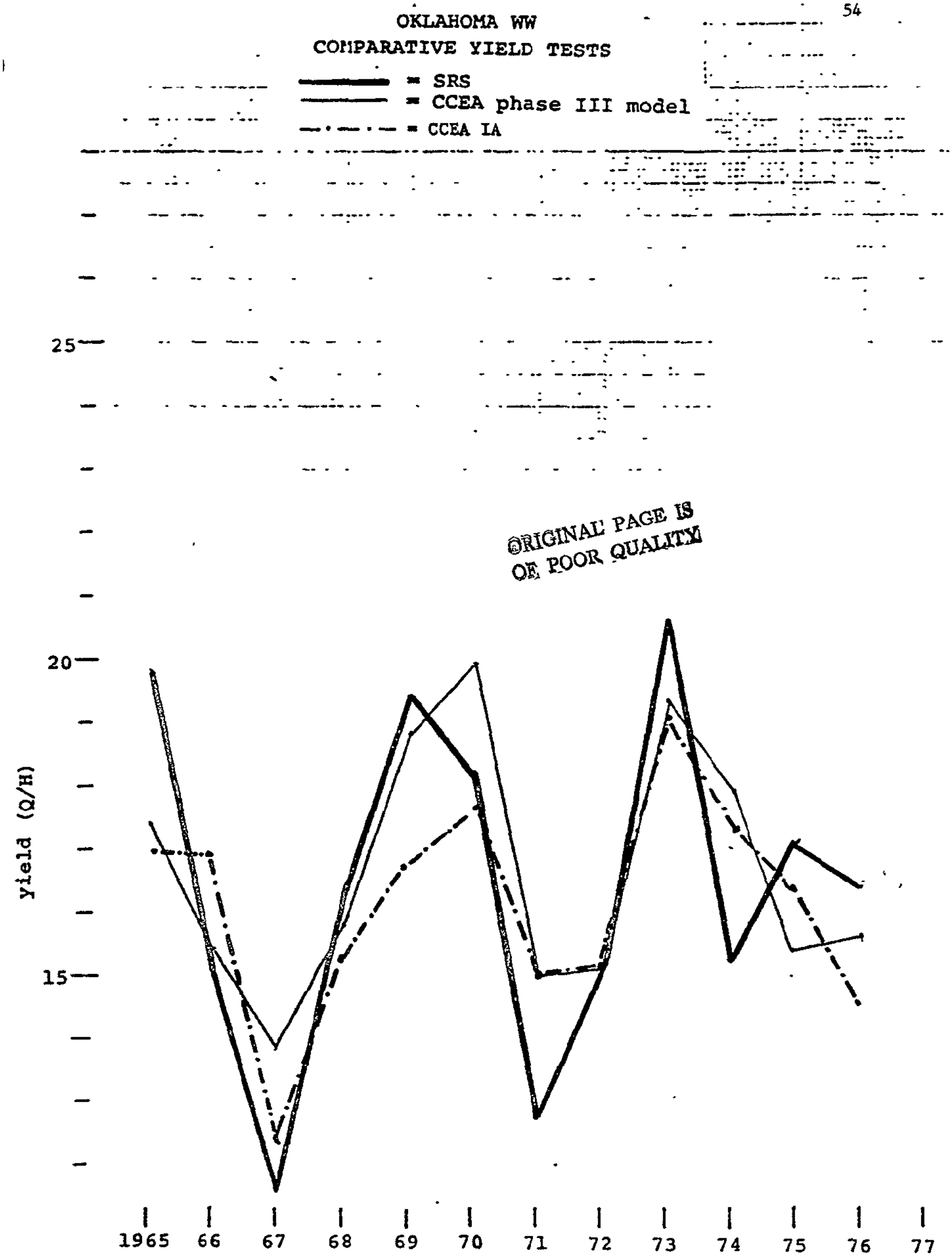
The 12-year "bootstrap" test of the selected model is shown in Figure 22.

7. Texas-Oklahoma Panhandle winter wheat

The yield data series for this area suggest two distinct samples: one for the period prior to about 1957 and the other for the period since 1958. For example see Figure 23 which shows the Texas winter wheat yield series for the period 1866-1977. One approach used to assess the contribution of the variables in recent years was to build a model on the sample period after 1958 where no trend is apparent with the understanding that differential responses with varietal changes may also be involved. With this procedure, it was found that the ratio precipitation/PET as well as the August to February precipitation were not effective nor stable. The precipitation for the September-February period was attempted, but statistically it was also weak. Variables that were tested to show the detrimental effects of warm winter temperature included December and January temperature and February temperature. In the end, the combined January-February temperature showed its greatest effect with yield. It is suggested that higher temperatures may be associated with potential disease problems involved with warmer and moist air flow from the Gulf of Mexico. The impact of higher than normal rainfall on yield during this period may also be associated with grazing limitation when livestocks are removed from the muddy wheat fields.

The inclusion of June precipitation is to reflect maturation and harvesting effects associated with thunderstorm activity and/or strong winds which can shatter maturing grains or lodge the plants.

Figure 22


OKLAHOMA WW
COMPARATIVE YIELD TESTS
= SRS
= CCEA phase III model
= CCEA IA
25
20
15
yield (Q/H)
1965
66
67
68
69
70
71
72
73
74
75
76
77

TEXAS WINTER WHEAT

YIELD 1866-1977

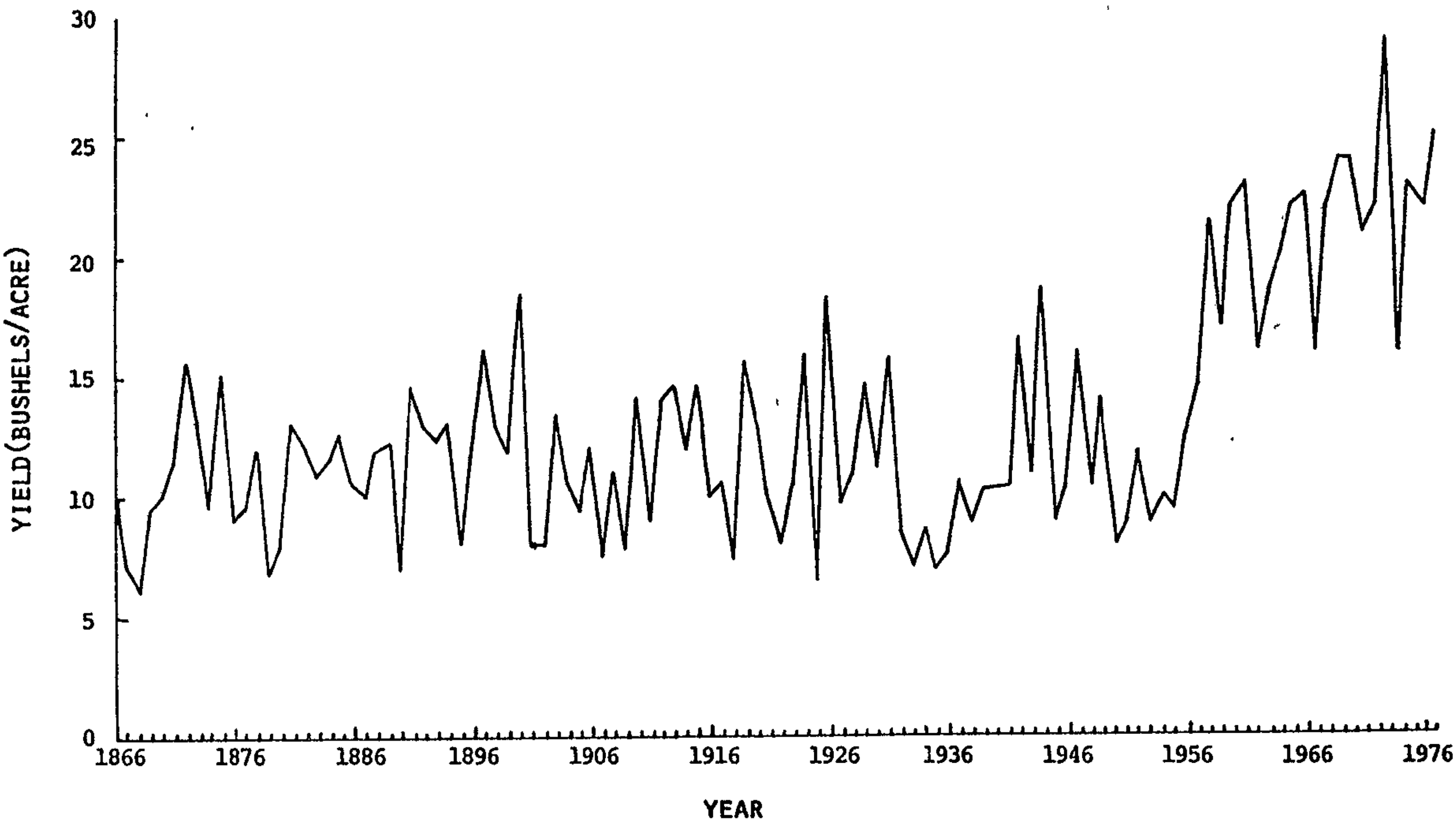


Figure 23

Examination of the Texas yield data series as well as the irrigation and fertilizer information indicates that whereas fertilizer application rates had increased from 1965 to 1973 and had since decreased (Figure 24), the percent irrigation of harvested acreage has been on the downward path since 1968 (Figure 25). In 1977, slightly over 20 percent of the harvested acreage was irrigated as compared to a high of 35 percent in 1971. The question as to when a linear trend should begin or end is controversial, and as previously discussed is guided by the reasonable degree of expression of the weather variables after trial attempts with the years. The 1932-1955 period was omitted because this variable would have biased the drought of the 1930's. The year 1957 was omitted because of rust and lodging problems associated with excessive precipitation.

A third trend from 1961 through 1977 was attempted, but discarded. In addition, a trend of 1943 through 1977 was also tried. It provided an estimate of 25.7 bushels for 1977, but led to a lower R^2 of 82 percent and a higher standard error of 2.05 quintals.

In the original CCEA I model, a May precipitation variable was included as a detrimental effect on yield. This is attributed to the damaging effect of above normal precipitation and winds associated with thunderstorms during this period. May precipitation was not as highly related to yield as the number of days above 90°F alone. Furthermore, it is known that temperature and precipitation are highly correlated and that a higher chance of thunderstorm rainfall is correlated with higher temperatures during that time of the year.

Figure 26 provides the results of the 12-year "bootstrap" test for the Oklahoma Panhandle area.

RATE OF FERTILIZER APPLICATION FOR WHEAT

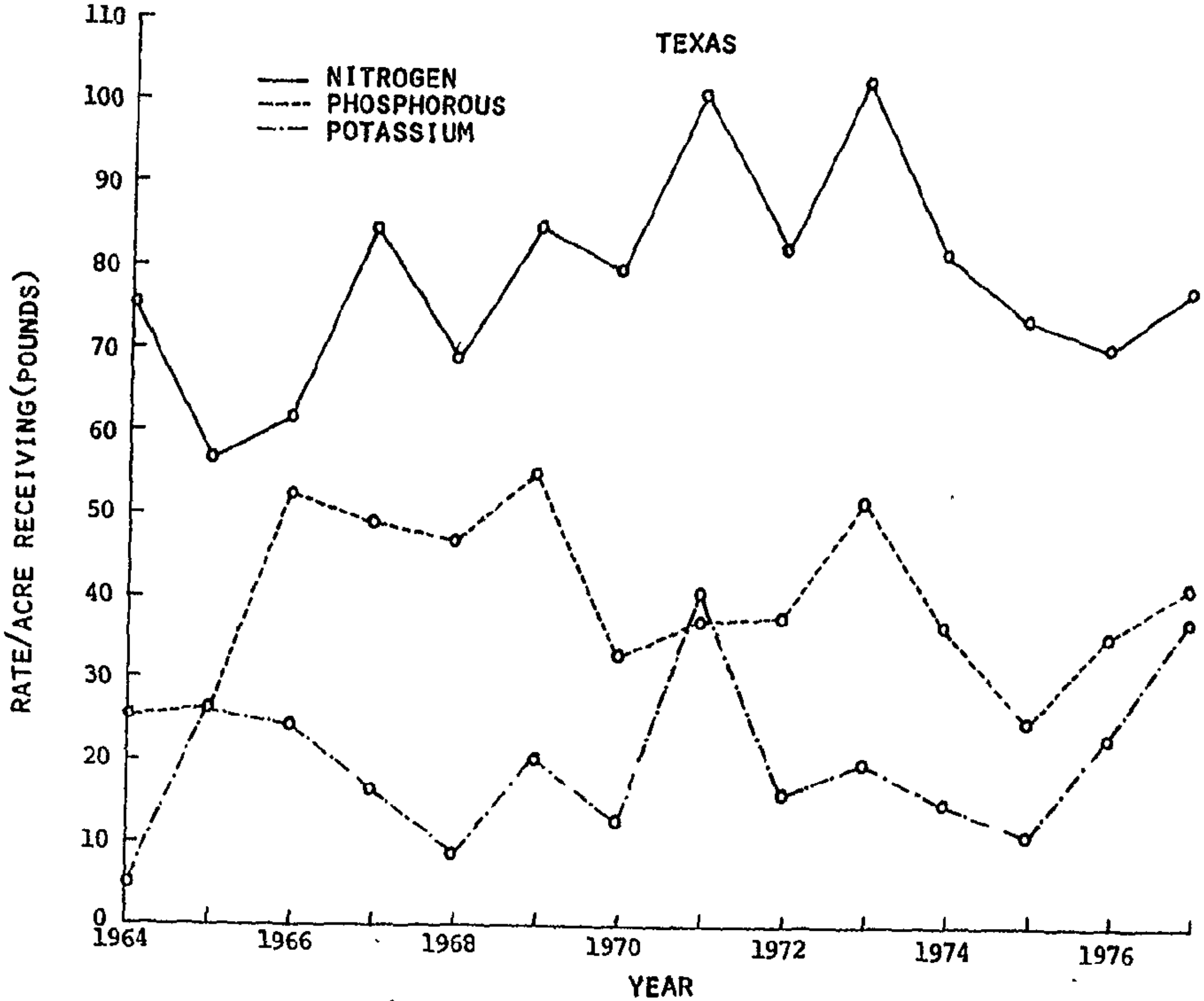


Figure 24

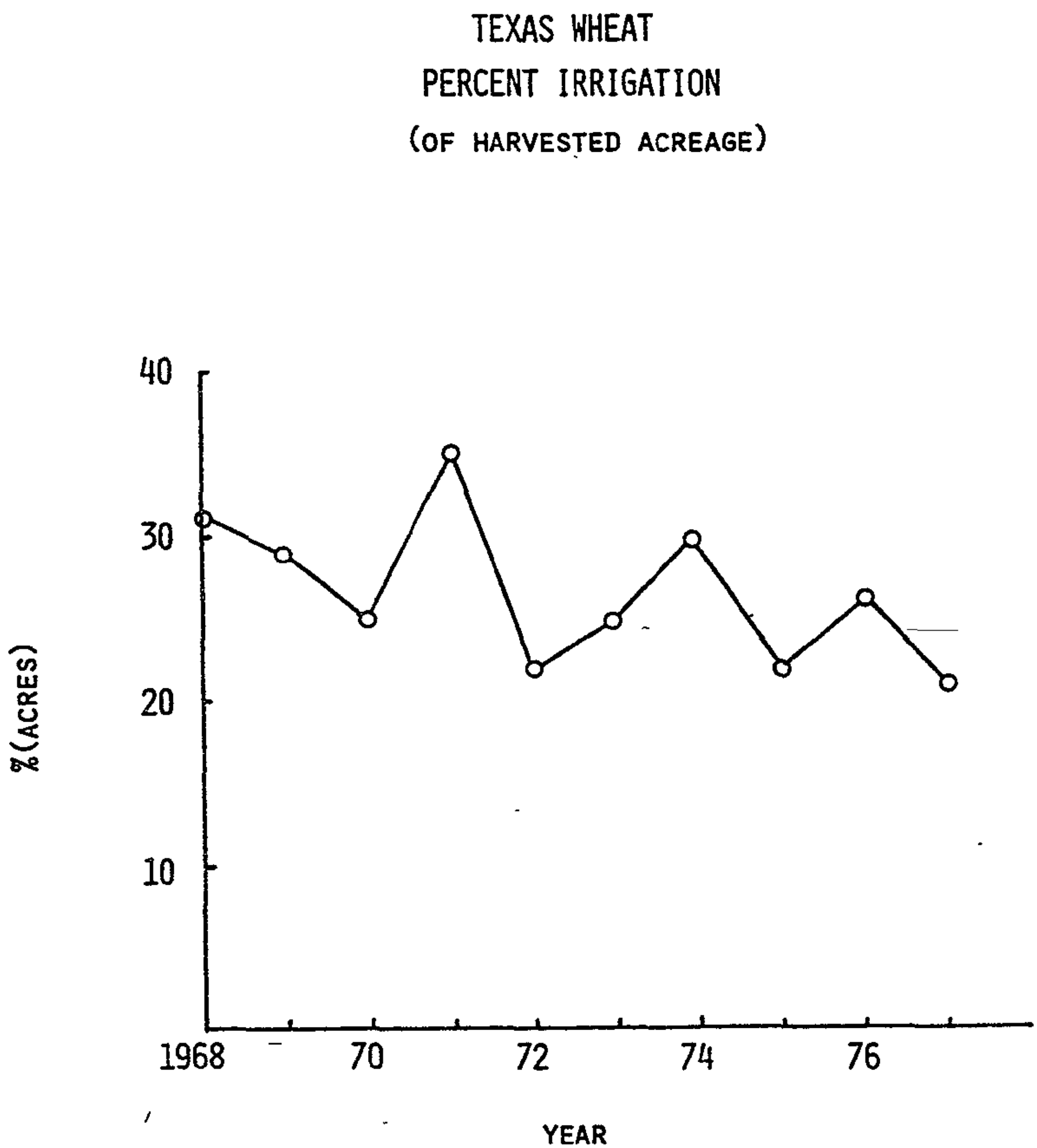
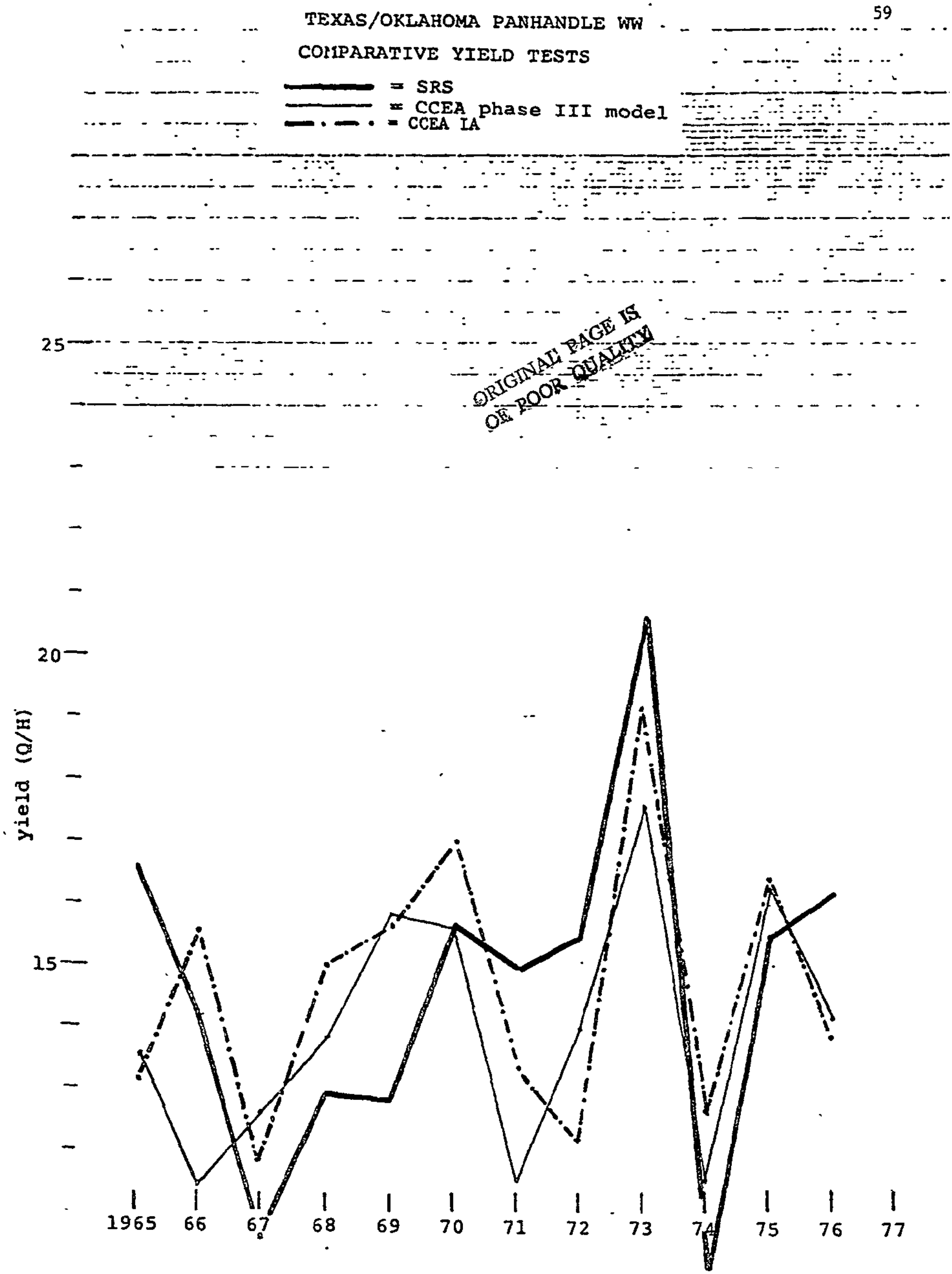

TEXAS WHEAT
PERCENT IRRIGATION
(OF HARVESTED ACREAGE)
40
30
20
10
%(ACRES)
1968
70
72
74
76
YEAR

Figure 25

Figure 26.


TEXAS/OKLAHOMA PANHANDLE WW
COMPARATIVE YIELD TESTS
= SRS
= CCEA phase III model
= CCEA IA
ORIGINAL PAGE IS OF POOR QUALITY
yield (Q/H)
25
20
15
1965
66
67
68
69
70
71
72
73
74
75
76
77

The Z-index

The Z-index is a moisture anomaly index which depicts the difference between the observed moisture supply and the "climatically appropriate" demand. This index has been used to produce a wheat yield model for Australia (Sakamoto, 1978). The observation has been that in drier climates, this index seems to work reasonably well, but in a much more humid area, there seems to be little difference between the use of more conventional moisture indices such as precipitation or potential evapotranspiration.

A preliminary analysis of the Z-index for application in the U.S. Great Plains was accomplished using the Texas-Oklahoma Panhandle and Oklahoma wheat yield model by retaining the same trend and substituting the variable where precipitation was included. The preliminary conclusion is that the Z-index did not appear to improve the performance of the model as indicated by the 12-year "bootstrap" test. See Tables 3a through 4b and Figures 27 and 28.

8. Texas Low Plains winter wheat

As with the other models, the starting point of the model revision is the assessment of the trend term. The changes are not done indiscriminately, but after inspection of the data series and qualitatively evaluating fertilizer, irrigation and other management inputs that affect yield. It was determined that 1955 was a choice year to begin trend. The 1932-1955 trend was eliminated from the original CCEA I model. The trend terms included the period 1955-1962 and 1962-1977. The second term could have been eliminated because of its low statistical significance.

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 OKLAHOMA (0040)
FOR TRUNCATION JUNE

OKLAHOMA WINTER WHEAT CCEA I

TABLE 3A

ANALYSIS OF VARIANCE

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	716.39844	9	79.59982	35.01471	0.00000002
RESIDUAL	79.56641	35	2.27332		
TOTALS	6999.00391	44	159.06827		

VARIABLE		DF	COEFFICIENT	STD DEV OF COE	T STATISTIC	SIGNIFICANCE
OVERALL CONSTANT		35	7.4900814036	0.5588674188	11.2163400650	0.0000000842
LINEAR TREND 1932-1955		35	0.1361454129	0.0482917018	2.8192291260	0.0080352314
LINEAR TREND 1955-1960		35	0.9528011680	0.1649791002	5.7752838135	0.0000220495
AUG TO FEB PREC	(DFN)	35	0.0064324546	0.0029376673	2.2100706100	0.0326168612
MAR PCP - P.E.T.	(DFN)	35	0.0389203019	0.0071345046	5.4552211761	0.0000368208
MAY PCP	(DFN)	35	-0.0131654218	0.0058124922	-2.2650213242	0.0298398638
MAY PCP	(SQF N)	35	-0.0001507373	0.0000628563	-2.3981237411	0.0213249885
MAY DEGREE DAYS ABOVE 90F		35	-0.7463718653	0.6265347004	-1.1912689209	0.2414489985
JUNE PCP	(DFN)	35	-0.0079358431	0.0058505982	-1.3564157486	0.1823777556

R SQUARED 0.90005
ADJUSTED R SQUARE 0.87720
STANDARD ERROR 1.50766
STANDARD DEVITATION OF YIELDS 4.30235

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 OKLAHOMA (0040)
FOR TRUNCATION JUNE

OKLAHOMA WINTER WHEAT Z-INDEX

TABLE 3B

ANALYSIS OF VARIANCE

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	692.80078	9	76.97785	26.11592	0.00000006
RESIDUAL	103.16406	35	2.94754		
TOTALS	6999.00391	44	159.06827		

VARIABLE		DF	COEFFICIENT	STD DEV OF COE	T STATISTIC	SIGNIFICANCE
OVERALL CONSTANT		35	7.4461421967	0.7257665661	10.2596545355	[illegible]
LINEAR TREND 1932-1955		35	0.1006673175	0.0523538664	1.9113536017	[illegible]
LINEAR TREND 1955-1960		35	1.0878362556	0.1888584495	5.7600612540	[illegible]
AUG TO FEB Z INDEX		35	0.0025617527	0.0018802201	1.3624744415	[illegible]
MARCH Z INDEX		35	0.0311186947	0.0065286160	4.7665071417	[illegible]
MAY Z INDEX		35	-0.0114564006	0.0082721971	-1.3851699824	[illegible]
MAY Z INDEX	(SQRD)	35	-0.0001219117	0.0000776562	-1.5699909760	[illegible]
MAY DEGREE DAYS ABOVE 90F		35	-0.7328416109	0.7714735276	-0.9499244510	[illegible]
JUNE Z INDEX		35	-0.0080208927	0.0058132294	-1.3797645540	[illegible]

R SQUARED 0.87038
ADJUSTED R SQUARE 0.84075
STANDARD ERROR 1.71689
STANDARD DEVITATION OF YIELDS 4.30235

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 TX OK PANHANDLE (0062)
FOR TRUNCATION MAY

TEXAS-OKLAHOMA PANHANDLE WINTER WHEAT CCEA I

ANALYSIS OF VARIANCE #### TABLE 4A

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	745.44531	9	82.82726	29.30202	0.00000004
RESIDUAL	98.93359	35	2.82667		
TOTALS	5013.60156	44	113.94543		

VARIABLE		DF	COEFFICIENT	STD DEV OF COE	T STATISTIC	SIGNIFICANCE
OVERALL CONSTANT		35	4.51629466E+00	7.57667720E-01	6.09276867E+00	1.36381805E-05
LINEAR TREND 1932-1955		35	1.09256446E-01	4.90443036E-02	2.22770882E+00	3.13569196E-02
LINEAR TREND 1955-1960		35	1.22758198E+00	1.77629709E-01	6.91090393E+00	4.44811121E-06
AUG TO FEB PREC	(DFN)	35	1.64216049E-02	4.73723188E-03	3.46649742E+00	1.80759351E-03
MAR PREC - P.E.T.	(DFN)	35	2.84310319E-02	1.31197646E-02	2.16703796E+00	3.58904749E-02
APR PREC/P.E.T.	(DFN)	35	2.60254765E+00	7.39127278E-01	3.52110863E+00	1.59900310E-03
MAY PREC	(DFN)	35	1.25724897E-02	1.07202530E-02	1.17277908E+00	2.48867035E-01
MAY PREC	(SQFN)	35	-3.01136402E-04	1.35899478E-04	-2.21587563E+00	3.21970247E-02
MAY DEGREE DAYS ABOVE 90F		35	-9.15403962E-02	7.05039680E-01	-1.29837215E-01	8.91087830E-01

R SQUARED 0.88284
ADJUSTED R SQUARE 0.85606
STANDARD ERROR 1.68119
STANDARD DEVITATION OF YIELDS 4.43125

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 TX OK PANHANDLE (0062)
FOR TRUNCATION MAY

TEXAS-OKLAHOMA PANHANDLE WINTER WHEAT Z-INDEX

ANALYSIS OF VARIANCE #### TABLE 4B

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	746.95703	9	82.99522	29.81705	0.00000004
RESIDUAL	97.42188	35	2.78349		
TOTALS	5013.60156	44	113.94543		

VARIABLE		DF	COEFFICIENT	STD DEV OF COE	T STATISTIC	SIGNIFICANCE
OVERALL CONSTANT		35	4.2871465683	0.6970405579	6.1504974365	0.0000125335
LINEAR TREND 1932-1955		35	0.1228865981	0.0507729501	2.4203157425	0.0202691741
LINEAR TREND 1955-1960		35	1.2523288727	0.1793116331	6.9840908051	0.0000040545
AUG TO FEB Z INDEX		35	0.0042805076	0.0019075205	2.2440156937	0.0302326307
MARCH Z INDEX		35	0.0143380687	0.0080127530	1.7894058228	0.0802142620
APRIL Z INDEX		35	0.0214849785	0.0079684891	2.6962423325	0.0107046030
MAY Z INDEX		35	0.0052967779	0.0069191307	0.7655264735	0.5446236730
MAY Z INDEX	(SQRD)	35	-0.0000773135	0.0000551466	-1.4019632339	0.1682492495
MAY DEGREE DAYS ABOVE 90F		35	-1.2386531330	0.9846125841	-1.2580099106	0.2160472274

R SQUARED 0.88464
ADJUSTED R SQUARE 0.85827
STANDARD ERROR 1.66825
STANDARD DEVITATION OF YIELDS 4.43125

Figure 27

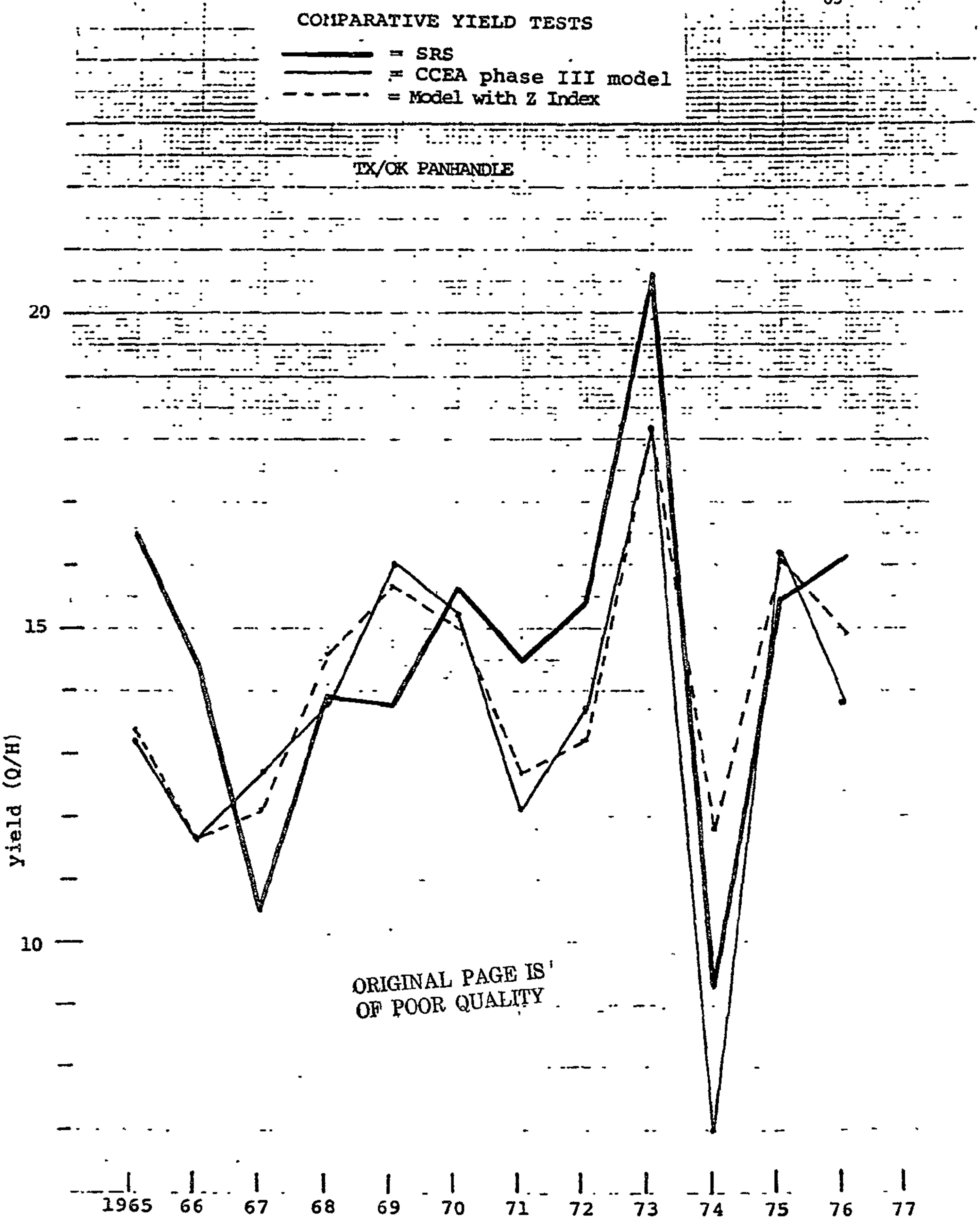
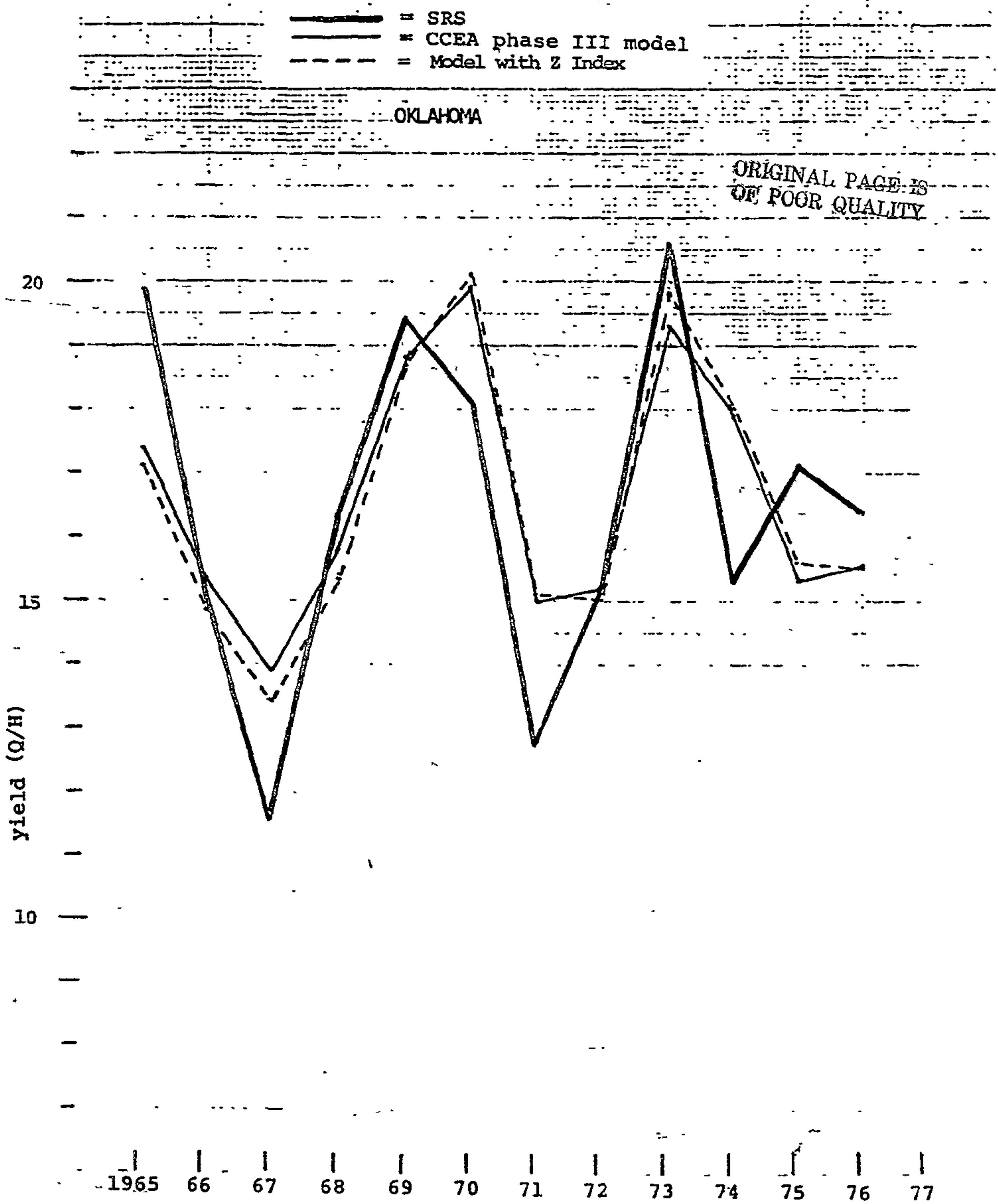

COMPARATIVE YIELD TESTS
= SRS
= CCEA phase III model
= Model with Z Index
TX/OK PANHANDLE
20
15
10
yield (Q/H)
1965
66
67
68
69
70
71
72
73
74
75
76
77

Figure 28

COMPARATIVE YIELD TESTS



When the candidate model was run with these two trends, the May precipitation variable lost ground in its significance. In its place April prec-PET was included.

In the least squares procedure, the change of one variable often affects the other variables. With the trend change, the variable August through December precipitation was replaced by two shorter period variables, September to October total precipitation and December to January average temperature. The December to January temperature, with its negative coefficient, is probably associated with humid and warm conditions and disease problems. Several combinations of months to depict early season fall and winter moisture were attempted including August to December, but the shorter period September to November prevailed. The variable May number of days greater than 90 degrees was also tried, but its effectiveness was even lower than that of using May precipitation alone.

Because of the large underestimation of the 1977 Texas yield, it was tempting to extend the trend from 1955 through 1977. The result of this trial was a higher 1977 estimate, 23.8 bushels, but also a poor coefficient of determination, $R^2 = .76$, although this was not the only criterion considered. February precipitation by itself was not as effective as January-February departure from normal precipitation. Another variable, the interaction of March and April precipitation, was attempted but the resulting negative coefficient, although highly significant, did not make sense.

In a sense, the revised model is better than CCEA I, although the peaks in 1970 and 1973 in the 12-year "bootstrap" test were not adequately accounted for by the present revised model. The new model shows a greater range of sensitivity when the results of the 12-year test are reviewed (Figure 29). The Weekly Weather and Crop Bulletin (1970, 1973) indicate that rain in February was heavy, roughly 100 to 200 percent of normal. In addition, in March 1970 small grain was side-dressed in many areas.

9. Texas-Edwards Plateau winter wheat

The original CCEA I Edwards Plateau model was a covariance model for crop district 70 (Edwards Plateau) and crop districts 81 and 82 (South Central and Coastal Border). This particular area was plagued with data problems with district 70 having a data base period that included the years 1931-1975, while districts 81 and 82 had the years 1961-1975. Furthermore, district 82 had fewer years of yield data than district 81. Because of these problems and the unsatisfactory performance of the covariance model, the area was separated into two models: one for district 70, the Edwards Plateau area, and the other for district 81 only, the South Central crop district. Consequently, this section will make reference to only the Edwards Plateau region.

The linear trend from 1931-1975 was dropped in favor of a double trend, 1955-1960 and the period 1965-1977. These trends were tried after visual inspection of yield series, which showed that yield appeared to actually decrease from 1961-1965, then began increasing again. The original variables in CCEA I consisted of a few variables that were not agronomically reasonable, even though they were statistically significant. For example, the 1931-1975 trend was thought to mask the weather effects of the dry 1930's. The March moisture variable included a precipitation as well as a prec-PET variable. Further, March precipitation was represented only by the squared deviation from normal. This was also true of the May temperature variable.

COMPARATIVE YIELD TESTS, TEXAS LOW PLAINS WW

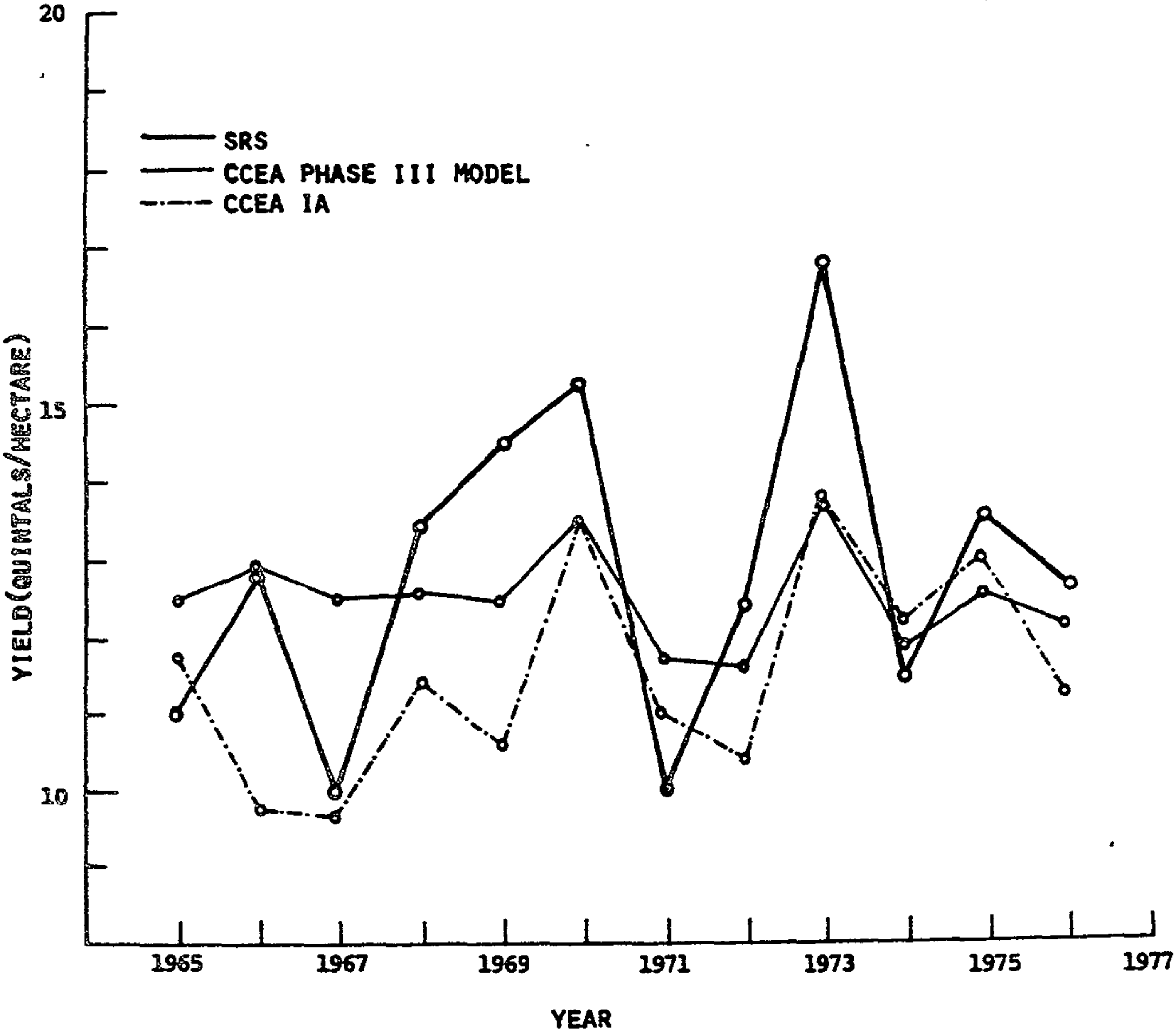


Figure 29

The detrimental effects of warm winter temperatures are indicated by the strong negative coefficient as well as a high level of statistical significance.

When the double trend of 1955-1960 and 1965-1977 was replaced with the period 1955-1965 and 1965-1977, the estimated yield for 1977 dropped to 17.9 bushels and the model provided an R^2 of 73 percent versus 76 percent for the revised CCEA IA, with a 1977 estimate of 19.9 bushels, a difference of two bushels. May temperature was also used in lieu of number of days in May greater than 90°F with the other variables remaining the same. The difference between these two variables in separate models was 1.2 bushels per acre, with the variable number of days greater than 90 degrees providing the higher estimate.

Figure 30 shows the results of the 12-year Edwards Plateau singular model when compared with the observed yield as well as that estimated from CCEA I covariance model.

10. Texas South Central Winter Wheat

This new model is based on the separation of the CCEA I so-called "Edwards Plateau" model which combined the crop districts of Edwards Plateau (CRD 70) and the south central areas (CRDs 81 and 82) of Texas. This new model includes the CRD 81 area only. This separation was initiated because of the large disparity of data years, where one area had about twice as many years as the other. Only 16 years of data (1961-1976) are available in the Texas South Central winter wheat model, but nevertheless they have provided a model with a reasonable capability to detect the wide swings of yield observed in that district (see Figure 31). The "jackknife" test was used in this case where the test year was omitted from the coefficient estimation. This was done 12 times, 1965-1976.

Figure 30

TEXAS EDWARDS WW

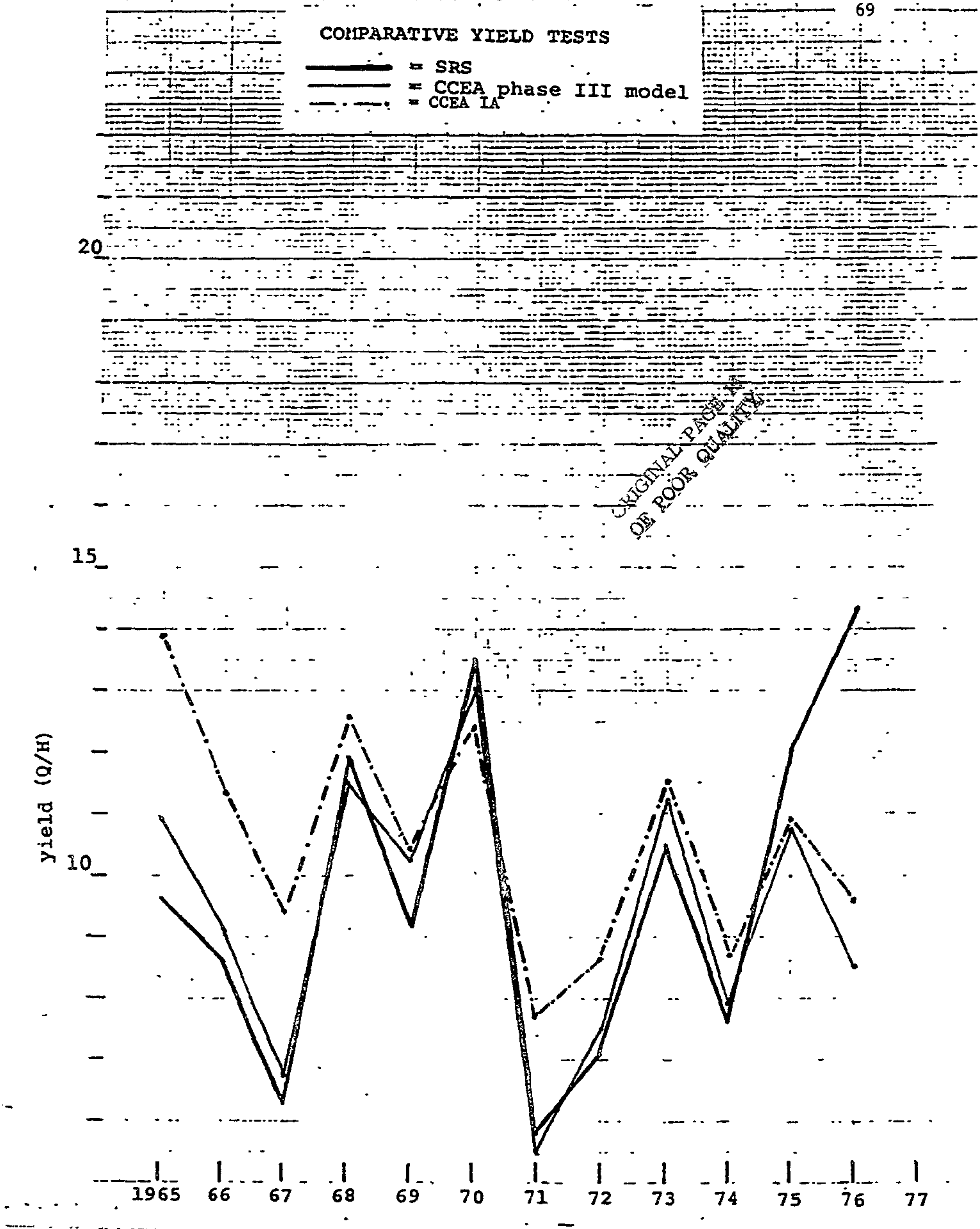
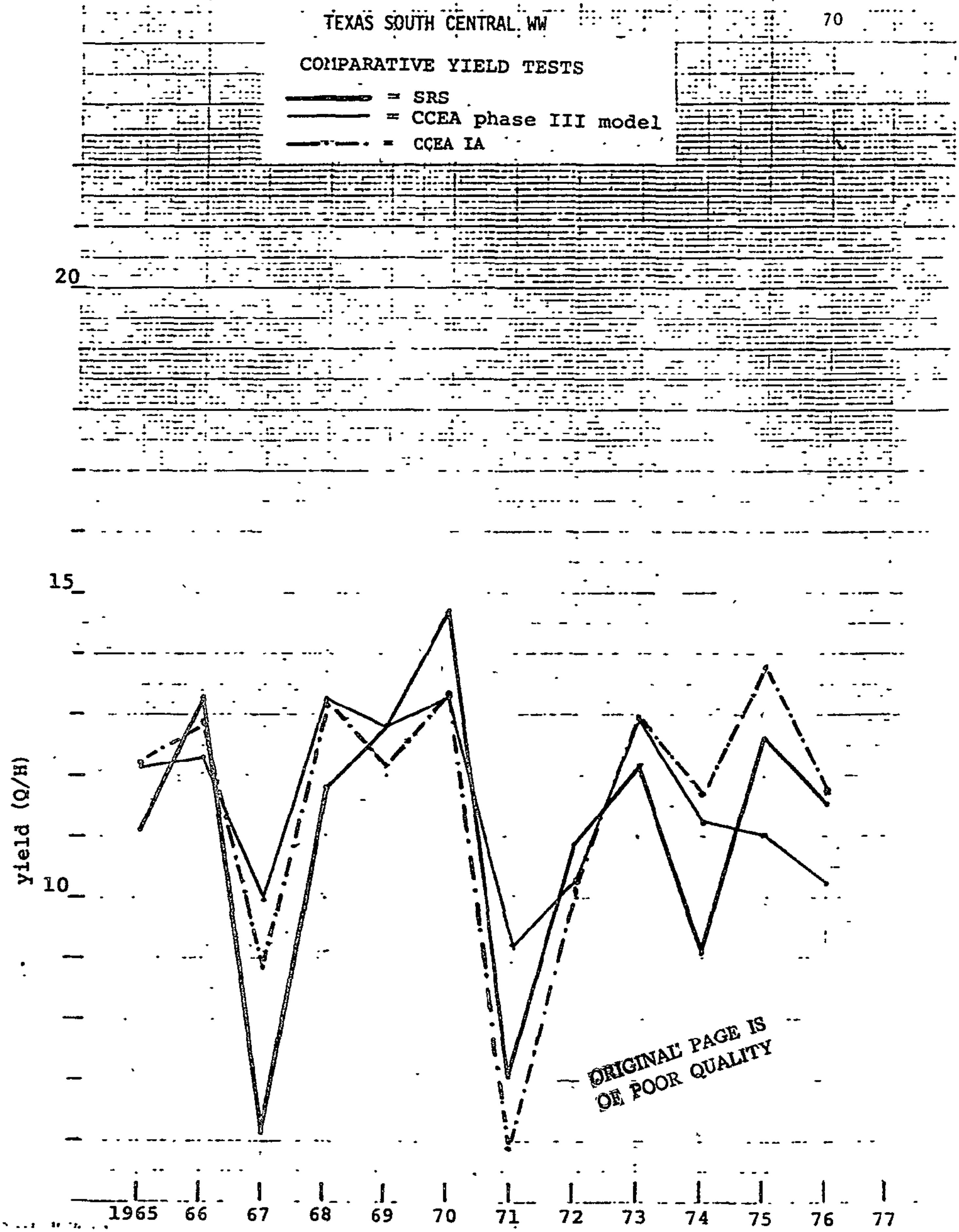


Figure 31


TEXAS SOUTH CENTRAL WW
COMPARATIVE YIELD TESTS
= SRS
= CCEA phase III model
= CCEA IA
yield (Q/H)
20
15
10
1965
66
67
68
69
70
71
72
73
74
75
76
77
ORIGINAL PAGE IS OF POOR QUALITY

This model does not include a trend term. The effects of winter temperature, such as January-February temperature as a single variable was attempted and as two separate variables for each month. It was found that using separate temperature months was better.

Other variables that were attempted, but failed to provide meaningful results, included March prec-PET, departure from normal (DFN) and squared departure from normal (SDFN), April temperature SDFN, and number of days greater than 90°F (32°C) in April.

REFERENCES

Bond, J. and D. Umberger. "Technical and Economic Causes of Changes in U.S. Wheat Production, 1949-1976." U.S. Department of Agriculture/ Foreign Agriculture Service. To be published by USDA/FAS in 1978.

CCEA Staff. "The Effect of Flagging and Trend Adjustments to Wheat Yield Estimates with CCEA Great Plains Models." Manuscript, Center for Climatic and Environmental Assessment, Environmental Data Service, 116 Federal Building, Columbia, Missouri, March 1976.

CCEA Staff. "Wheat Yield Models for the United States." Technical Note 75-1, Center for Climatic and Environmental Assessment, Environmental Data Service, 116 Federal Building, Columbia, Missouri, April 1977.

Haigh, P. A. "Separating the Effects of Weather and Management on Crop Production." James D. McQuigg, Certified Consulting Meteorologist, 405 B Bernadette Drive, Columbia, Missouri, November 1977, 93 pages.

NASA. "Yield Advisory Group Report." LACIE-00466, JSC-13730, Johnson Space Center, Houston, Texas, February 1978.

Palmer, W. C. and A. V. Havens. "A Graphical Technique for Determining Evapotranspiration by the Thornthwaite Method." Monthly Weather Review, 123-128, April 1958.

Poostchi, I, I. Rovhani, and K. Razmi. "Influences of Levels of Spring Irrigation and Fertility on Yield of Winter Wheat (Triticum Aestivum L.) Under Semi-Arid Conditions." Agronomy Journal, 64(4):438-440, 1972.

Sakamoto, C. M. "The Z-Index as a Variable for Crop Yield Estimation." Accepted for publication in Agricultural Meteorology, 1978.

Thornthwaite, C. W. "An Approach Toward a Rational Classification of Climate." Geographical Review, 38:55-94, 1948.

Texas Department of Agriculture and U.S. Department of Agriculture/Statistical Reporting Service. Texas Small Grain Statistics (for various years), Texas Crop and Livestock Reporting Service.

U.S. Department of Agriculture/Economic Research Service. Fertilizer Situation (FS-1, FS-2, FS-3, FS-4, FS-5, FS-6, FS-7).

U.S. Department of Agriculture/Statistical Reporting Service. Cropping Practices: Corn, Cotton, Soybeans, Wheat, 1965-1970. SRS-17, June 1971.

U.S. Department of Commerce and U.S. Department of Agriculture/Economics, Statistics and Cooperative Service. Weekly Weather and Crop Bulletin (various issues).

APPENDIX A

The Regression Models

A mathematical model was developed for each region regressing wheat yield against a time variable as a surrogate for factors affecting yield trend and a set of weather variables measuring the influence of weather. The basic general model for a particular region which may include several subregions is:

$$Y_{ij} = \alpha_j + \beta T_i + \sum_{k=1}^{n} \gamma_{jk} W_{ijk} + \varepsilon_{ij}$$

where:

i = year,

j = subregion, $j = 1, 2, \ldots, m$ and m differs with models,

k = weather variable, $k = 1, \ldots, n$ and n differs with models,

Y_{ij} = estimated yield for the ith year and jth subregion,

α_j = constant for the jth subregion,

β = coefficient for trend, T,

T_i = trend for ith year (e.g., 1958 = 1, 1959 = 2, ..., 1973 = 16),

γ_{jk} = coefficient for kth weather variable W_{ijk} where the kth weather variable is not the same function for each model,

n = the number of distinct weather variables and will vary by region, and

ε_{ij} = unexplained variation of the ith year and jth subregion.

The Weather Variables

The basic weather data, consisting of monthly temperature and monthly precipitation, are used to derive monthly weather variables. A moisture stress index, also expressed as the departure from normal wheat normal is the average value, is defined as monthly precipitation minus potential evapotranspiration (P.E.T.). Thornthwaite's procedure (Palmer and Havens, 1958; Thornthwaite, 1948) for estimating potential evapotranspiration is utilized. The formula for P.E.T. is:

$$\text{P.E.T.} = 16.0 \{10(T)_m/I\}^a$$

where:

P.E.T. = monthly potential evapotranspiration in millimeters for the month m,

$(T)_m$ = monthly mean temperature (°C) for month m,

I = heat index = $\sum_{m=1}^{12} h_m$ and $h_m = \{(T)_m/5\}^{1.514}$ for m = 1 (January) through m = 12 (December), and

$a = 6.75 \times 10^{-7}I^3 - 7.71 \times 10^{-5}I^2 + 1.79 \times 10^{-2}I + 0.49$.

Expressions for a and h_m were determined empirically by Thornthwaite (1948). I is a heat index which is a constant for a given location. Daylight corrections are applied as a fraction of 12 hours.

In some cases, the departure of the observed precipitation, P_m, from the average precipitation, $\overline{P}_m$, was used as a moisture index. In most cases, the first weather variable to enter the model is typically the accumulated preseason moisture.

The monthly temperature departure from normal is defined as $T_m - \overline{T}_m$ where T_m is the observed temperature, and $\overline{T}_m$ is the average temperature over the data period for month m.

Estimates of wheat yield are desired as early in the season as possible. Hence, truncated models were developed using as much weather data as is available at the truncated period. For example, a truncated winter wheat model for March used weather coefficients through the month of March.

APPENDIX B

PRECEDING PAGE BLANK NOT FILMED

MINNESOTA STATE SPRING WHEAT MODEL

Crop District	Weight	Crop District	Weight
50 Central	.5466	80 South Central	.1888
70 Southeast	.2646		

P.E.T. A = 1.155
P.E.T. I = 41.722

April Daylength = 1.1126

Latitude = 44°N

						Truncation			
Variable	Deviation	Normal	Trend	March	April	May	June	July	August
Overall Constant		1.00	10.83123	10.56154	10.52968	10.56382	12.22502	14.06278	14.06686
Linear Trend 1955-1978		24.00	0.65301	0.69698	0.70396	0.69918	0.72147	0.70196	0.71049
Oct-Mar Prec (mm)	DFN	171.50		-0.01608	-0.01685	-0.01671	-0.02733	-0.02847	-0.02852
Apr Prec - P.E.T. (mm)	DFN	24.82			-0.01128	-0.01042	-0.02250	-0.02093	-0.02245
May Prec (mm)	DFN	87.00				-0.00602	-0.00865	-0.02007	-0.02061
Jun Number Days Above 32C		2.98					-0.62808	-0.62895	-0.60882
Jul Number Days Above 32		7.20						-0.24177	-0.25753
Aug Temp (°C)	DFN	21.25							0.29392
R Squared			0.71874	0.74245	0.74628	0.74821	0.80662	0.85419	0.85919
Standard Error (Q/Ha)			2.87177	2.78059	2.79328	2.81721	2.50036	2.19957	2.19050
Standard Variance (Q/Ha)			8.24706	7.73168	7.80241	7.93666	6.25180	4.83811	4.79828

Standard Deviation of Yields = 5.35310 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Spring Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

April 1978

MONTANA STATE SPRING WHEAT MODEL

Crop District	Weight	Crop District	Weight
20 North Central	.2962	90 Southeast	.0399
30 Northeast	.6639		

Variable	Deviation	Normal	Trend	Truncation March	May	June	July
Overall Constant		1.00	8.59262	8.66495	8.74586	9.46619	9.24161
Linear Trend 1955-1978		22.00	0.41618	0.40439	0.38784	0.40574	0.38781
Aug-Mar Prec (mm)	DFN	135.74		0.02465	0.02547	0.01185	0.01026
May Prec (mm)	DFN	45.30			0.02825	0.02502	0.02091
Jun Prec (mm)	DFN	77.65				0.03627	0.03569
Jun Number Days Above 32C		2.63				-0.33820	-0.20492
Jul Temp (°C)	DFN	20.97					-0.64292
R Squared			0.53350	0.57286	0.60303	0.77089	0.82079
Standard Error (Q/Ha)			2.73597	2.64897	2.58466	2.01329	1.80390
Standard Variance (Q/Ha)			7.48554	7.01707	6.68046	4.05335	3.25404

Standard Deviation of Yields = 3.95998 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Spring Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

NORTH DAKOTA SPRING WHEAT MODEL

Crop District	Weight
10 Northwest	.2509
20 North Central	.1558
40 West Central	.1178
50 Central	.1616
70 Southwest	.0948
80 South Central	.0834
90 Southeast	.1357

					TRUNCATION			
Variable	Deviation	Normal	Trend	November	April	May	June	July
Overall Constant		1.00	6.58518	6.79246	6.74983	6.75875	7.51035	9.28993
Linear Trend 1955-1965		11.00	0.84185	0.83154	0.83647	0.79759	0.84166	0.79490
Linear Trend 1965-1972		8.00	0.10848	0.03754	0.04752	0.11837	0.11283	0.10456
Aug-Nov Prec (mm)	DFN	126.14		0.03630	0.03590	0.03536	0.03146	0.02417
Apr Prec (mm)	DFN	37.63			-0.00463	-0.01154	-0.02450	-0.01439
May Prec (mm)	DFN	55.90				0.02973	0.02740	0.01700
Jun Prec (mm)	DFN	89.32					0.02667	0.01727
Jun Number Days Above 32C		2.20					-0.45265	-0.42247
Jul Number Days Above 32C		7.82						-0.20617
R Squared			0.65039	0.72392	0.72426	0.75008	0.85458	0.87798
Standard Error (Q/Ha)			2.97510	2.67580	2.70740	2.61037	2.04426	1.89840
Standard Variance (Q/Ha)			8.85122	7.15991	7.33002	6.81401	4.17901	3.60392

Standard Deviation of Yields - 4.91593 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Spring Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

RED RIVER VALLEY SPRING WHEAT

Crop District	Weight	Crop District	Weight
10 Northwest (Minnesota)	.2704	30 Northeast (North Dakota)	.3643
40 West Central (Minnesota)	.1372	60 East Central (North Dakota)	.2282

Variable	Deviation	Normal	Trend	November	TRUNCATION April	June	July
Overall Constant		1.00	10.09402	10.15777	10.14966	10.95628	13.72350
Linear Trend 1955-1978		24.00	0.64080	0.63040	0.63329	0.63779	0.58866
Aug-Nov Prec (mm)	DFN	176.96		0.01767	0.01688	0.01294	0.00451
Apr Temp (°C)	DFN	4.82			0.28712	0.23795	0.20658
Jun Number Days Above 32C		2.31				-0.37879	-0.25227
Jul Number Days Above 32C		6.53					-0.42494
R Squared			0.69810	0.72691	0.73989	0.76355	0.87039
Standard Error (Q/Ha)			2.96250	2.85095	2.81609	2.71833	2.03820
Standard Variance (Q/Ha)			8.77638	8.12792	7.93036	7.38933	4.15426

Standard Deviation of Yields = 5.33013 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yield Measured in Quintals per Hectare

Weights Based on 1973 Spring Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

SOUTH DAKOTA SPRING WHEAT MODEL

Crop District	Weight	Crop District	Weight
10 Northwest	.1471	50 Central	.1253
20 North Central	.4294	60 East Central	.0364
30 Northeast	.2483	90 Southeast	.0135

P.E.T. A = 1.147
P.E.T. I = 41.191

April Daylength = 1.1166

Latitude = 45°N

Variable	Deviation	Normal	Trend	November	Truncation April	June	July
Overall Constant		1.00	6.85107	6.95420	7.60488	8.89686	8.71271
Linear Trend 1955-1978		24.00	0.38086	0.36405	0.34113	0.35443	0.34176
Sep-Nov Prec (mm)	DFN	76.34		0.04065	0.03581	0.02073	0.01111
Apr Prec/P.E.T. (mm)	DFN	1.66			1.00156	0.60449	0.70703
Apr Prec/P.E.T. (mm)	SDFN	1.66			-0.39479	-0.30388	-0.32218
Sep*Jun Prec (mm)	DFN	3237.12				0.00035	0.00027
Jun Number Days Above 32C		4.37				-0.35256	-0.29043
Jul Temp (°C)	DFN	22.99					-0.68891
R Squared			0.43090	0.55148	0.59235	0.77011	0.84335
Standard Error (Q/Ha)			3.07710	2.76406	2.70018	2.08041	1.74041
Standard Variance (Q/Ha)			9.46857	7.64002	7.29100	4.32810	3.02902

Standard Deviation of Yields = 4.03231 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Spring Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

April 1978

BADLANDS WINTER WHEAT MODEL

Crop District	Weight
10 Panhandle (Nebraska)	.6228

Crop District	Weight
40 West Central (South Dakota)	.1351
70 Southeast (South Dakota)	.1351
50 Central (South Dakota)	.1974
80 South Central (South Dakota)	.0447

P.E.T. A = 1.188
P.E.T. I = 43.953

March Daylength = .9833
April Daylength = 1.1087

Latitude = 43°N

Variable	Deviation	Normal	Trend	November	March	Truncation April	May	June	July
Overall Constant		1.00	5.21869	5.88708	6.02854	5.51920	5.74800	6.82518	6.55410
Linear Trend 1932-1955		24.00	0.44288	0.39255	0.38587	0.43077	0.41622	0.37336	0.39090
Linear Trend 1955-1972		18.00	0.22448	0.26353	0.25685	0.20306	0.20948	0.24627	0.24322
Oct-Nov Prec (mm)	DFN	35.24		0.11511	0.12319	0.10732	0.10458	0.10952	0.11043
Mar Prec - P.E.T. (mm)	DFN	18.20			-0.04410	-0.04490	-0.04702	-0.04202	-0.03844
Apr Prec - P.E.T. (mm)	DFN	12.51				0.03160	0.02671	0.02324	0.02540
May Temp (°C)	DFN	13.81					-0.20942	-0.35272	-0.30878
Jun Prec (mm)	DFN	79.75						0.02198	0.02421
Jun Prec (mm)	SDFN	79.75						-0.00051	-0.00053
Jul Prec (mm)	DFN	52.09							-0.01623
R Squared			0.60436	0.69936	0.70600	0.72608	0.72990	0.75364	0.75659
Standard Error (Q/Ha)			3.70167	3.26589	3.26976	3.19633	3.21544	3.15503	3.18056
Standard Variance (Q/Ha)			13.70236	10.66602	10.69131	10.21650	10.33907	9.95420	10.11597

Standard Deviation of Yields = 5.74971 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

April 1978

COLORADO STATE WINTER WHEAT MODEL

Crop District	Weight	Crop District	Weight
20 Northeast	.3229	90 Southeast	.3198
60 East Central	.3572		

					Truncation		
Variable	Deviation	Normal	Trend	February	April	May	June
Overall Constant		1.00	10.20494	10.29129	10.16807	10.84382	11.41748
Linear Trend 1955-1978		25.00	0.30565	0.29954	0.32686	0.33888	0.33722
Oct-Feb Prec (mm)	DFN	72.94		0.08924	0.08563	0.08779	0.08287
Mar*Apr Prec (mm)	DFN	1003.92			0.00084	0.00046	0.00054
May Number Days Above 32C		1.56				-0.47496	-0.55411
May Prec (mm)	DFN	61.00				0.02880	0.02286
Jun Prec (mm)	DFN	51.82					0.02631
Jun Prec (mm)	SDFN	51.82					-0.00070
R Squared			0.28170	0.63382	0.66168	0.74975	0.78141
Standard Error (Q/Ha)			3.33067	2.40692	2.34228	2.06679	1.98456
Standard Variance (Q/Ha)			11.09337	5.79326	5.48626	4.27160	3.93847

Standard Deviation of Yields = 3.88392 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1972 and 1974-1976
Meteorological Normals Based on 1931-1976

April 1978

KANSAS STATE WINTER WHEAT MODEL

Crop District	Weight	Crop District	Weight
10 Northwest	.1129	60 South Central	.2289
20 West Central	.1229	70 Northeast	.0232
30 Southwest	.1838	80 East Central	.0268
40 North Central	.1088	90 Southeast	.0442
50 Central	.1486		

P.E.T. A = 1.481   May Daylength = 1.1785   Latitude = 38°N

P.E.T. I = 62.832

Variable	Deviation	Normal	Trend	November	Truncation March	May	June
Overall Constant		1.00	7.94047	7.93856	8.14029	9.64031	9.40812
Linear Trend 1943-1955		13.00	0.26762	0.30267	0.23759	0.23530	0.24259
Linear Trend 1955-1972		18.00	0.53526	0.48160	0.55176	0.51971	0.52790
Aug-Nov Prec (mm)	DFN	202.21		0.02082	0.02068	0.01820	0.01939
Mar Prec (mm)	DFN	33.49			0.05644	0.05582	0.05664
May Prec - P.E.T. (mm)	DFN	44.01				-0.01034	-0.01211
May Prec - P.E.T. (mm)	SDFN	44.01				-0.00028	-0.00017
May Number Days Above 32C		3.05				-0.29770	-0.30083
Jun Prec (mm)	DFN	98.98					-0.00745
R Squared			0.78620	0.84268	0.89058	0.92388	0.92775
Standard Error (Q/Ha)			2.31404	2.01095	1.69956	1.47877	1.46242
Standard Variance (Q/Ha)			5.35477	4.04392	2.88851	2.18676	2.13866

Standard Deviation of Yields = 4.88097 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1965, 1967-1972, and 1975-1976
Meteorological Normals Based on 1931-1965, 1967-1972, and 1975-1976

April 1978

MONTANA STATE WINTER WHEAT MODEL

Crop District	Weight	Crop District	Weight
20 North Central	.5309	70 Southwest	.0248
30 Northeast	.1164	80 South Central	.1106
50 Central	.1520	90 Southeast	.0653

P.E.T. A = 1.019
P.E.T. I = 32.694

May Daylength = 1.2479

Latitude = 47°N

Variable	Deviation	Normal	Trend	Truncation April	May	June
Overall Constant		1.00	11.02818	11.31636	11.44134	11.69398
Linear Trend 1943-1978		36.00	0.29774	0.27634	0.26563	0.29321
Sep-Apr Prec (mm)	DFN	147.87		0.04391	0.04068	0.02038
May Prec - P.E.T. (mm)	DFN	-25.35			0.02534	0.02767
Jun Prec (mm)	DFN	75.58				0.03979
Jun Number Days Above 32C		2.51				-0.27420
R Squared			0.61254	0.67873	0.71034	0.82446
Standard Error (Q/Ha)			2.68670	2.47542	2.37899	1.89888
Standard Variance (Q/Ha)			7.21836	6.12768	5.65959	3.60573

Standard Deviation of Yields = 4.26692 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

April 1978

NEBRASKA WINTER WHEAT MODEL

Crop District	Weight	Crop District	Weight
50 Central	.0531	80 South Central	.1802
60 East Central	.1434	90 Southeast	.2415
70 Southwest	.3818		

Variable	Deviation	Normal	Trend	November	Truncation February	May	June
Overall Constant		1.00	7.14690	7.31002	7.32164	7.76731	9.42270
Linear Trend 1932-1955		24.00	0.28449	0.29411	0.29334	0.27200	0.29457
Linear Trend 1955-1978		24.00	0.51578	0.46115	0.46069	0.45191	0.38317
Sep-Nov Prec (mm)	DFN	120.22		0.02246	0.02233	0.02099	0.02325
Jan-Feb Temp (^{o}C)	DFN	-2.49			-0.04772	-0.26170	-0.24287
May Temp (^{o}C)	DFN	16.33				-0.78949	-0.73604
May Prec (mm)	DFN	90.21				-0.01886	-0.02317
Jun Prec (mm)	DFN	101.62					-0.04347
Jun Number Days Above 32C		7.30					-0.22419
R Squared			0.75875	0.79556	0.79586	0.84439	0.88417
Standard Error (Q/Ha)			3.00668	2.80135	2.83406	2.53861	2.25028
Standard Variance (Q/Ha)			9.04011	7.84758	8.03190	6.44454	5.06374

Standard Deviation of Yields = 5.98064 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

OKLAHOMA WINTER WHEAT MODEL

Crop District	Weight	Crop District	Weight
20 West Central	.1741	50 Central	.1404
30 Southwest	.2393	60 South Central	.0101
40 North Central	.4116		

P.E.T. A = 1.744
P.E.T. I = 78.166

March Daylength = .9870

Latitude = 36^{O}N

Variable	Deviation	Normal	Trend	December	February	March	May	June
				Truncation				
Overall Constant		1.00	7.32950	7.51822	7.35893	7.66295	8.52236	8.53641
Linear Trend 1943-1962		20.00	0.41718	0.40023	0.41458	0.39013	0.38774	0.38902
Sep-Dec Prec (mm)	DFN	211.36		0.01724	0.01730	0.01611	0.01263	0.01346
Jan-Feb Prec (mm)	DFN	54.41			0.01407	0.00520	0.00666	0.01412
Mar Prec - P.E.T. (mm)	DFN	18.94				0.03073	0.03147	0.03286
May Prec (mm)	DFN	110.54					-0.02017	-0.02001
May Number Days Above 32C		5.02					-0.16258	-0.16489
Jun Prec (mm)	DFN	94.14						-0.01568
R Squared			0.61921	0.71834	0.72942	0.78060	0.84667	0.86844
Standard Error (Q/Ha)			2.68814	2.33929	2.32058	2.11559	1.81456	1.70337
Standard Deviation (Q/Ha)			7.22612	5.47229	5.38508	4.47571	3.29261	2.90148

Standard Deviation of Yields = 4.30643 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

April 1978

TEXAS EDWARDS PLATEAU WINTER WHEAT MODEL

Crop District

70 Edwards Plateau

P.E.T. A = 2.085
P.E.T. I = 95.317

March Daylength = .9897

Latitude = 30°N

Variable	Deviation	Normal	Trend	January	February	March	April	May
					Truncation			
Overall Constant		1.00	5.79829	6.26857	6.21673	6.36104	6.83298	7.51248
Linear Trend 1955-1960		6.00	0.63730	0.46079	0.46530	0.48828	0.46543	0.45919
Linear Trend 1965-1978		11.00	0.11506	0.15449	0.17341	0.22019	0.20321	0.19408
Dec-Jan Temp (°C)	DFN	9.30		-0.52661	-0.41632	-0.38970	-0.39373	-0.37906
Sep-Feb Prec (mm)	DFN	284.93			0.00984	0.00728	0.00712	0.00631
Mar Prec - P.E.T. (mm)	DFN	-8.67				0.02970	0.02412	0.02284
Mar Prec - P.E.T. (mm)	SDFN	-8.67				-0.00032	-0.00026	-0.00034
Apr Number Days Above 32C		4.30					-0.09597	-0.08255
May Number Days Above 32C		11.44						-0.05399
R Squared			0.43960	0.50187	0.65874	0.73867	0.75017	0.75989
Standard Error (Q/Ha)			1.95240	1.86304	1.56119	1.40168	1.38887	1.38039
Standard Variance (Q/Ha)			3.81186	3.47090	2.43733	1.96469	1.92897	1.90547

Standard Deviation of Yields = 2.54810 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

April 1978

TEXAS LOW PLAINS WINTER WHEAT MODEL

Crop District	Weight	Crop District	Weight
21 North Low Plains	.6518	30 Cross Table	.3482
22 South Low Plains	.6518	40 Black Lands	.3482

P.E.T. A = 1.939
P.E.T. I = 88.354

March Daylength = .9884
April Daylength = 1.0755
June Daylength = 1.1819

Latitude = 33^{o}N

Variable	Deviation	Normal	Trend	November	January	Truncation February	March	April	June
Overall Constant		1.00	6.85090	7.08940	7.20527	7.13794	7.15186	7.15139	7.09286
Linear Trend 1955-1962		8.00	0.70807	0.66243	0.60070	0.62332	0.61680	0.61945	0.66748
Linear Trend 1962-1978		17.00	0.03796	0.01844	0.05405	0.05137	0.05741	0.05462	0.02098
Sep-Nov Prec (mm)	DFN	182.68		0.00843	0.00740	0.00931	0.00661	0.00666	0.00678
Dec-Jan Temp (C)	DFN	6.82			-0.39226	-0.27721	-0.32045	-0.32736	-0.44716
Jan-Feb Prec (mm)	DFN	69.55				0.01284	0.00651	0.00654	0.01105
Mar Prec - P.E.T. (mm)	DFN	5.68					0.02276	0.02253	0.01965
Apr Prec - P.E.T. (mm)	DFN	-1.00						0.00209	0.00413
Jun Prec - P.E.T. (mm)	DFN	-88.05							-0.01127
R Squared			0.69996	0.73212	0.75393	0.78388	0.81960	0.82059	0.84710
Standard Error (Q/Ha)			1.63542	1.56403	1.51761	1.44040	1.33319	1.34738	1.26099
Standard Variance (Q/Ha)			2.67460	2.44619	2.30314	2.07474	1.77739	1.81543	1.59010

Standard Deviation of Yields = 2.91700 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1976
Meteorological Normals Based on 1931-1976

April 1978

TEXAS-OKLAHOMA PANHANDLE WINTER WHEAT MODEL

Crop District	Weight	Crop District	Weight
10 Panhandle (Oklahoma)	.3155	11 North High Plains (Texas)	.6845
		12 South High Plains (Texas)	.6845

P.E.T. A = 1.584
P.E.T. I = 69.015

March Daylength = .9875
April Daylength = 1.0815

Latitude = 35°N

Variable	Deviation	Normal	Trend	December	February	Truncation March	April	May	June
Overall Constant		1.00	5.65547	5.75545	5.59922	5.85664	5.66564	6.33713	6.07953
Linear Trend 1955-1962		8.00	1.13686	1.11000	1.15751	1.09330	1.14960	1.14159	1.18221
Sep-Dec Prec (mm)	DFN	127.46		0.02006	0.02479	0.01677	0.01285	0.01058	0.01397
Jan-Feb Prec (mm)	DFN	29.21			0.06724	0.04024	0.03337	0.02380	0.03834
Jan-Feb Temp (°C)	DFN	3.75			0.02447	-0.09956	-0.17866	-0.28417	-0.19995
Mar Prec - P.E.T. (mm)	DFN	-2.88				0.04533	0.03073	0.03193	0.02898
Apr Prec - P.E.T. (mm)	DFN	-21.68					0.03945	0.03830	0.03619
May Number Days Above 32C		5.59						-0.11530	-0.09328
Jun Prec (mm)	DFN	67.54							-0.01541
R Squared			0.66444	0.71923	0.78670	0.82960	0.86674	0.87429	0.88437
Standard Error (Q/Ha)			2.69039	2.49152	2.22805	2.01814	1.80934	1.78225	1.73428
Standard Variance (Q/Ha)			7.23817	6.20768	4.96422	4.07288	3.27372	3.17642	3.00774

Standard Deviation of Yields = 4.58875 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Weights Based on 1973 Winter Wheat Harvested Acreage
Yields Based on 1932-1956, 1958-1973, 1975-1976
Meteorological Normals Based on 1931-1956, 1958-1973, 1975-1976

TEXAS SOUTH CENTRAL WINTER WHEAT MODEL

Crop District

81 South Central

Crop District

82 Coastal Border

Variable	Deviation	Normal	Trend	December	Truncation January	April	May
Overall Constant		1.00	11.42938	12.89205	12.83806	12.90016	13.84468
Dec Temp (^oC)	DFN	12.61		-0.75060	-0.64503	-0.67487	-0.66819
Sep-Dec Prec (mm)	DFN	343.29		0.01022	0.00924	0.00999	0.00862
Sep-Dec Prec (mm)	SDFN	343.29		-0.00012	-0.00011	-0.00012	-0.00010
Jan Temp (^oC)	DFN	10.98			-0.30004	-0.31004	-0.43123
Apr Temp (^oC)	DFN	21.54				0.16708	0.21747
May Number Days Above 32C		6.24					-0.18491
R Squared			0.00000	0.65901	0.72711	0.73703	0.85939
Standard Error (Q/Ha)			2.28171	1.48965	1.39188	1.43304	1.10456
Standard Variance (Q/Ha)			5.20618	2.21905	1.93733	2.05360	1.22005

Standard Deviation of Yields = 2.28171 Q/Ha

DFN = Departure from Normal
SDFN = Squared Departure from Normal
Yields Measured in Quintals per Hectare

Yields Based on 1961-1976
Meteorological Normals Based on 1960-1976

APPENDIX C

PRECEDING PAGE BLANK NOT FILMED

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78080

LEVEL 1 UNITED STATES (US 1)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 NORTH DAKOTA (0038) NORTH DAKOTA SPRING WHEAT
FOR TRUNCATION JULY

ANALYSIS OF VARIANCE

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	933.60547	9	103.73393	28.78600	0.00000004
RESIDUAL	129.73047	36	3.60352		
TOTALS	6270.65625	45	139.34722		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	36	10.50247	0.00000012	9.28993
LINEAR TREND 1955-1965	36	8.03376	0.00000108	0.79490
LINEAR TREND 1965-1972	36	0.59100	0.56431922	0.10456
AUG-NOV PRECIP	36	2.71615	0.00958748	0.02417
MAPRIL PRECIP DFN	36	-0.92011	0.63395184	-0.01439
MAY PRECIP DFN	36	1.47256	0.14780927	0.01700
JUNE PRECIP DFN	36	1.67627	0.10030460	0.01727
JUN DAYS > 32C	36	-2.75026	0.00934127	-0.42247
JUL DAYS > 32C	36	-2.62755	0.01244524	-0.20617

R SQUARED	0.87790
ADJUSTED R SQUARE	0.85067
STANDARD ERROR	1.89840
STANDARD DEVITATION OF YIELDS	4.91593

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 RED RIVER (0063)
FOR TRUNCATION JULY

RED RIVER VALLEY SPRING WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1088.09766	6	181.34961	43.65613	0.00000001
RESIDUAL	162.00781	39	4.15405		
TOTALS	10100.64453	45	224.45876		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	39	19.48752	0.00000000	13.72350
LINEAR TREND 1955-1977	39	13.00975	0.00000002	0.58866
AUG-NOV PRECIP DFN	39	0.70872	0.51045412	0.00451
APR TEMP	39	1.40975	0.16496831	0.20658
JUNE DAYS > 32 DEG C	39	-1.75531	0.08500075	-0.25227
ULY DAYS > 32 DEG C	39	-5.67002	0.00002231	-0.42494

R SQUARED	0.87039
ADJUSTED R SQUARE	0.85378
STANDARD ERROR	2.03820
STANDARD DEVITATION OF YIELDS	5.33013

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 RED RIVER (0063)
FOR TRUNCATION JULY

RED RIVER VALLEY SPRING WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1125.31250	7	160.75893	48.95178	0.00000001
RESIDUAL	124.79297	38	3.28403		
TOTALS	10100.64453	45	224.45876		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	38	18.22760	0.00000000	12.41785
LINEAR TREND 1955-1965	38	9.50550	0.00000024	0.86222
LINEAR TREND 1965-1977	38	1.38566	0.17247492	0.17804
AUG-NOV PRECIP DFN	38	1.17294	0.24815065	0.00669
APRIL TEMP DFN	38	1.82365	0.07409465	0.23825
JUNE DAYS > 32 DEG C	38	-1.89469	0.06388438	-0.24220
ULY DAYS > 32 DEG C	38	-5.14911	0.00005584	-0.35808

R SQUARED	0.90015
ADJUSTED R SQUARE	0.88438
STANDARD ERROR	1.81240
STANDARD DEVITATION OF YIELDS	5.33013

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 MINNESOTA (0027)
FOR TRUNCATION AUGUST

MINNESOTA SPRING WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1077.58984	8	134.69873	27.18715	0.00000005
RESIDUAL	183.31641	37	4.95450		
TOTALS	11166.11719	45	248.13593		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	37	17.05876	0.00000000	14.03195
LINEAR TREND 1955-77	37	13.25313	0.00000002	0.71005
OCT-MARCH PRECIP DFN	37	-3.92210	0.00063682	-0.02810
APRIL PREC - P.E.I.	37	-1.93299	0.05911831	-0.02354
MAY PRECIPITATION DFN	37	-2.09980	0.04121358	-0.01948
JUNE DAYS > 90 DEG F	37	-3.70120	0.00103147	-0.60983
JULY DAYS > 90 DEG F	37	-3.55696	0.00142340	-0.25171
AUGUST TEMPERATURE	37	1.28698	0.20519680	0.33240

R SQUARED	0.85458
ADJUSTED R SQUARE	0.82707
STANDARD ERROR	2.22609
STANDARD DEVITATION OF YIELDS	5.35310

C-3

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 MINNESOTA (0027)
FOR TRUNCATION AUGUST

MINNESOTA SPRING WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1105.53906	8	138.19238	32.90990	0.00000002
RESIDUAL	155.36719	37	4.19911		
TOTALS	11166.11719	45	248.13593		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	37	23.70296	0.00000000	10.27136
LINEAR TREND 1955-77	37	14.76399	0.00000001	0.73676
OCT - MARCH PREC	37	-4.70368	0.00013044	-0.03059
APRIL PREC - P.E.T.	37	-3.01913	0.00491706	-0.03502
MAY PRECIPITATION DFN	37	-1.65853	0.10361391	-0.01386
JUNE TEMPERATURE	37	-4.48938	0.00019758	-0.94204
JULY TEMPERATURE	37	-3.96446	0.00058151	-0.89431
AUGUST TEMPERATURE	37	1.44618	0.15486741	0.34654

R SQUARED	0.87677
ADJUSTED R SQUARE	0.85346
STANDARD ERROR	2.04920
STANDARD DEVITATION OF YIELDS	5.35310

ORIGINAL PAGE IS
OF POOR QUALITY

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78079

MONTANA SPRING WHEAT

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 MONTANA (0030)
FOR TRUNCATION JULY

ANALYSIS OF VARIANCE

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	566.36328	7	80.90903	24.86284	0.00000009
RESIDUAL	123.66016	38	3.25421		
TOTALS	6279.69141	45	139.54869		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	38	17.67328	0.00000000	9.24161
LINEAR TREND 1955-1977	39	9.57499	0.00000022	0.38781
AUG TO MAR PREC	38	1.06017	0.29712832	0.01026
MAY PRECIP DFN	38	1.64144	0.07141232	0.02091
JUNE PRECIPITATION	38	2.96494	0.00552156	0.03569
JUNE DAYS > 90 DEG F	38	-1.31567	0.19500756	-0.20492
JULY TEMP DFN	38	-3.25266	0.00281360	-0.64292

R SQUARED	0.82079
ADJUSTED R SQUARE	0.79249
STANDARD ERROR	1.80390
STANDARD DEVITATION OF YIELDS	3.95998

C-2

C-4

C.2

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78058

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 SOUTH DAKOTA (0046)
FOR TRUNCATION JULY

SOUTH DAKOTA SPRING WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	603.37134	8	75.42142	24.89951	0.00000007
RESIDUAL	112.07422	37	3.02903		
TOTALS	4513.48438	45	100.29965		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	37	15.67645	0.00000001	8.71271
LINEAR TREND 1955-1977	37	8.61316	0.00000059	0.34176
SEP-NOVE PRECIP DFN	37	1.15259	0.25659382	0.01111
APRIL PRECIP/PET DFN	37	2.09451	0.04169613	0.70703
APRIL PRECIP/PET SDFN	37	-2.09230	0.04189951	-0.32218
SEP*JUNE PRECIP DFN	37	2.38655	0.02159441	0.00027
JUNE DAYS > 90 DEG F	37	-3.67620	0.00109025	-0.29043
JULY TEMP DFN	37	-4.15900	0.00038583	-0.68891

R SQUARED	0.84335
ADJUSTED R SQUARE	0.81371
STANDARD ERROR	1.74041
STANDARD DEVITATION OF YIELDS	4.03231

ORIGINAL PAGE IS OF POOR QUALITY

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 BADLANDS (0061)
FOR TRUNCATION JULY

BADLANDS WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1102.26563	10	110.22656	10.94849	0.00000269
RESIDUAL	352.37109	35	10.06775		
TOTALS	10861.51172	45	241.36691		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	35	3.76341	0.00093645	6.94725
LINEAR TREND 1932-1955	35	4.22945	0.00035082	0.39446
LINEAR TRNED 1955-1972	35	2.36284	0.02311240	0.24343
OCT-NOV PCP	35	3.15515	0.00367923	0.11711
MARC H PRECIP-PET DFN	35	-0.82341	0.57876813	-0.04043
APRIL PRECIP-PET DFN	35	1.11125	0.27476817	0.02396
MAY TEMP DFN	35	-1.07232	0.29214066	-0.34277
JUN PCP DFN	35	1.04310	0.30568409	0.02157
JUN PCP SDFN	35	-1.92273	0.06087504	-0.00061
JULY PRECIP DFN	35	-0.73111	0.52376723	-0.01898

R SQUARED	0.75770
ADJUSTED R SQUARE	0.69539
STANDARD ERROR	3.17336
STANDARD DEVITATION OF YIELDS	5.74971

ORIGINAL PAGE IS OF POOR QUALITY

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 BADLANDS (0061)
FOR TRUNCATION JULY

BADLANDS WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1111.11328	10	111.11133	11.32061	0.00000224
RESIDUAL	343.52344	35	9.81495		
TOTALS	10861.51172	45	241.36691		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	35	2.04546	0.04684088	4.57266
LINEAR TREND 1932-1947	35	4.38998	0.00025410	0.66448
LINEAR TRNED 1955-1972	35	3.48501	0.00173387	0.31640
OCT-NOV PCP	35	2.45256	0.01882408	0.09289
MARC H PRECIP-PET DFN	35	-0.81740	0.57528484	-0.03962
APRIL PRECIP-PET DFN	35	1.54283	0.12996793	0.03418
MAY TEMP DFN	35	-0.66377	0.51800382	-0.21549
JUN PCP DFN	35	0.73863	0.52834964	0.01532
JUN PCP SDFN	35	-1.91304	0.06212782	-0.00060
JULY PRECIP DFN	35	-0.75912	0.54076821	-0.01944

R SQUARED	0.76387
ADJUSTED R SQUARE	0.70316
STANDARD ERROR	3.13264
STANDARD DEVITATION OF YIELDS	5.74971

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78090

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 COLORADO (0008)
FOR TRUNCATION JUNE

COLORADO WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	511.70313	8	63.96289	16.81015	0.00000048
RESIDUAL	136.98047	36	3.80501		
TOTALS	6974.31250	44	158.50710		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	36	18.89973	0.00000000	11.29032
LINEAR TEND 1955-1977	36	7.35165	0.00000245	0.33774
OCT-FEB PRECIP DFN	36	7.04274	0.00000357	0.07946
MARCH*APRIL PRECIP DFN	36	1.29254	0.20348418	0.00053
MAY DAYS > 32C	36	-2.07098	0.04410530	-0.49995
MAY PRECIP DFN	36	1.71369	0.09314132	0.02286
JUN PREC	36	1.69197	0.09724486	0.02217
JUN PREC SDFN	36	-2.03614	0.04757657	-0.00048

R SQUARED	0.78881
ADJUSTED R SQUARE	0.74775
STANDARD ERROR	1.95069
STANDARD DEVITATION OF YIELDS	3.88392

ORIGINAL PAGE IS OF POOR QUALITY

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78068

LEVEL 1	UNITED STATES	(US)
LEVEL 2	GREAT PLAINS	(00)
LEVEL 3	KANSAS	(0020)

KANSAS WINTER WHEAT

FOR TRUNCATION JUNE

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	906.26563	9	100.69617	47.10045	0.00000001
RESIDUAL	70.55078	33	2.13790		
TOTALS	7922.33203	42	188.62695		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	33	15.31069	0.00000001	9.34822
LINEAR TREND 1943-19955	33	4.04307	0.00054265	0.24259
LINEAR TREND 1955-1972	33	9.69801	0.00000030	0.52790
AUG-NOV PRECIP DFN	33	4.54036	0.00020159	0.01939
MARCH PRECIP DFN	33	4.44636	0.00024162	0.05664
MAY PRECIP - PET DFN	33	-1.43352	0.15954435	-0.01228
MAY PRECIP-PET SDFN	33	-1.04317	0.30609387	-0.00017
MAY DAYS > 90 DEG F	33	-2.86651	0.00737609	-0.30082
JUNE PRECIP DFN	33	-1.32841	0.19205976	-0.00745

R SQUARED	0.92775
ADJUSTED R SQUARE	0.91023
STANDARD ERROR	1.46242
STANDARD DEVITATION OF YIELDS	4.88097

(→ 20

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78038

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 MONTANA (0030)
FOR TRUNCATION JUNE

MONTANA WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	660.53125	6	110.08853	30.53801	0.00000005
RESIDUAL	140.59375	39	3.60497		
TOTALS	10977.12500	45	243.93610		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	39	21.38264	0.00000000	11.69398
LINEAR TREND 1943-1977	39	10.82017	0.00000008	0.29321
SEP-APR PRECIP DFN	39	1.61567	0.11217797	0.02038
MAY PREC - P.E.T.	39	2.88890	0.00654046	0.02767
JUNE PRECIPITATION	39	3.09814	0.00398893	0.03979
JUNE DAYS > 90 DEG F	39	-1.89743	0.06331456	-0.27420

R SQUARED	0.82446
ADJUSTED R SQUARE	0.80195
STANDARD ERROR	1.89888
STANDARD DEVITATION OF YIELDS	4.26692

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS ( )
LEVEL 3 NEBRASKA (0031)
FOR TRUNCATION JUNE

NEBRASKA WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1391.55078	9	154.61674	30.53307	0.00000003
RESIDUAL	182.30078	36	5.06391		
TOTALS	12236.63672	45	271.92505		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	36	6.98691	0.00000383	9.42270
LINEAR TREND 1932-1955	36	5.15743	0.00005882	0.29457
LINEAR TREND 1955-1977	36	5.76040	0.00002164	0.38317
SEP-NOV PRECIP	36	3.42521	0.00195034	0.02325
JAN-FEB TEMP DFN	36	-1.45946	0.15140396	-0.24287
MAY TEMP	36	-3.58814	0.00135115	-0.73604
MAY PRECIP DFN	36	-2.11900	0.03969731	-0.02317
JUN PREC	36	-3.44749	0.00185422	-0.04347
JUNE DAYS > 90 DEG F	36	-2.01330	0.04998428	-0.22419

R SQUARED	0.88417
ADJUSTED R SQUARE	0.85843
STANDARD ERROR	2.25028
STANDARD DEVITATION OF YIELDS	5.98064

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS ( )
LEVEL 3 NEBRASKA (0031)
FOR TRUNCATION JUNE

NEBRASKA WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	1361.93750	8	170.24219	29.72412	0.00000004
RESIDUAL	211.91406	37	5.72741		
TOTALS	12236.63672	45	271.92505		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	37	9.46457	0.00000027	11.54568
LINEAR TREND 1943-1955	37	4.62082	0.00015289	0.42377
LINEAR TREND 1955-1977	37	4.86609	0.00009617	0.36481
SEP-NOV PRECIP	37	3.28009	0.00267759	0.02363
MAY TEMP	37	-3.62448	0.00122340	-0.74032
MAY PRECIP DFN	37	-2.25126	0.02939559	-0.02623
JUN PREC	37	-3.05559	0.00451457	-0.04084
JUNE DAYS > 90 DEG F	37	-2.20452	0.03265619	-0.25953

R SQUARED	0.86535
ADJUSTED R SQUARE	0.83988
STANDARD ERROR	2.39318
STANDARD DEVITATION OF YIELDS	5.98064

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78090

FOR TRUNCATION JUNE

OKLAHOMA WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	703.51953	8	87.93994	29.87044	0.00000004
RESIDUAL	108.92969	37	2.94405		
TOTALS	7272.85156	45	161.61891		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	37	13.78108	0.00000002	8.56112
LINEAR TREND 1943-1962	37	11.47486	0.00000006	0.38737
SEP-DEC PRECIP DFN	37	3.94415	0.00060736	0.01342
JAN-FEB PRECIP DFN	37	1.59303	0.11765987	0.01422
MARCH PRCIP-PET DFN	37	3.93378	0.00062103	0.03259
MAY PCP	37	-4.22736	0.00033498	-0.02018
MAY DAYS > 32C	37	-1.90221	0.06309247	-0.16436
JUNE PRECIP DFN	37	-2.44730	0.01877164	-0.01575

R SQUARED	0.86588
ADJUSTED R SQUARE	0.84051
STANDARD ERROR	1.71607
STANDARD DEVITATION OF YIELDS	4.29699

ORIGINAL PAGE IS OF POOR QUALITY

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78062

TEXAS-OKLAHOMA PANHANDLE WINTER WHEAT

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 TEX-OK PANHANDLE (0062)
FOR TRUNCATION JUNE

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	778.81250	9	86.53471	27.86320	0.00000006
RESIDUAL	105.59375	34	3.10570		
TOTALS	5086.62109	43	118.29350		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	34	9.48607	0.00000033	6.10211
LINEAR TREND 1955-1962	34	12.70937	0.00000004	1.18077
SEP-DEC PREC IP DFN	34	2.10034	0.04178651	0.01332
~~JAN-FEB TEMP DFN~~	34	-0.93259	0.63914382	-0.21177
JAN-FEB PRECIP DFN	34	1.66744	0.10259885	0.03667
MAR PREC - P.E.T.	34	2.08365	0.04333347	0.02902
APRIL PRECIP -PET DFN	34	2.96135	0.00584403	0.03681
MAY DAYS > 90DEG F	34	-1.21184	0.23364258	-0.09652
JUNE PRECIP DFN	34	-1.60563	0.11563134	-0.01453

R SQUARED	0.88061
ADJUSTED R SQUARE	0.85252
STANDARD ERROR	1.76224
STANDARD DEVITATION OF YIELDS	4.58875

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78065

LEVEL 1 UNITED STATES (US)
LEVEL 2 GREAT PLAINS (0001)
LEVEL 3 TEXAS LOW PLAINS (0048)
FOR TRUNCATION JUNE

TEXAS LOW PLAINS WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	315.98438	9	35.10938	21.62743	0.00000011
RESIDUAL	58.44141	36	1.62337		
TOTALS	4580.62500	45	101.79166		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	36	22.70280	0.00000000	7.09776
LINEAR TREND 1955-1962	36	7.02722	0.00000364	0.66084
LINEAR TREND 1962-1977	36	0.38055	0.70602810	0.02695
SEP-NOV PREC IP DFN	36	2.00399	0.05099568	0.00658
DEC-JAN TEMP DFN	36	-2.48705	0.01725020	-0.46234
JAN-FEB PRECIP DFN	36	1.93514	0.05906994	0.01048
MAR PREC - P.E.T.	36	2.42105	0.02008606	0.01883
APRIL PRECIP-PET DFN	36	1.06141	0.29693615	0.00457
JUNE PREC - P.E.T.	36	-2.45830	0.01843458	-0.01109

R SQUARED	0.84391
ADJUSTED R SQUARE	0.80922
STANDARD ERROR	1.27408
STANDARD DEVITATION OF YIELDS	2.91700

ORIGINAL PAGE IS OF POOR QUALITY

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78073

TEXAS EDWARDS PLATEAU WINTER WHEAT

```
LEVEL 1  UNITED STATES       (US  )
LEVEL 2  GREAT PLAINS        (0001)
LEVEL 3  TEXAS               (0048)
LEVEL 4  EDWARDS PLATEAU     (0070)
FOR TRUNCATION MAY
```

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	217.11694	9	24.12410	12.66081	0.00000145
RESIDUAL	68.59497	36	1.90542		
TOTALS	3173.69385	45	70.52652		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	36	9.63182	0.00000024	7.51248
LINEAR TREND 1955-1960	36	3.82246	0.00080649	0.45919
LINEAR TREND 1965-1977	36	1.79790	0.07858908	0.19408
DEC-JAN TEMP DFN	36	-2.03391	0.04790657	-0.37906
SEP-FEB PRECIP DFN	36	2.74504	0.00945606	0.00631
MARCH PRECIP-PET DFN	36	2.37155	0.02250043	0.02284
MARCH PRECIP-PET SDFN	36	-1.59357	0.11778688	-0.00034
APRIL DAYS > 90DEG F	36	-1.11684	0.27211845	-0.08255
MAY DAYS 90DEG F	36	-1.20674	0.23513538	-0.05399

R SQUARED	0.75969
ADJUSTED R SQUARE	0.70653
STANDARD ERROR	1.38039
STANDARD DEVITATION OF YIELDS	2.54810

YES/MAYBE YIELD PREDICTION SYSTEM -- VERSION 3.1 -- JULIAN DATE: 78073

FOR TRUNCATION MAY

TEXAS SOUTH CENTRAL WINTER WHEAT

**** ANALYSIS OF VARIANCE ****

SOURCE	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	SIGNIFICANCE
REGRESSION	67.11401	7	9.58772	7.85863	0.00379821
RESIDUAL	10.98022	9	1.22002		
TOTALS	2168.18286	16	135.51143		

VARIABLE	DF	T STATISTIC	SIGNIFICANCE	COEFFICIENT
OVERALL CONSTANT	9	25.61127	0.00000257	14.37377
DECEMBER TEMPERATURE DFN	9	-3.95611	0.00370261	-0.66819
SEPT TO DEC PREC	9	2.89657	0.01759954	0.00837
SEPT TO DEC PREC	9	-4.40927	0.00208108	-0.00010
JAN TEMP DFN	9	-2.85308	0.01856069	-0.43123
APRIL TEMP DFN	9	1.03335	0.33061749	0.21747
MAY DAYS > 90 DEG F	9	-2.79858	0.02057290	-0.18491

R SQUARED	0.85939
ADJUSTED R SQUARE	0.76565
STANDARD ERROR	1.10456
STANDARD DEVITATION OF YIELDS	2.28171

ORIGINAL PAGE IS OF POOR QUALITY