AgRISTARS

YM-N4-04454
JSC 18906

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Yield Model Development

JANUARY 16, 1984

BRAZIL WHEAT YIELD COVARIANCE MODEL

(E84-10103) BRAZIL WHEAT YIELD COVARIANCE MODEL (National Oceanic and Atmospheric Administration) 22 p HC A02/MF A01 CSCL 02C

N84-21921

Unclas
G3/43 00103

SUSAN L. CALLIS
CLARENCE SAKAMOTO

USDA/NOAA
CIAD/MODELS BRANCH
ROOM 200, FEDERAL BLDG
608 CHERRY STREET
COLUMBIA, MO 65201

Lyndon B. Johnson Space Center
Houston, Texas 77058

1. Report No.
YM-N4-04454, JSC 18906

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Brazil Wheat Yield Covariance Model

5. Report Date
January 16, 1984

6. Performing Organization Code

7. Author(s)
Susan L. Callis and Clarence Sakamoto

8. Performing Organization Report No.

9. Performing Organization Name and Address
USDC/NOAA
CIAD/Models Branch
Room 200, Federal Bldg, 608 Cherry St.
Columbia, MO 65201

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, TX 77058

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A model based on multiple regression was developed to estimate wheat yields for the wheat-growing states of Rio Grande do Sul, Parana, and Santa Catarina in Brazil. The meteorological data of these three states were "pooled" and the years 1972 to 1979 were used to develop the model since there was no technological trend in the yields during these years. Predictor variables were derived from monthly total precipitation, average monthly mean temperature, and average monthly maximum temperature.

17. Key Words (Suggested by Author(s))
Multiple regression analysis
Predictor variables

18. Distribution Statement

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclasssified

21. No. of Pages
19

22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

BRAZIL WHEAT YIELD COVAPIANCE MODEL

by

Susan L. Callis

and

Clarence Sakamoto

AISC Models Branch

January 16, 1984

INTRODUCTION

The purpose of this study was to select monthly weather variables that could be used to estimate wheat yields for the wheat growing areas of Brazil. Wheat is grown in seven states in Brazil: Rio Grande do Sul, Santa Catarina, Parana, Sao Paulo, Mato Grosso, Goias, and Minas Gerais. Rio Grande do Sul is Brazil's original wheat-producing state; until 1972 it was the country's most important production area. Increasingly, however, Parana, Mato Grosso and Sao Paulo have grown in importance. In 1977, Parana took over the number one spot. Figure 1 shows the wheat-growing areas of Brazil.

Although wheat has been grown since the sixteenth century, Brazil has yet to develop a high-quality wheat variety that produces well under the country's widely varied climatic conditions. Brazil's wheat crops have continuously been plagued with problems resulting in consistently low yields. Frosts and plant disease occasionally reduce yields. The high cost discourages use of fungicides. Expansion of acreage sown to wheat was met with cultivating problems and high costs. New land areas cultivated in wheat are highly acidic and low in fertility. Fertilizer is costly. Late-season rains frequently delay harvest and reduce yield.

The climate of the southern wheat-producing states is "subtropical humid"; rainfall is relatively abundant and well-distributed throughout the year, with slightly more rainfall in the warm months. There is usually no season of drought. The northern states are "semiarid" with a winter dry season and less total annual rainfall. Summers are hot and winters are mild. Parana and southern Sao Paulo are the northern limit for frost ocurrence.

Wheat is planted in the months of April through June and is harvested in November and December.

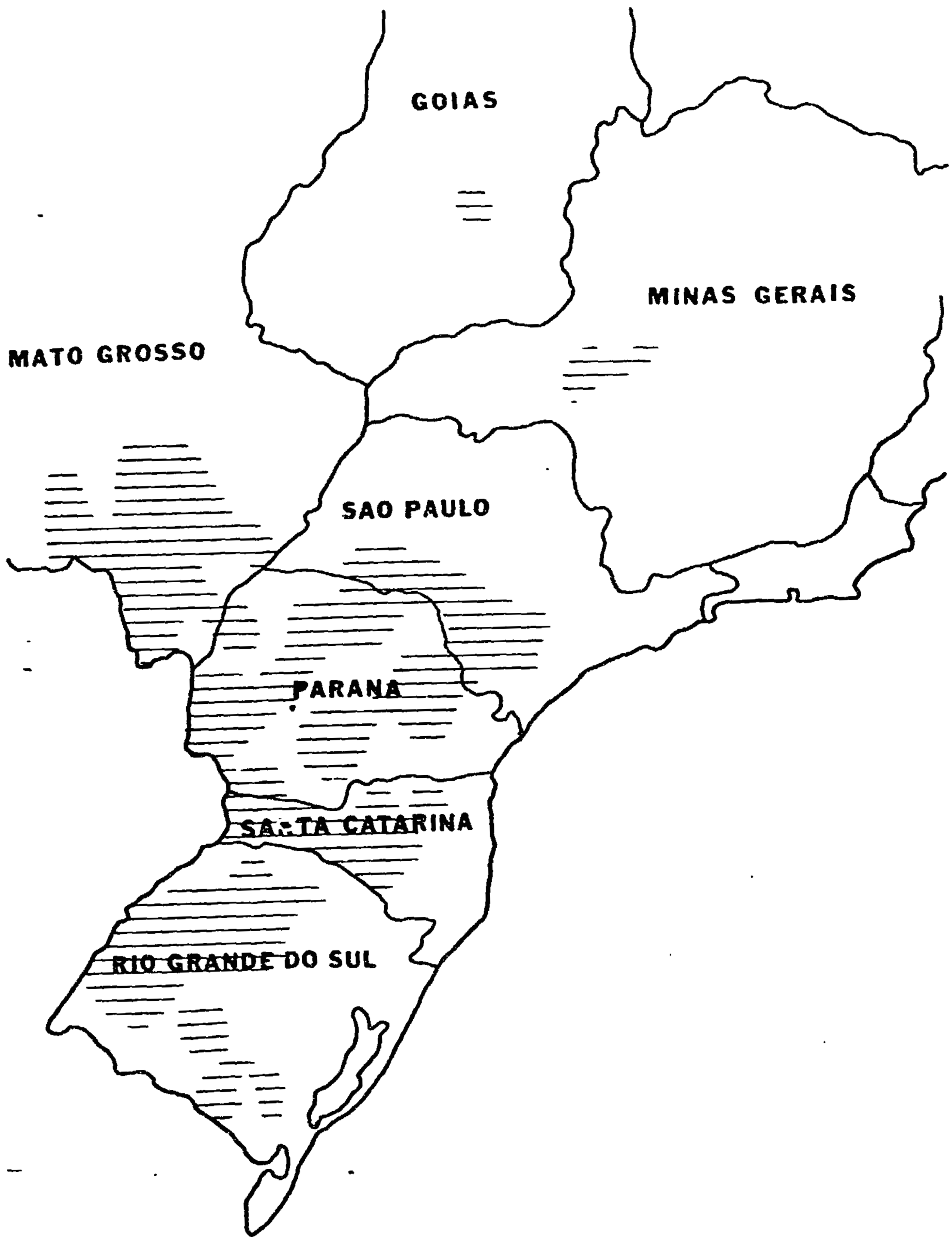


Figure 1. Wheat-growing areas of Brazil.
(J. McQuigg, R. Willis, 1982, personal communication)

METHOD

Multiple regression analysis of yield with selected agroclimatic indices was used to derive a suitable model. The index P-PET (precipitation minus potential evapotranspiration) was used in the regression equations to represent available soil moisture, monthly precipitation, and monthly maximum temperature.

The regression equation is:

$$\hat{Y} = \alpha + B_1 TX_i + B_2 R_i + B_3 (P\text{-}PET)_i + E$$

where

$\hat{Y}$ = Estimated yield,

α = Constant,

B_j = Coefficients of variables j = 1-3,

TX_i = Maximum temperature for month i,

R_i = Total precipitation for month i,

$(P\text{-}PET)_i$ = Precipitation minus PET for month i, and

E = Unexplained error.

In developing the model, various procedures of the Statistical Analysis System (SAS Institute, Inc., 1979) were used. The procedures used and the operations performed with each are summarized in the Appendix. The selected model had the highest R^2 and included variables that were significant at the 10 per cent level and agronomically meaningful.

DATA

The Brazil crop data were obtained from the Foreign Agricultural Service (Sam Ruff, Personal Communication, 1982). The data was recorded with year of yield as year of harvest, so the weather influencing the crop occurred during year - 1.

Meteorological data from 1972 through 1977 were used to model because there is no apparent trend in the yield data during this period. Furthermore, 1977 represented the latest available data. Table 1 lists the stations used to derive the meteorological data sets for each state. Figure 2 shows the location of each station.

PROCEDURES

Since Rio Grande do Sul's meteorological data has the longest period of record, initial models were developed for this state alone. Various weather variables were tried in regression equations in many different combinations. The results were not good. Several different trends were tried with different regression models, but none were significant at the 10 per cent level. From historical accounts, it is believed that some sort of trend of increased yield began in 1962 because of increased use of fertilizer and more adaptable varieties of wheat. Yet the yield data did not indicate this. It was decided to model for years 1972-1979 for which it was believed no trend existed. Eliminating years of data created the problem of fewer degrees of freedom. However, by combining data for the states of Rio Grande do Sul, Parana, and Santa Catarina, a covariance model could be devloped.

Variables used in the regression equations for the covariance model, included "dummy variables" for Parana and Santa Catarina. The "dummy variables" adjust the contributions to yield of both states to a base yield which, in this case, is Rio Grande do Sul's yield. The "dummy variable" for Parana was not significant at the 10 per cent level in the final model. The coefficient for Santa Catarina's "dummy variable" is negative, indicating that its yield is below that of the norm set by Rio Grande do Sul.

STATE	METEOROLOGICAL STATION	WMO NUMBER
Mato Grosso	Campo Grande	83611
	Ponta Pora	83702
	Pres Prudente	83716
Parana	Londrina	83766
	Santa Branca	83810
	Curitiba	83842
	Porto Uniao	83864
Rio Grande do Sul	Ijui	83805
	Sao Borja	83901
	Passo Fundo	83914
	Julio de Castilhas	83935
	Santa Maria	83936
	Sao Gabriel	83957
	Bage	83980
Santa Catarina	Porto Uniao	83864
	Vacaria	83918
	Sao Joaquim	83920
Sao Paulo	Pres Prudente	83716
	Bauru	83722
	Jau	83723
	Tiete	83777
	Ataliba Leonel	83803
	Tatui	83816

Table 1. Meteorological Stations Used to Derive Data Sets for the Brazil Wheat Model.

Figure 2. Location of Meteorological Stations Used to Derive Data Sets for the Brazil Wheat Model.

The following is the selected model:

DUM	Dummy variable to adjust Santa Catarina's yield
TM7	July Mean Temperature
P-PET8	August P-PET
SP-PET8	Squared August P-PET
P-PET9	September P-PET
RDFN11	Deviation from normal of November precipitation

Too high temperatures in July and too much rainfall in November both reduce yield. The negative coefficient for the linear term P-PET8 suggests that in August excess precipitation above demand, PET8, is damaging to yield. This is reasonable in Brazil when in August the crop is in the tillering stage. The quadratic term indicates that increased yield is favorable at some level when PET is higher than precipitation. However, one is cautioned not to extend this interpretation beyond the limits of the data base used. The statistics of the selected model are summarized in Table 2.

The same variables were used in regression equations for only the two states of Rio Grande do Sul and Santa Catarina. The problem encountered was that models with agronomically reasonable variables had too low an R^2; models with acceptable R^2 had too many variables for the number of degrees of freedom.

Finally, modeling was attempted for the northern states of Mato Grosso and Sao Paulo. Overlapping plots of weather variables versus yield were made for both states. From these plots, it was determined that modeling for a combination of data for these two states would not be acceptable; their climates are too different. Next, reasonable weather variables were tried in regression for both states separately. No suitable models were derived. For information, plots of yields for both states are shown in Figure 3.

TEST RESULTS

A jackknife test was run on the selected model. In this test, a year was eliminated from the crop data and the model was used to predict that year's yield. This process was done for each successive year beginning with 1972. The test had to be run separately on each state. The results are printed on Tables 3 through 5 and plotted on Figures 4 through 6.

APPENDIX

Definition of Variables

P-PET, precipitation minus potential evapotranspiration, is used a measure of the amount of moisture available for plant growth. Potential evapotranspiration is determined by the procedure developed by Thornthwaite (1948). It requires only temperature:

$$PET = \left(\frac{10T}{I}\right)^{a}$$

where I = heat index, which is the sum of the 12 monthly indices i,

$$i = \left(\frac{T}{5}\right)^{1.514}$$

T = monthly temperature in °C, and

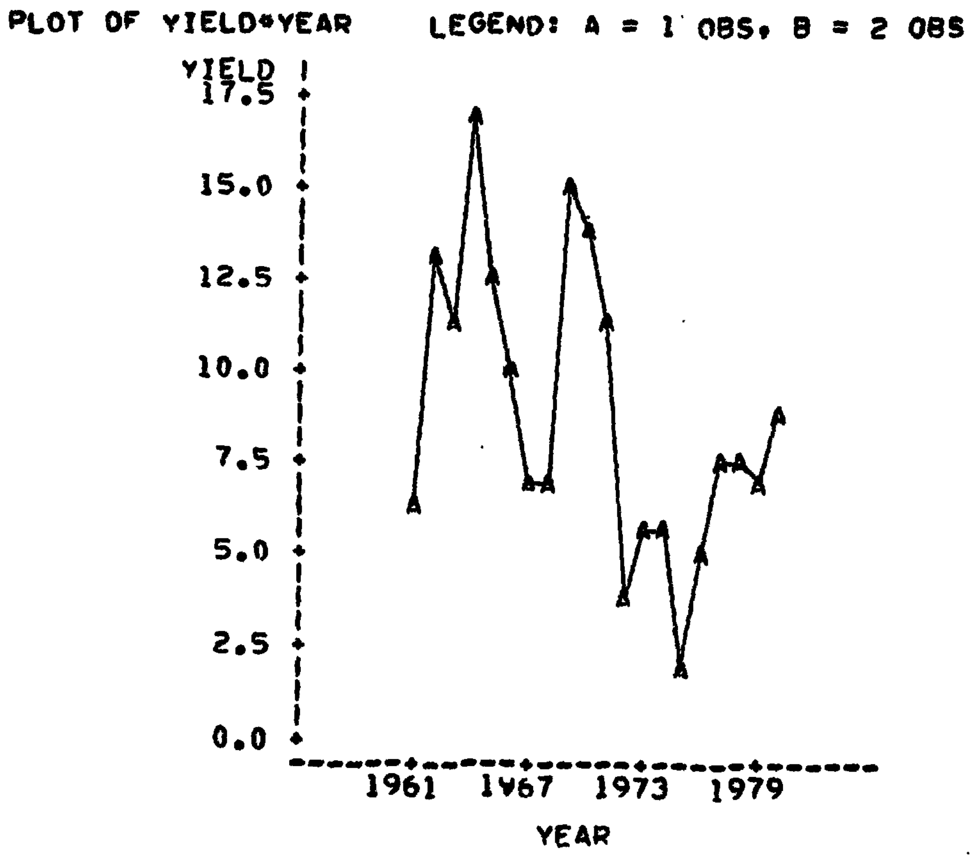
a = an empirical exponent $6.75 \times 10^{-7}I^3 - 7.71 \times 10^{-5}I^2 + 1.79 \times 10^{-2}I + 0.49$.

The duration of daylight is used to adjust potential evapotranspiration as a portion of 12 hours.

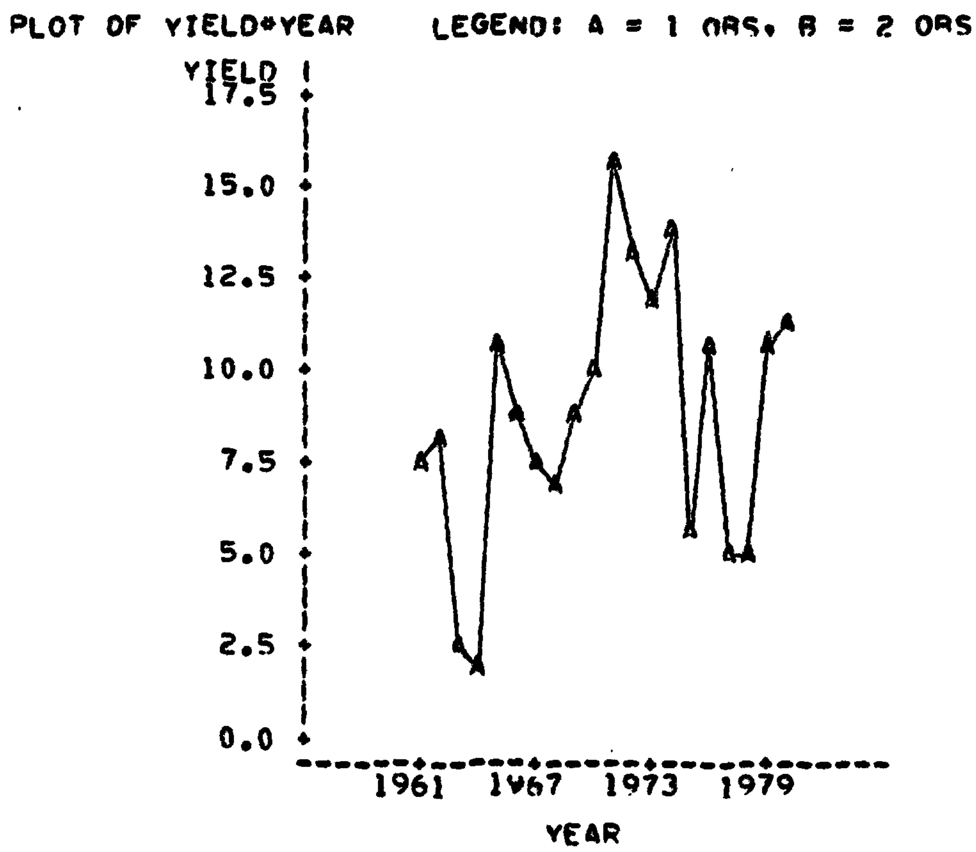
Statistical Analysis System Procedures Used

PROC CORR	Computes correlation coefficients between variables, including Pearson product-moment and weighted product-moment correlation.
PROC PLOT	Graphs one variable against another, producing a printer plot.
PROC STEPWISE	Provides five methods for stepwise regression. Stepwise is useful when selecting variables to be included in a regression model from a collection of independent variables.
PROC STEPWISE FORWARD	Begins by finding the one-variable model that produces the highest R^2. For each of the other independent variables, FORWARD calculates F-statistics reflecting the contribution to the model if the variable were to be included.

PROC STEPWISE BACKWARD	Begins by calculating statistics for a model including all the indepedent variables. The variables are deleted from the model one by one until all the remaining variables produce F-statistics significant at the .10 level.
PROC STEPWISE STEPWISE	The stepwise method is a modification of the forward selection technique, differing in that variables already in the model do not necessarily stay there. After a variable is added (as in the forward selection method) the stepwise method looks at all the variables already included in the model and deletes any variable that does not produce an F-statistic significant at the .10 level. Only after this check is made and the necessary deletions accomplished can another variable be added to the model.
PROC STEPWISE MAXR	(Maximum R^2 improvement) Unlike the three techniques above, this method does not settle on a single method. Instead it looks for the "best" two-variable model, the "best" three variable model, and so forth.
PROC PETM	Uses latitude and mean monthly temperature to calculate Thornthwaite's potential evapotranspiration for each month.
PROC ZINDEX	Uses monthly PET's, precipitation, SS (beginning moisture in surface layer), AWCS (available water capacity in surface layer), SU (beginning moisture in the underlying layer), and AWCU (available water capacity in the underlying layer) to calculate Palmer's soil moisture budget, drought index Z, ET, and $\hat{ET}$.



MATO GROSSO



SAO PAULO

Figure 3. Plots of Yields Versus Year for the States of Mato Grosso and Sao Paulo.

STATISTICAL ANALYSIS SYSTEM 16:30 MONDAY, OCTOBER

BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE YIELD

ALL VARIABLES ENTERED R SQUARE = 0.66192865 C(P) = 7.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	127.21107023	21.20184504	5.55	0.0024
ERROR	17	64.97137977	3.82184587		
TOTAL	23	192.18245000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	27.91871003				
DUM2 (Santa Catarina)	-4.90522435	1.45414184	43.54320431	11.39	0.0036
TM7	-1.04143789	0.43136638	22.28065116	5.83	0.0273
P_PET8	-0.04612431	0.01950938	21.36220762	5.59	0.0302
SQ_PET8	0.00016216	0.00007626	17.27858281	4.52	0.0484
P_PET9	-0.02743603	0.00990298	29.33485132	7.68	0.0131
POFN11	-0.04206852	0.00980494	70.35548490	18.41	0.0005

BLES IN THE MODEL ARE SIGNIFICANT AT THE 0.1000 LEVEL.

Table 2. Statistics of Brazil Wheat Model

ORIGINAL PAGE IS
OF POOR QUALITY

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   16:30 MONDAY, OCTOBER

ETA3	BEGMODYR	ENDMODYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES	BETA1	BETA2
.3376	1973	1979	1972	5.9553	6.46	0.712347	1.46356	14	3.33041	33.0919	-6.3795
.2773	1972	1979	1973	8.5777	11.28	0.666831	1.04638	14	3.92005	31.8241	-5.5376
.0703	1972	1979	1974	12.1987	13.86	0.608324	1.59529	14	3.96807	27.9912	-4.7060
.0597	1972	1979	1975	5.7944	5.55	0.631051	2.35069	14	4.54600	26.0310	-4.8158
.0430	1972	1979	1976	7.6308	9.30	0.665166	0.68394	14	4.37230	28.0588	-5.0136
.1443	1972	1979	1977	11.7472	8.99	0.764795	3.86971	14	2.73269	14.6674	-2.1415
.0180	1972	1979	1978	9.3025	7.81	0.681851	0.68430	14	3.91461	27.3328	-4.7851
.9298	1972	1978	1979	9.7477	10.98	0.677955	1.84271	14	3.93095	25.8588	-4.8607

BETA4	BETA5	BETA6	BETA7	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	CONRIB6	CONRIB7	B
.054569	0.000234444	-0.037211	-0.039880	33.0919	0	-18.459	-8.6644	5.91045	-7.5438	1.6201	
.052746	0.000136275	-0.030710	-0.045481	31.8241	0	-19.288	-7.7577	4.02948	-2.8513	2.6208	
.0[illegible]9979	0.000173004	-0.023269	-0.041071	27.9912	0	-15.841	-2.2036	0.32324	0.0956	1.8328	
.044516	0.000143520	-0.024670	-0.042139	28.0310	0	-12.717	-2.5330	0.48086	-2.8584	-4.6090	
.053361	0.000133142	-0.025419	-0.045017	28.0588	0	-15.436	-6.8350	3.00476	-2.3601	1.1986	
.033306	0.000102880	-0.022168	-0.031598	14.0674	0	-2.511	1.0513	0.10251	-0.6031	-0.9598	
.044129	0.000155548	-0.026655	-0.042177	27.3328	0	-15.677	-0.9743	0.07584	-0.7222	-0.7328	
.038251	0.000132423	-0.024716	-0.042105	25.8588	0	-11.902	-0.7994	0.05783	-2.9469	-0.5210	

ORIGINAL PAGE IS
OF POOR QUALITY

Table 3. Results of Jackknife Test for State of Parana Wheat Model

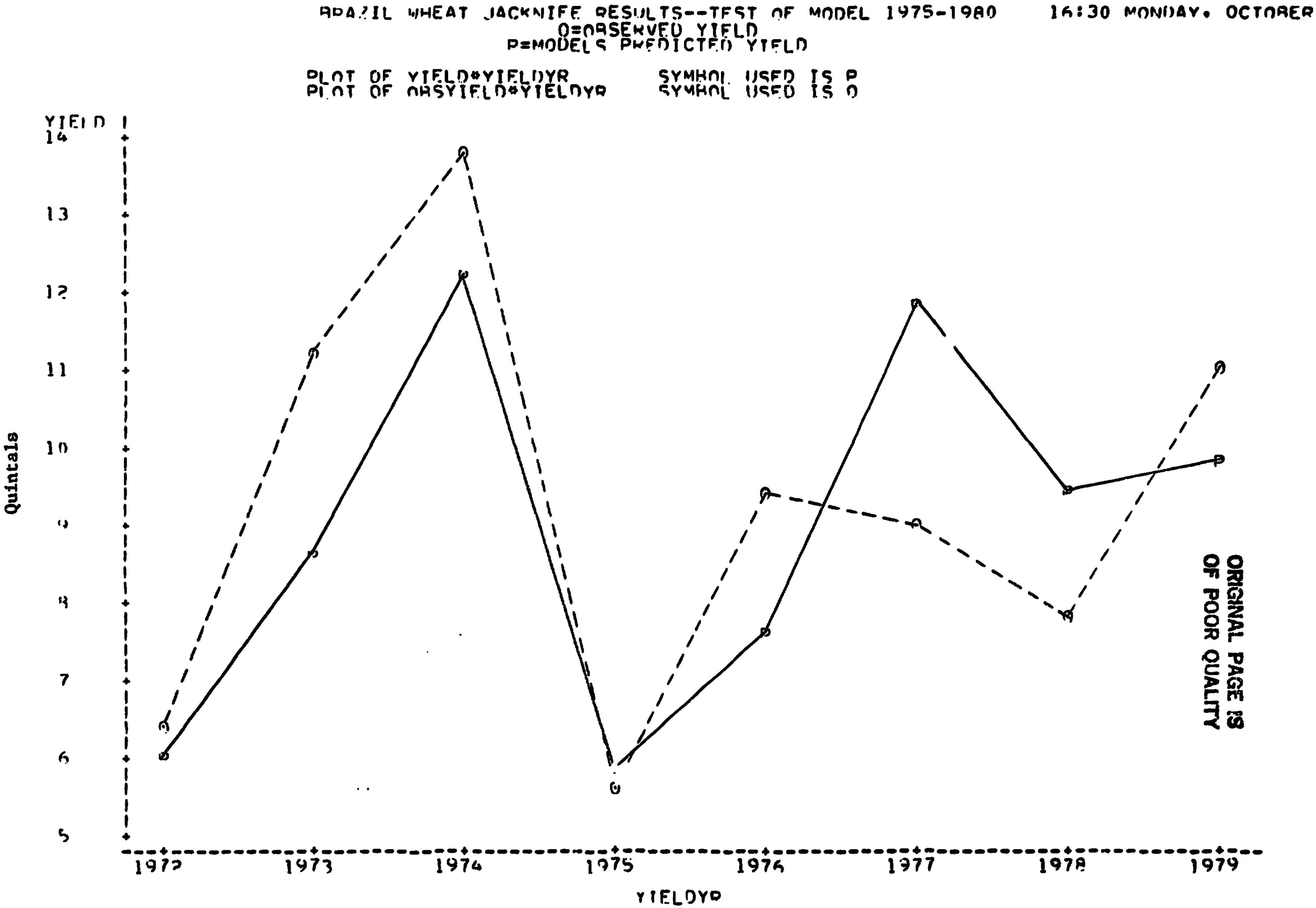


Figure 4. State of Parana Wheat Model.

BRAZIL WHEAT JACKNIFE RESULTS--TEST OF MODEL 1975-1980   16:30 MONDAY, OCTOBER

O=OBSERVED YIELD

P=MODELS PREDICTED YIELD

BETA3	BEGMODLYR	ENDMODLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES	BETA1	BETA2
.3376	1973	1979	1972	8.6982	3.56	0.712347	7.55088	14	3.33041	33.0919	-6.3795
.2773	1972	1979	1973	13.1756	11.19	0.666831	3.65706	14	3.92005	31.8241	-5.5376
.0703	1972	1979	1974	7.6617	10.80	0.608324	1.02987	14	3.96807	27.9912	-4.7060
.0597	1972	1979	1975	7.0672	6.50	0.631051	0.86685	14	4.54600	28.0310	-4.8158
.0430	1972	1979	1976	8.9191	9.00	0.665166	0.86604	14	4.37230	28.0588	-5.0136
.1443	1972	1979	1977	8.8652	4.53	0.764795	2.08209	14	2.73269	14.6674	-2.1415
.0180	1972	1979	1978	9.2426	12.10	0.681851	0.63813	14	3.91461	27.3328	-4.7851
.9298	1972	1978	1979	7.8307	4.90	0.677955	0.87393	14	3.93095	25.8588	-4.8507

BETA4	BETA5	BETA6	BETA7	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	CONRIB6	CONRIB7
.054569	0.000234444	-0.037211	-0.039880	33.0919	0	-17.656	-13.860	15.1241	-5.8828	-2.1196
.052746	0.000186275	-0.030710	-0.045481	31.8241	0	-17.244	-7.061	3.3385	-2.2242	4.5424
.050979	0.000173004	-0.023269	-0.041071	27.9912	0	-16.911	-5.120	1.7451	-0.4081	0.3645
.044516	0.000144520	-0.024670	-0.042139	28.0310	0	-13.670	-6.688	3.3519	-3.4046	-0.5531
.053361	0.000133142	-0.025419	-0.045017	28.0588	0	-13.455	-4.003	1.0304	-1.6719	-1.0410
.033306	0.000102880	-0.022168	-0.031548	14.6674	0	-2.410	-3.394	1.0685	-0.8096	-0.2567
.044129	0.000155598	-0.026655	-0.042177	27.3328	0	-15.270	-1.148	0.1053	-0.6761	-1.1019
.038251	0.000132423	-0.024716	-0.042105	25.8588	0	-12.088	-4.378	1.7348	-3.9234	0.6263

Table 4. Results of Jackknife Test for State of Rio Grande do Sul Wheat Model

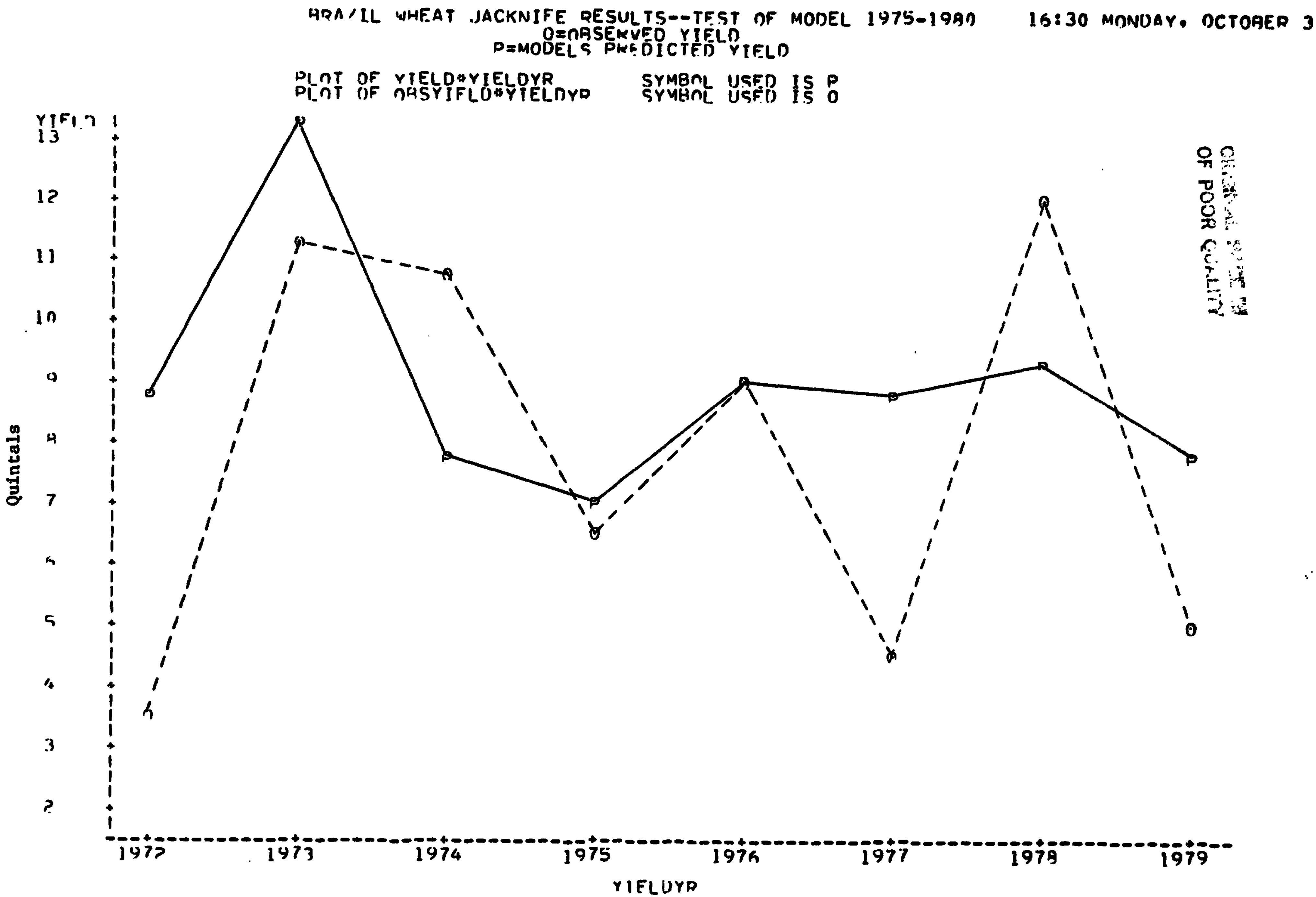


Figure 5. State of Rio Grande do Sul Wheat Model

BRAZIL WHEAT JACKNIFE RESULTS--TEST OF MODEL 1975-1980 16:30 MONDAY, OCTOBER

O=OBSERVED YIELD

P=MODELS PREDICTED YIELD

BETA2	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	PSQ	PDEP	DFRES	MSRES	BETA1
.184269	1973	1979	1972	5.6879	5.10	0.344354	12.8700	15	7.08494	7.3504
.145179	1972	1979	1973	7.0093	8.68	0.404981	5.8994	15	6.53424	7.9057
.067167	1972	1979	1974	8.8690	8.16	0.363560	1.9440	15	6.01792	8.6446
.027416	1972	1979	1975	7.2199	4.50	0.404770	4.5806	15	6.84517	9.6434
.171277	1972	1979	1976	3.9227	5.42	0.435712	7.2783	15	6.87730	7.6186
.451800	1972	1979	1977	10.7720	3.82	0.731782	0.4588	15	2.90850	5.1787
.064255	1972	1979	1978	10.0950	8.26	0.463774	1.6311	15	6.15804	9.1948
.224322	1972	1978	1979	5.4724	6.15	0.459698	1.9774	15	6.15536	6.2287

BETA3	BETA4	BETA5	BETA6	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	CONRIB6
.018689	0.0000541226	-0.009602	-0.024867	7.35043	2.11910	-4.7694	3.52506	-2.3229	-0.2145
.023050	0.0000323832	-0.007579	-0.019501	7.90570	1.74215	-5.3990	2.16077	-1.1237	1.7234
.021009	0.0000411920	-0.006056	-0.025397	8.64460	0.84630	-1.3503	0.17016	0.0154	0.5429
.019352	0.0000287391	-0.007553	-0.031867	9.64346	0.25771	-2.2195	0.37803	-1.5847	0.7449
.022002	0.0000559551	-0.007790	-0.030820	7.61866	1.71277	-2.5858	0.59851	-0.1353	-3.2862
.021544	0.0000493990	-0.015540	-0.024336	5.17872	6.28002	-1.0136	0.10936	0.0138	0.2038
.020423	0.0000396174	-0.009736	-0.031134	9.19480	0.83532	-0.5631	0.03012	-0.6591	1.2570
.005449	0.0000012694	-0.011512	-0.026926	6.22878	2.28809	-0.2896	0.00359	-0.9645	-1.7940

Table 5. Results of Jackknife Test for State of Santa Catarina Wheat Model

ORIGINAL PAGE IS
OF POOR QUALITY

BRAZIL WHEAT JACKNIFE RESULTS--TEST OF MODEL 1975-1980 16:30 MONDAY, OCTOBER 31

O=OBSERVED YIELD

P=MODELS PREDICTED YIELD

PLOT OF YIELD*YIELDYR SYMBOL USED IS P

PLOT OF OBSYIELD*YIELDYR SYMBOL USED IS O

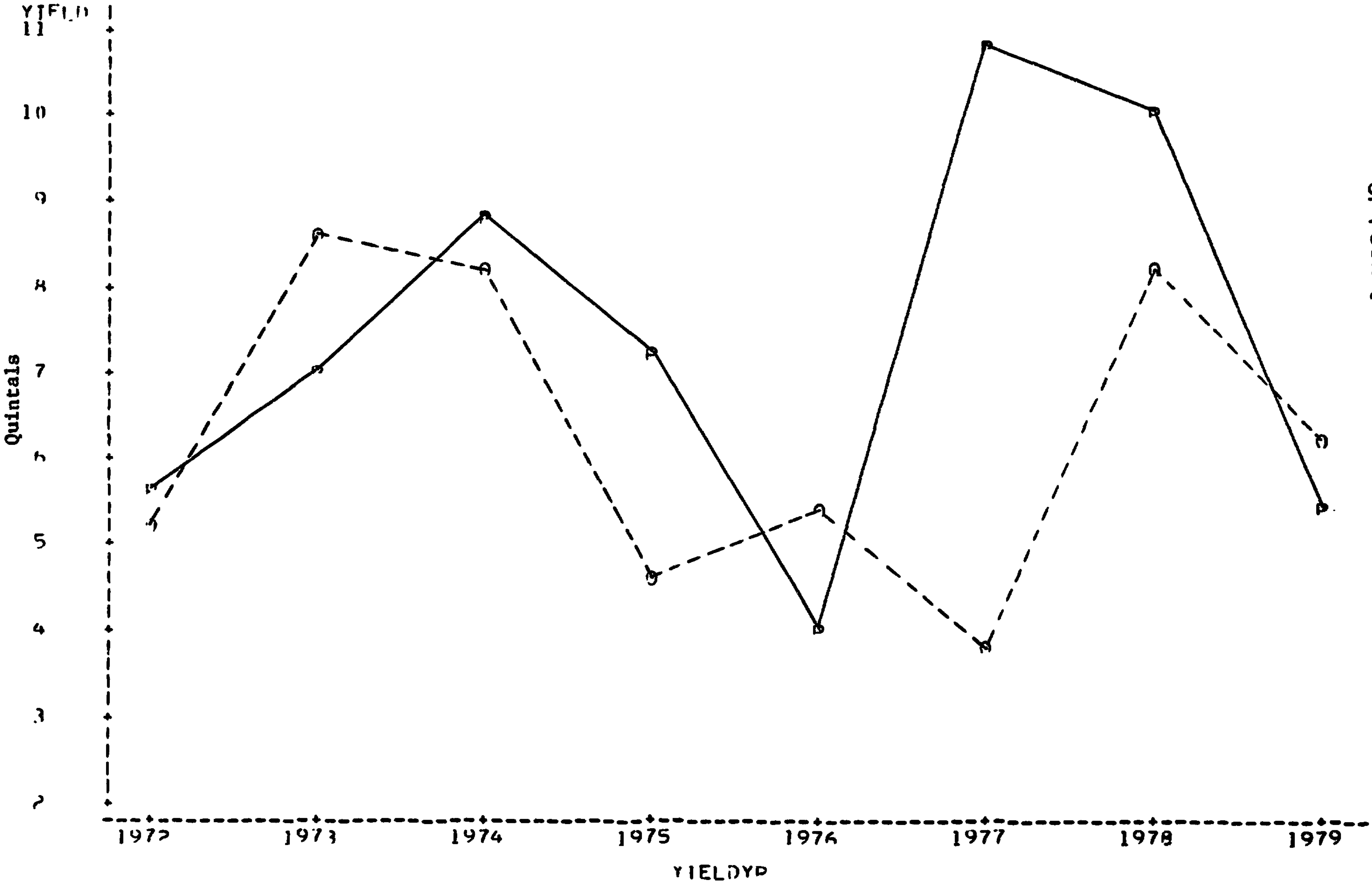


Figure 6. State of Santa Catarina Wheat Model