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YM-N4-04455
JSC 18907

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

Yield Model Development

JANUARY 16, 1984

BRAZIL SOYBEAN YIELD COVARIANCE MODEL

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
YM-N4-04455, JSC 18907		

4. Title and Subtitle	5. Report Date
Brazil Soybean Yield Covariance Model	January 16, 1984
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Susan L. Callis and Clarence Sakamoto	
	10. Work Unit No.

9. Performing Organization Name and Address	11. Contract or Grant No.
USDC/NOAA CIAD/Models Branch Room 200, Federal Bldg, 608 Cherry St. Columbia, MO 65201	
	13. Type of Report and Period Covered

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, TX 77058	

15. Supplementary Notes

16. Abstract

A model based on multiple regression was developed to estimate soybean yields for the seven soybean-growing states of Brazil. The meteorological data of these seven states were "pooled" and the years 1975 to 1980 were used to model since there was no technological trend in the yields during these years. Predictor variables were derived from monthly total precipitation and monthly average temperature.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Multiple regression analysis Predictor variables	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	24	

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

BRAZIL SOYBEAN YIELD COVARIANCE MODEL

by

Susan L. Callis

and

Clarence Sakamoto

AISC Models Branch

January 16, 1984

INTRODUCTION

The purpose of this study was to select weather variables that could be used to estimate the soybean yields for the country of Brazil. Soybean production in Brazil had its inception in the state of Rio Grande do Sul where soybeans were first planted in rotation with wheat. Presently, soybeans are planted in seven southern states: Rio Grande do Sul, Santa Catarina, Parana, Sao Paulo, Mato Grosso, Goias and Minas Gerais. This means that a variety of growing conditions are covered in this extensive area. Figure 1 is a map of the soybean-growing areas of Brazil.

The northern part of the soybean area, including the states of Mato Grosso, Goias, and Minas Gerais, are characterized by a "wet-and-dry" climate with a dry season of two or more months. The rest of the area is subtropical humid with relatively abundant rainfall which is well-distributed throughout the year but with slightly more rainfall in the warm months. Summers are hot and winters relatively mild. Temperatures in the summer are above 40°C in the plains of Rio Grande do Sul when warm air masses penetrate the plains. Southern Sao Paulo is the northern limit for frost occurrence.

The soybean growing season begins with planting in October and November and runs through April and May when harvest starts.

METHOD

Multiple regression analysis of yield with selected agroclimatic indices was used tc derive a suitable model. The first approach taken was to develop a model for each state. However, lack of data for several states posed a problem and no suitable models were derived. Therefore, it was decided to create a covariance model whereby all the available data are combined to obtain a model for the country.

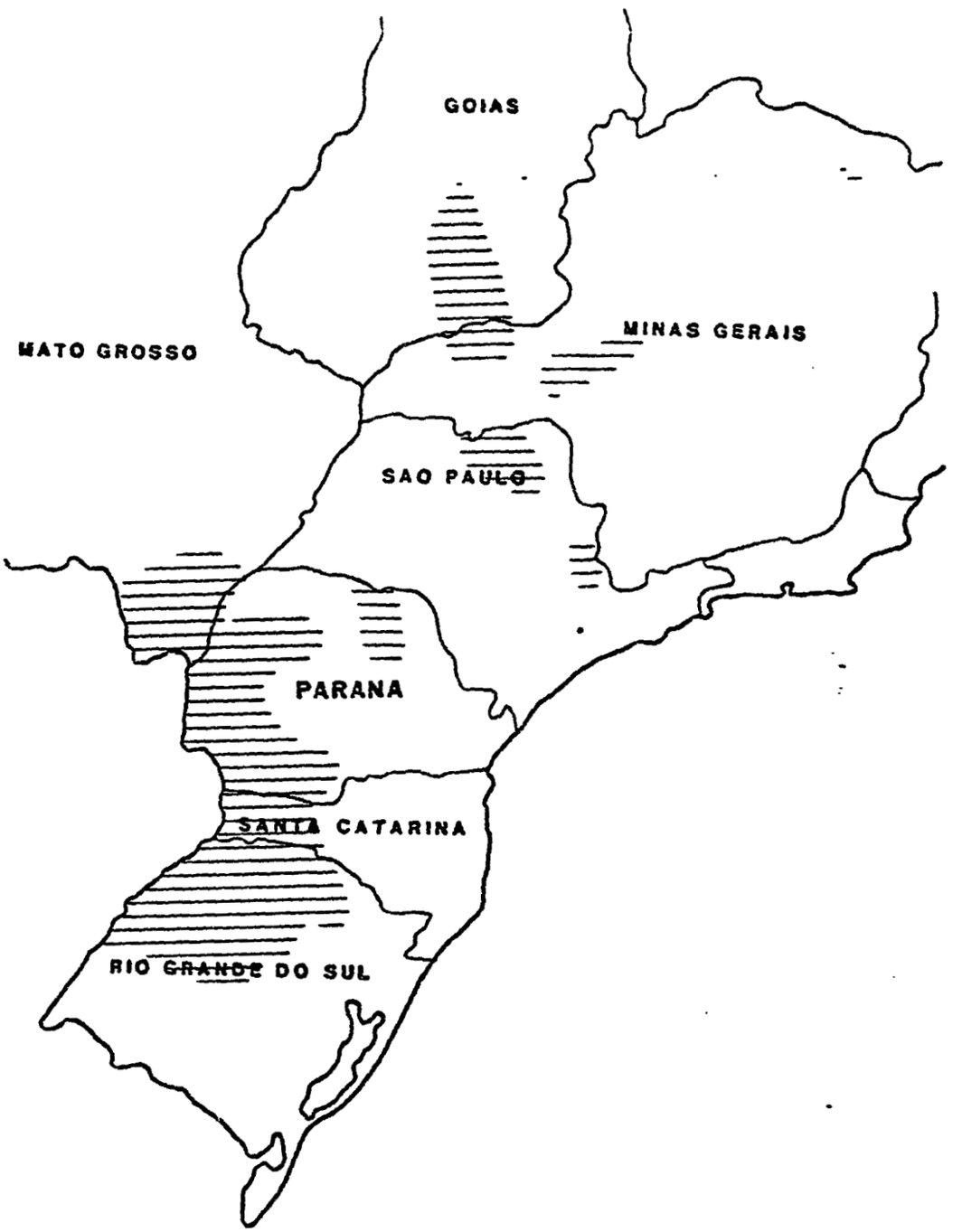

Figure 1. Soybean-growing areas of Brazil. (Pitcher, 1971)

Since moisture stress was considered a prime determinant of yield, the index P-PET (precipitation minus potential evapotranspiration) was used in the regressions.

The regression equation is:

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

where

$\hat{Y}$ = Estimated yield,

α = Constant,

B_j = Coefficients of the variables j = 1 - 3,

D = Dummy variable to adjust each state's yield to a base yield set by Rio Grande's do Sul's yield,

$RDFN_i$ = Deviation from normal of 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 significant at (or close to) the 10 per cent level and agronomically meaningful.

DATA

The Brazil crop data for 1961 thru 1977 were obtained from the Foreign Agricultural Service (Sam Ruff, personal communication, 1982). The data were recorded with year of yield as year of harvest, so the weather influencing the crop occurred during year-1.

Meteorological data from 1975 through 1980 were used to model because there is no apparent trend in the yield data during this period. Table 1 lists

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

STATE	METEOROLOGICAL STATION	WMO NUMBER
Goias	Brasilia/Cruzeiro	83377
	Goiania	83423
Mato Grosso	Ponta Pora	83702
	Pres Prudente	83716
	Foz do Iguacu	83826
Minas Gerais	Montes Claros	83437
	Araxa	83579
Parana	Londrina	83766
	Santa Branca	83810
	Foz do Iguacu	83826
	Porto Uniao	83864
Rio Grande do Sul	Ijui	83805
	Veranopolis	83806
	Farroupilha	83807
	Sao Borja	83901
	Passo Fundo	83914
	Julio de Castilhas	83935
	Santa Maria	83936
Santa Catarina	Porto Uniao	83864
	Sao Joaquim	83920
	Vacaria	83918
Sao Paulo	Pindorama	83664
	Ribeiro Preto	83668
	Mococa	83680
	Bauru	83722
	Jau	83723
	Limeira	83728
	Campinas	83729
	Monte Alegre do Sul	83730
	Tiete	83777
	Sao Paulo	83800
	Jundiqi	83802

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

the stations used to derive the meteorological data set for each state. Figure 2 shows the location of each station. The seven states of Rio Grande do Sul, Santa Catarina, Parana, Sao Paulo, Mato Grosso, Goias, and Minas Gerais were included in the covariance model.

PROCEDURES

The original variables used in the regression equation included "dummy variables" for six of the seven states (Rio Grande do Sul was the exceptio... The "dummy variables" adjust the contributions to yield of each of the states to a base yield which, in this case, is Rio Grande do Sul's yield. Weather variables selected reflected available moisture for the months December through March. The variables which were significant at the 10 per cent level were the "dummy variables" for Sao Paulo, Parana, and Santa Catarina and the P-PET for January and February (see the Appendix for a definition of P-PET). The coefficient for the Santa Catarina "dummy variable" was negative, indicating its yield was below that of the norm set by Rio Grande do Sul; the coefficients for the other dummy variables were positive. The coefficients for January and February P-PET were positive, indicating a need for moisture during those critical months. The statistics of the selected model are summarized in Table 2.

TEST RESULTS

A jackknife test was run on the final 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 1975. The test had to be run separately on each state. The results are printed on Tables 3 through 9 and plotted on Figures 3 through 9.

APPENDIX

Definition of Variables

P-PET, precipitation minus potential evapotranspiration, is an index used to measure the amount of moisture available for plant growth. Potential evapotranspiration is determined by the procedure developed by Thornthwaite (1948) which uses 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 independent 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 ET.

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 14:37 TUESDAY, NOVEMBI

BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE YIELD

ALL VARIABLES ENTERED R SQUARE = 0.78015340 C(P) = 6.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	367.92708501	73.58541700	25.55	0.0001
ERROR	36	103.68156547	2.88004321		
TOTAL	41	471.60864048			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	14.01238649				
DUM4 (Sao Paulo)	3.19206660	0.77780630	48.50650422	16.84	0.0002
DUM5 (Parana)	5.66181789	0.77538347	153.55986428	53.32	0.0001
DUM6 (Santa Catarina)	-2.02308857	0.78146302	19.30242760	6.70	0.0138
DP_PET1	0.01724433	0.00304775	92.20057197	32.01	0.0001
DP_PET2	0.01021039	0.00340283	25.93009625	9.00	0.0049

ABLES IN THE MODEL ARE SIGNIFICANT AT THE 0.1000 LEVEL.

Table 2. Statistics of Brazil Soybean Model

BRAZIL SOYBEAN JACKNIFE RESULTS--TEST OF MODEL 1975-1980
O=OBSERVED YIELD
P=MODELS PREDICTED YIELD

14:37 TUESDAY, NOVI

BETA2	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES	BETA1
3.52783	1976	1980	1975	12.6281	13.60	0.761662	0.25262	29	3.23711	13.9006
3.44230	1975	1980	1976	10.7397	14.80	0.795559	0.49241	29	2.80618	13.6744
3.47177	1975	1980	1977	13.2269	13.60	0.778618	0.65619	29	3.03799	14.1556
2.67107	1975	1980	1978	15.4910	11.11	0.859119	0.14115	29	1.95932	14.3360
2.98822	1975	1980	1979	17.4906	18.50	0.772079	0.81110	29	2.94903	14.1454
3.16776	1975	1979	1980	19.8857	18.56	0.755441	1.44984	29	3.11795	13.8794

BETA3	BETA4	BETA5	BETA6	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	CONRIB6
5.35628	-2.1065	0.0171992	0.0110723	13.9006	0	0	0	-1.2056	-0.06685
5.63172	-1.6158	0.0213146	0.0070771	13.6744	0	0	0	-3.1190	0.18440
5.53279	-2.3067	0.0186637	0.0068621	14.1556	0	0	0	-0.1325	-0.79626
6.09044	-2.2149	0.0156629	0.0126482	14.3360	0	0	0	0.1044	1.05051
5.83360	-1.7355	0.0142275	0.0111423	14.1454	0	0	0	3.1998	0.14547
5.61586	-2.1980	0.0176922	0.0098263	13.8794	0	0	0	4.0012	2.00511

Table 3. Results of Jackknife Test for State of Goias Soybean Model.

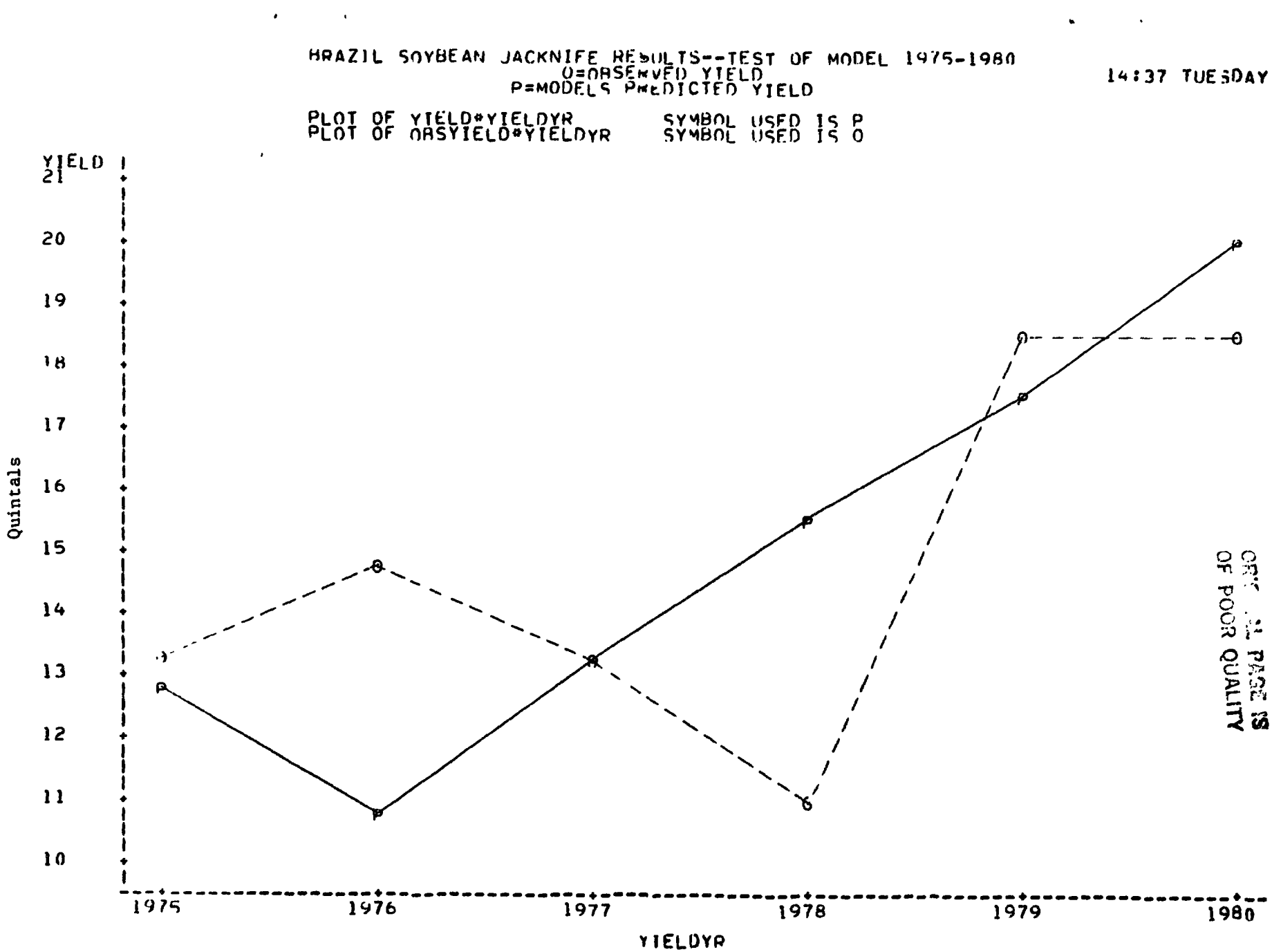

Figure 3. State of Goias Soybean Model.

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BETA2	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES	BETA1
.52783	1976	1980	1975	13.1023	14.03	0.761662	0.208841	29	3.23711	13.9006
.44230	1975	1980	1976	13.7371	15.40	0.795559	0.258191	29	2.80618	13.6744
.47177	1975	1980	1977	16.0000	16.87	0.778618	0.756751	29	3.03799	14.1556
.67107	1975	1980	1978	12.3155	12.12	0.859119	0.223157	29	1.95932	14.3360
.98822	1975	1980	1979	13.9890	14.46	0.772079	0.149887	29	2.94903	14.1454
.16776	1975	1979	1980	14.3398	16.34	0.755441	0.265288	29	3.11795	13.8794

BETA3	BETA4	BETA5	BETA6	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	CONRIB
.35628	-2.1065	0.0171992	0.0110723	13.9006	0	0	0	-0.62259	-0.175
.63172	-1.6158	0.0213146	0.0070771	13.6744	0	0	0	-0.52136	0.584
.53279	-2.3067	0.0186637	0.0068621	14.1556	0	0	0	2.22888	-0.384
.09044	-2.2149	0.0156629	0.0126482	14.3360	0	0	0	-0.96383	-1.056
.83360	-1.7355	0.0142275	0.0111423	14.1454	0	0	0	-0.17727	0.020
.61586	-2.1980	0.0176922	0.0098263	13.8794	0	0	0	-0.40595	0.866

Table 4. Results of Jackknife Test for State of Mato Grosso Soybean Model.

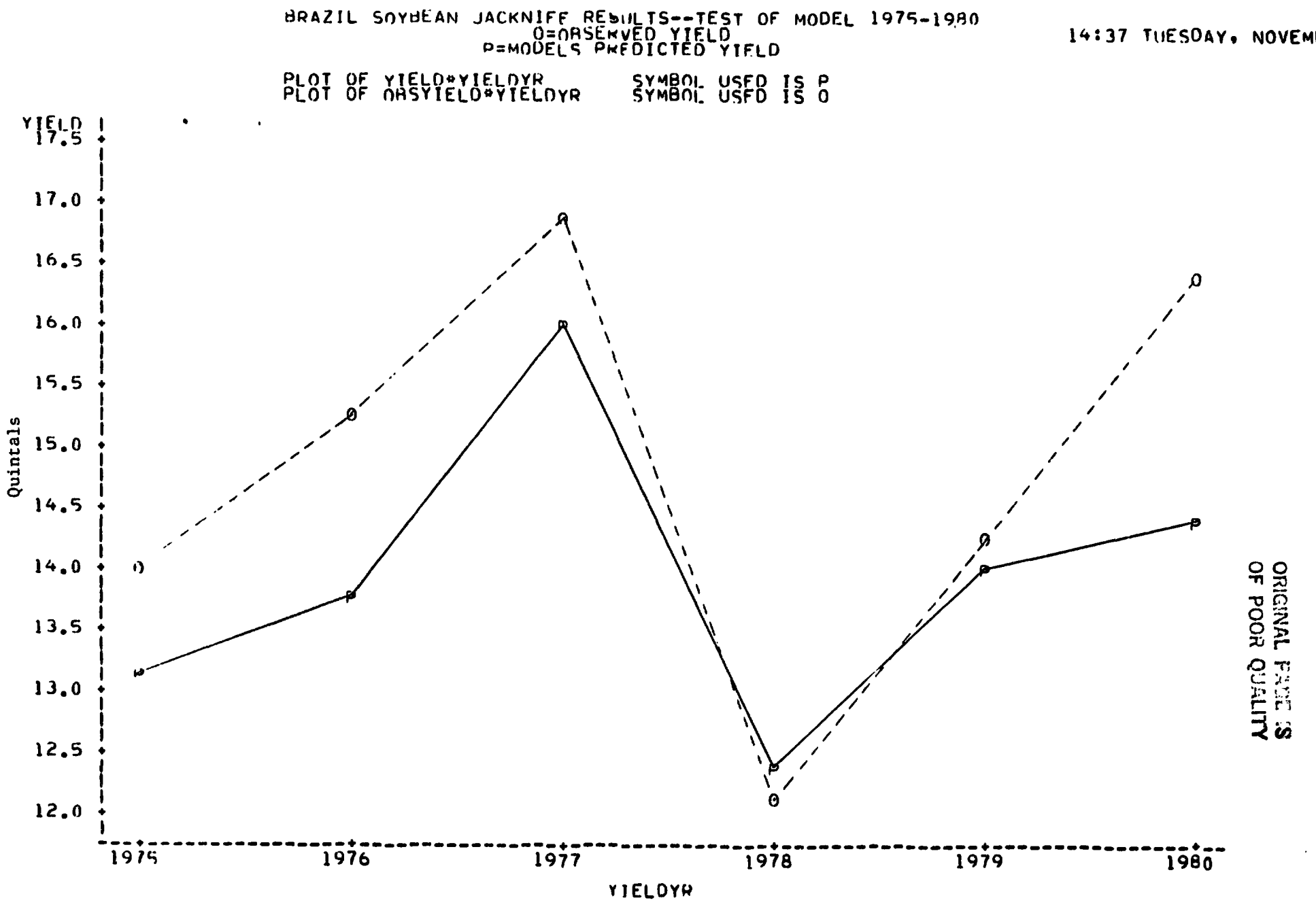

Figure 4. State of Mato Grosso Soybean Model.

BRAZIL SOYBEAN JACKNIFE RESULTS--TEST OF MODEL 1975-1980
O=OBSERVED YIELD
P=MODELS PREDICTED YIELD

14:37 TUESDAY,

BETA2	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES	BETA1
3.52783	1976	1980	1975	11.6265	11.83	0.761662	0.36225	29	3.23711	13.900
3.44230	1975	1980	1976	10.7882	13.45	0.795559	0.59274	29	2.80618	13.674
3.47177	1975	1980	1977	14.3705	10.58	0.778618	1.05210	29	3.03799	14.155
2.67107	1975	1980	1978	15.9830	12.43	0.859119	0.23152	29	1.95932	14.336
2.98822	1975	1980	1979	17.4271	16.85	0.772079	0.55237	29	2.94903	14.145
3.16776	1975	1979	1980	16.1272	17.54	0.755441	0.36431	29	3.11795	13.879

BETA3	BETA4	BETA5	BETA6	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	CONRI
5.35628	-2.1065	0.0171992	0.0110723	13.9006	0	0	0	-1.7948	-0.47
5.63172	-1.6158	0.0213146	0.0070771	13.6744	0	0	0	-3.2946	0.40
5.53279	-2.3067	0.0186637	0.0068621	14.1556	0	0	0	1.1363	-0.92
6.09044	-2.2149	0.0156629	0.0126482	14.3360	0	0	0	-0.0332	1.68
5.83360	-1.7355	0.0142275	0.0111423	14.1454	0	0	0	1.4005	1.88
5.61586	-2.1980	0.0176922	0.0098263	13.8794	0	0	0	2.1610	0.08

Table 5. Results of Jackknife Test for State of Minas Gerais Soybean Model.

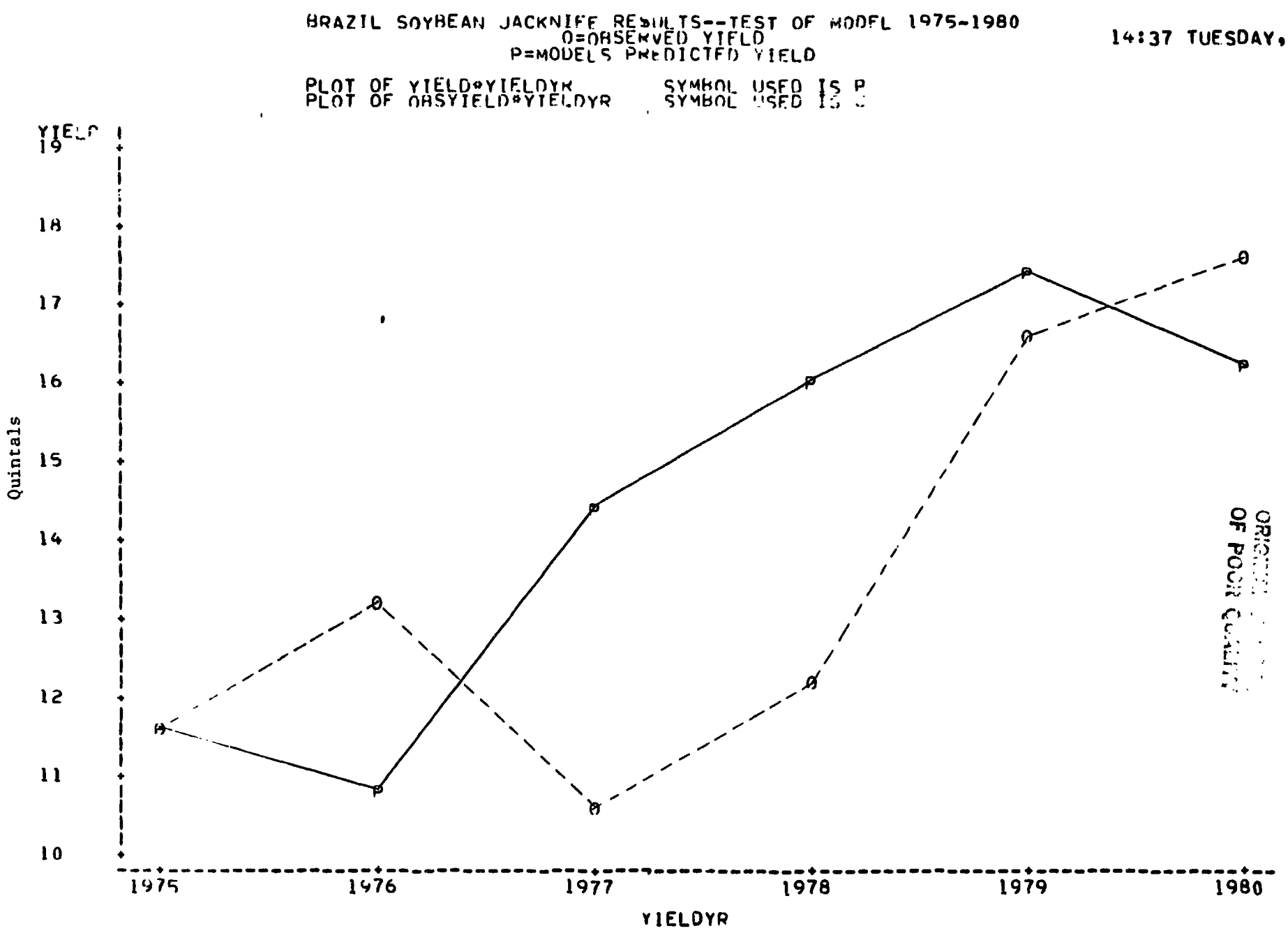

Figure 5. State of Minas Gerais Soybean Model.

BRAZIL SOYBEAN JACKNIFE RESULTS--TEST OF MODEL 1975-1980
O=OBSERVED YIELD
P=MODELS PREDICTED YIELD

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BETA1	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES
15.0134	1976	1980	1975	15.4554	22.21	0.473183	0.30106	30	6.9167
14.8320	1975	1980	1976	14.6331	21.60	0.479810	0.66166	30	6.9021
15.2267	1975	1980	1977	16.5180	21.36	0.473163	2.45650	30	6.9887
15.5470	1975	1980	1978	13.5751	13.88	0.491461	0.62524	30	6.8368
15.3140	1975	1980	1979	14.1176	17.09	0.411667	0.55525	30	7.3589
15.0047	1975	1979	1980	16.6808	22.40	0.415470	0.31043	30	7.2039

BETA2	BETA3	BETA4	BETA5	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	RUN
2.39441	-3.2069	0.0155437	0.0101771	15.0134	0	0	0.4668	-0.02474	1
2.26819	-2.7930	0.0204606	0.0052118	14.8320	0	0	-0.6709	0.47204	2
2.29322	-3.3582	0.0166398	0.0074985	15.2267	0	0	2.0305	-0.73919	3
1.45144	-3.4333	0.0162353	0.0126083	15.5470	0	0	-1.5107	-0.46120	4
1.86183	-2.9595	0.0161446	0.0103711	15.3140	0	0	-1.3774	0.18090	5
2.04191	-3.3444	0.0172110	0.0084098	15.0047	0	0	1.0332	0.64299	6

Table 6. Results of Jackknife Test for State of Parana Soybean Model.

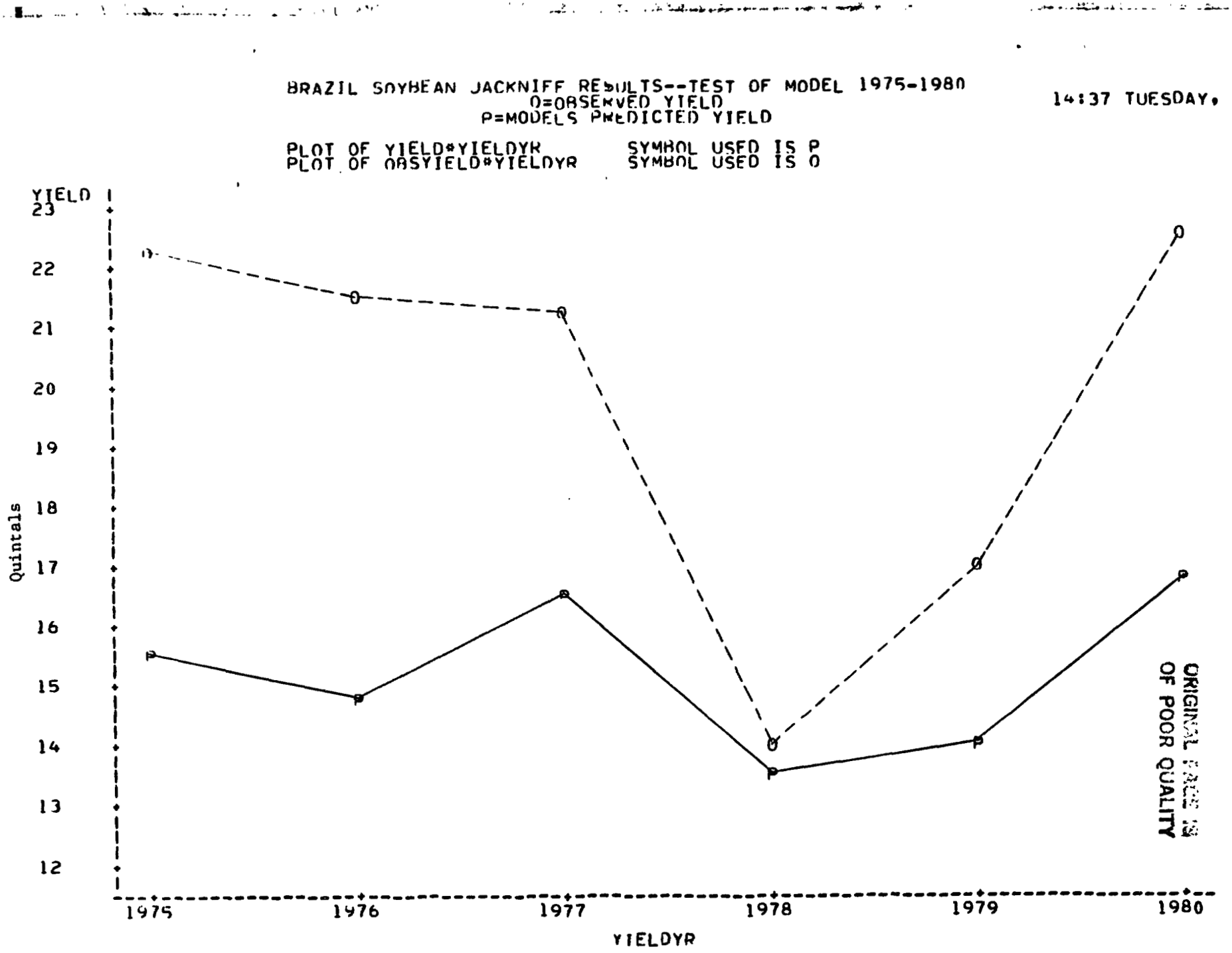

Figure 6. State of Parana Soybean Model.

BRAZIL SOYBEAN JACKNIFE RESULTS--TEST OF MODEL 1975-1980
O=OBSERVED YIELD
P=MODELS PREDICTED YIELD

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BETA2	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES	BETA1
3.52783	1976	1980	1975	14.1255	15.06	0.761662	0.165034	29	3.23711	13.9006
3.44230	1975	1980	1976	14.7959	15.50	0.795559	0.155796	29	2.80618	13.6744
3.47177	1975	1980	1977	15.6346	16.47	0.778618	0.203560	29	3.03799	14.1556
2.67107	1975	1980	1978	13.4020	13.24	0.859119	0.148729	29	1.95932	14.3360
2.98822	1975	1980	1979	12.5524	9.00	0.772079	0.344852	29	2.94903	14.1454
3.16776	1975	1979	1980	13.2554	14.34	0.755441	0.172344	29	3.11795	13.8794

BETA3	BETA4	BETA5	BETA6	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	CONRIB6
5.35628	-2.1065	0.0171992	0.0110723	13.9006	0	0	0	0.0867	0.13829
5.63172	-1.6158	0.0213146	0.0070771	13.6744	0	0	0	1.1221	-0.00051
5.53279	-2.3067	0.0186637	0.0068621	14.1556	0	0	0	1.1534	0.32558
6.09044	-2.2149	0.0156629	0.0126482	14.3360	0	0	0	-0.2519	-0.68213
5.83360	-1.7355	0.0142275	0.0111423	14.1454	0	0	0	-1.7498	0.15681
5.61586	-2.1980	0.0176922	0.0098263	13.8794	0	0	0	-0.4063	-0.21771

Table 7. Results of Jackknife Test for State of Rio Grande do Sul Soybean Model.

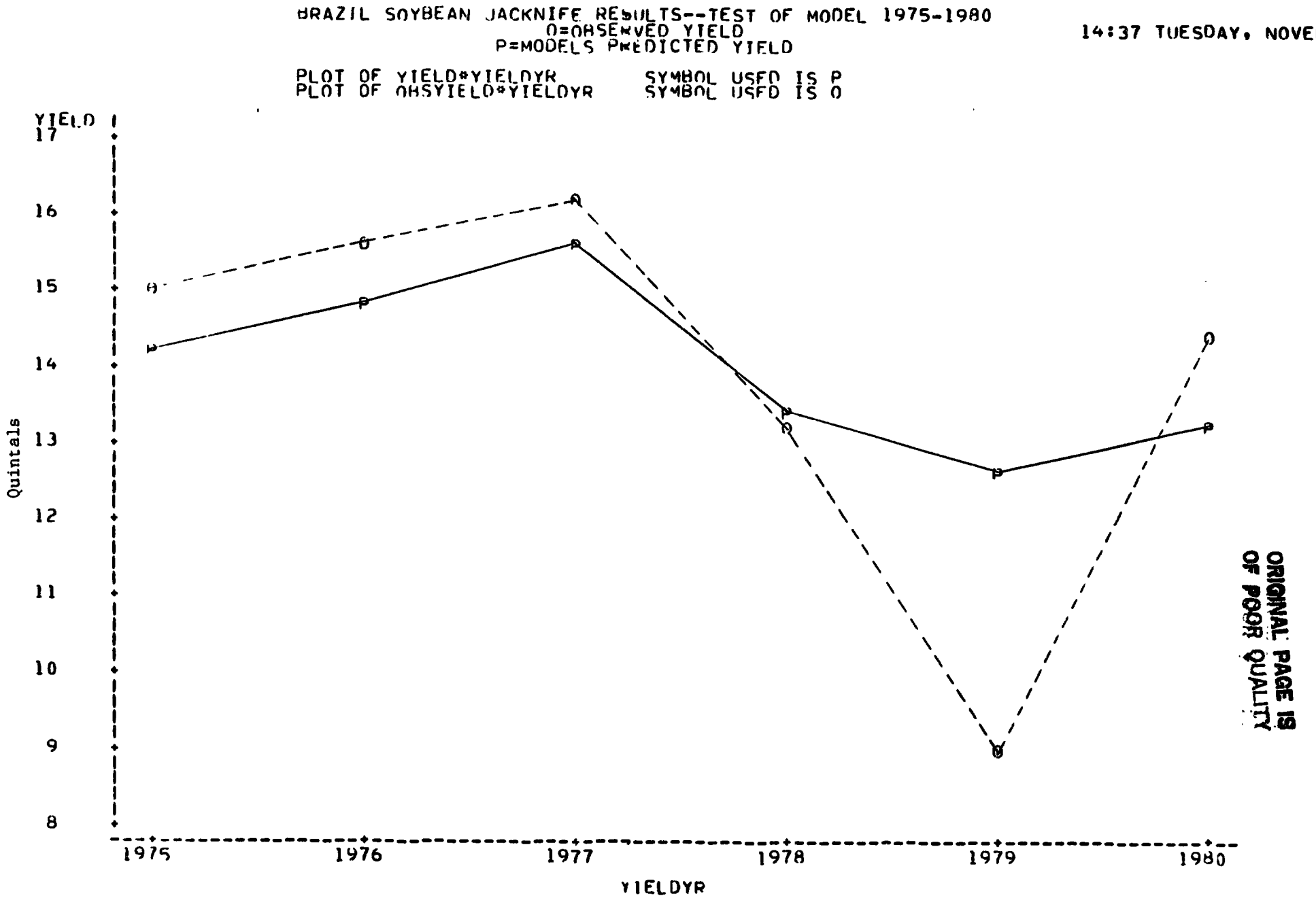

Figure 7. State of Rio Grande do Sul Soybean Model.

BRAZIL SOYBEAN JACKNIFE RESULTS--TEST OF MODEL 1975-1980
O=OBSERVED YIELD
P=MODELS PREDICTED YIELD

14:37 TUESDAY, N

BETA1	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRE
13.4603	1976	1980	1975	13.3204	12.92	0.717379	0.175641	30	3.710
13.3417	1975	1980	1976	14.3112	12.08	0.769657	0.141229	30	3.056
13.6101	1975	1980	1977	14.8679	13.59	0.729827	0.196828	30	3.583
13.8829	1975	1980	1978	13.3216	11.11	0.810870	0.153306	30	2.542
13.7977	1975	1980	1979	12.5884	8.94	0.740627	0.202610	30	3.244
13.4365	1975	1979	1980	13.8017	13.81	0.704207	0.156419	30	3.645

BETA2	BETA3	BETA4	BETA5	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	RUN
3.96114	5.78579	0.0172286	0.0121866	13.4603	0	0	0.17445	-0.31434	
3.78019	5.96829	0.0215739	0.0077218	13.3417	0	0	1.04180	-0.07226	
3.77858	5.93564	0.0170772	0.0104443	13.6101	0	0	0.96445	0.24337	
3.08356	6.53010	0.0155878	0.0135404	13.8829	0	0	0.14771	-0.70895	
3.30340	6.19264	0.0133421	0.0118091	13.7977	0	0	-0.76296	-0.44631	
3.58765	6.05724	0.0169946	0.0109705	13.4365	0	0	0.09967	0.26555	

Table 8. Results of Jackknife Test for State of Santa Catarina Soybean Model.

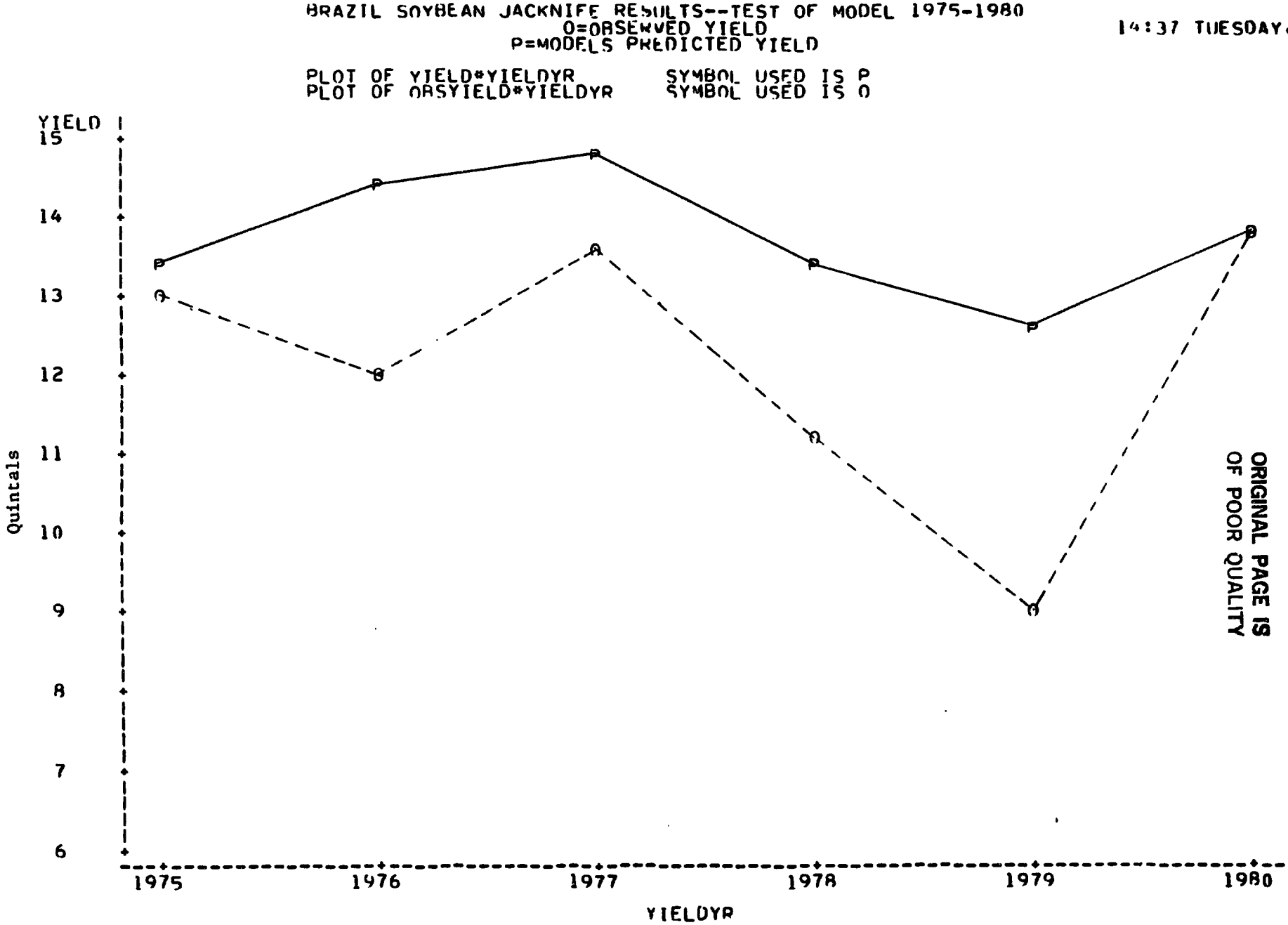

Figure 8. State of Santa Catarina Soybean Model.

BRAZIL SOYBEAN JACKNIFE RESULTS--TEST OF MODEL 1975-1980
O=OBSERVED YIELD
P=MODELS PREDICTED YIELD

14:37 TUESDAY, NO

BETA1	BEGMDLYR	ENDMDLYR	YIELDYR	YIELD	OBSYIELD	RSQ	PDER	DFRES	MSRES
14.6383	1976	1980	1975	15.9285	17.33	0.637620	0.38306	30	4.75778
14.3930	1975	1980	1976	15.3455	19.42	0.678872	0.71525	30	4.26091
14.7104	1975	1980	1977	15.4753	17.09	0.662696	1.52123	30	4.47449
14.8335	1975	1980	1978	10.9747	14.00	0.789632	0.57203	30	2.82819
14.7135	1975	1980	1979	13.2745	15.83	0.678658	0.28692	30	4.01920
14.5054	1975	1979	1980	16.1914	19.79	0.647278	0.46569	30	4.34704

BETA2	BETA3	BETA4	BETA5	CONRIB1	CONRIB2	CONRIB3	CONRIB4	CONRIB5	RUNNUMI
4.61634	-2.8312	0.0156519	0.0103842	14.6383	0	0	0.0802	1.2100	1
4.92185	-2.3303	0.0195468	0.0067112	14.3930	0	0	-0.1416	1.0941	2
4.81999	-2.7910	0.0157593	0.0098735	14.7104	0	0	1.7553	-0.9905	3
5.56485	-2.7075	0.0157852	0.0141960	14.8335	0	0	-2.6461	-1.2127	4
5.26362	-2.2792	0.0137531	0.0128504	14.7135	0	0	-0.6792	-0.7598	5
4.98085	-2.8131	0.0169201	0.0098561	14.5054	0	0	0.5480	1.1380	6

Table 9. Results of Jackknife Test for State of Sao Paulo Soybean Model.

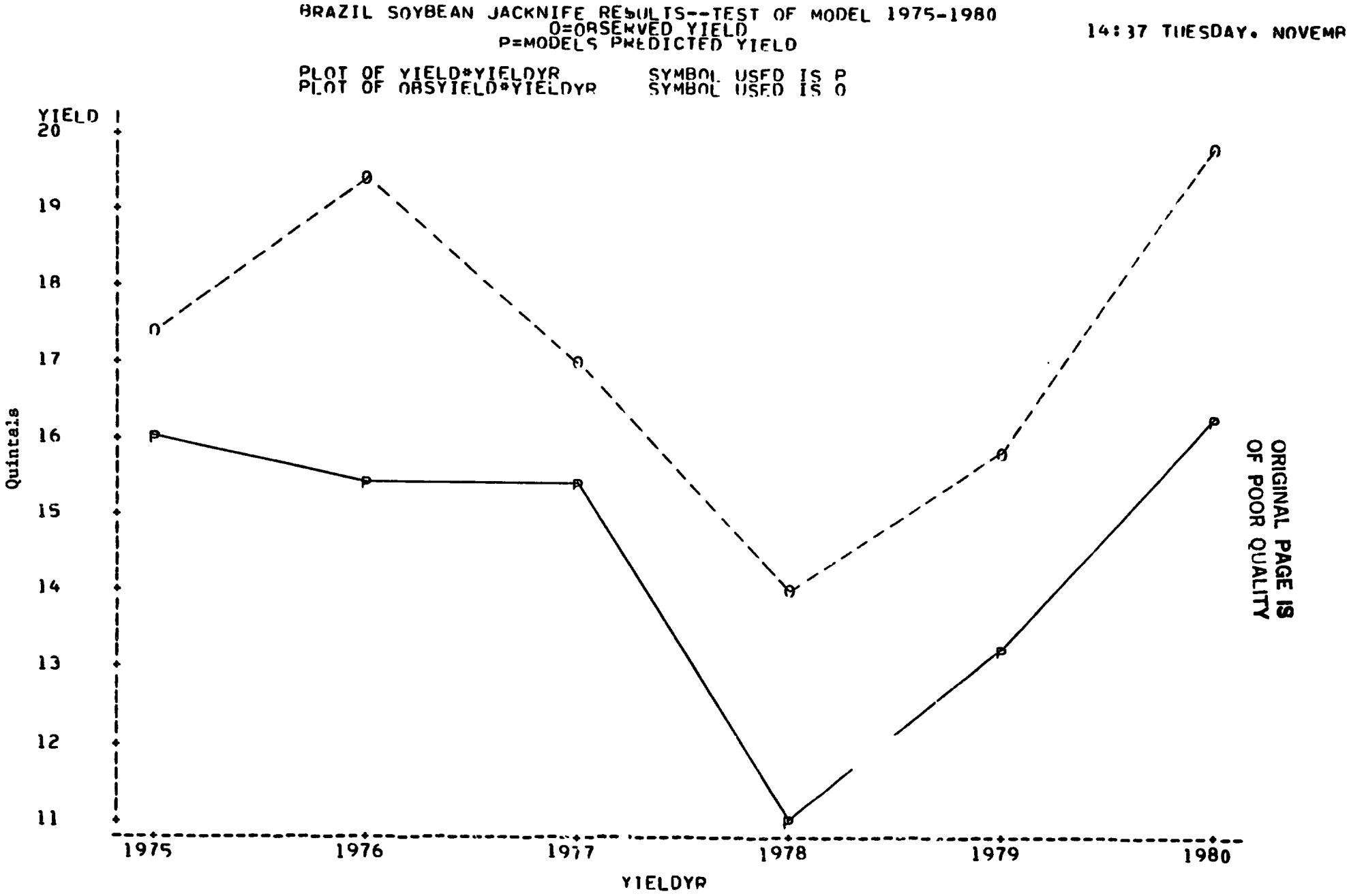

Figure 9. State of Sao Paulo Soybean Model.