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ARGENTINA WHEAT YIELD MODEL

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YM-N4-04457, JSC 18909

2. Government Accession No.  

3. Recipient's Catalog No.  

4. Title and Subtitle  
Argentina Wheat Yield Model

5. Report Date  
January 16, 1984

6. Performing Organization Code  

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


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  


15. Supplementary Notes  

16. Abstract  
Five models based on multiple regression were developed to estimate wheat yields for the five wheat-growing provinces of Argentina. Meteorological data sets were obtained for each province by averaging data for stations within each province. Predictor variables for the models were derived from monthly total precipitation, average monthly mean temperature, and average monthly maximum temperature. Buenos Aires was the only province for which a "trend variable" was included because of increasing trend in yield due to technology from 1950 to 1963.

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

18. Distribution Statement  

19. Security Classif. (of this report)  
Unclassified

20. Security Classif. (of this page)  
Unclassified

21. No. of Pages  
35

22. Price*  
*For sale by the National Technical Information Service, Springfield, Virginia 22161
ARGENTINA WHEAT YIELD MODELS

by

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AISC Models Branch

January 16, 1984
INTRODUCTION

The purpose of this study was to select monthly weather variables that could be used in models to predict wheat yields for the five main wheat-growing provinces of Argentina: Buenos Aires, Cordoba, Entre Rios, La Pampa and Santa Fe (see Figure 1). Each province was treated as a separate entity.

Most of Argentina's wheat-growing area is located in a humid subtropical climate known as the Pampa Humida. High temperatures in the winter can have an adverse effect on the wheat yield in the northern sections. Excessive rainfall in Entre Rios, where annual rainfall ranges from 900 to 1100 mm, can also be a problem during the growing season. The western edge of the wheat area, however, is semi-arid with warm to hot summers. There, drought and high temperatures can be a problem during the growing season.

Wheat is planted from early May through July. Harvest is generally from November through January.

METHOD

Three indices representing available soil moisture, monthly precipitation, and monthly maximum temperature (Sakamoto, 1976) were used in multiple regression models. They include: monthly Z-index, ET (evapotranspiration) minus ET (climatically appropriate evapotranspiration), and precipitation minus PET (potential evapotranspiration). Terms are defined in the Appendix. Large positive Z-index, P-PET, and ET-ET values suggest wet conditions.

The regression equation is:

\[ \hat{Y} = \alpha + B_1T + B_2TX_i + B_3R_i + B_4Z_i + B_5 (P-PET)_i + B_6 (ET-ET)_i + E \]

where

\[ \hat{Y} = \text{Estimated yield}, \]
Each dot represents 2,000 hectares (or fraction of more than 400 ha).

- Low density

Figure 1. Density of area sown to wheat in Argentina, 1971-72. (Total area in wheat: 4,986,000 ha)
\( \alpha \) = Constant,
\( B_j \) = Coefficients of the variables \( j = 1-6 \),
\( T \) = Trend,
\( T X_i \) = Maximum temperature for month \( i \),
\( R_i \) = Total precipitation for month \( i \),
\( Z_i \) = Z-index for month \( i \),
\( (P-PET)_i \) = Precipitation minus PET for month \( i \),
\( (ET-\hat{ET})_i \) = ET minus \( \hat{ET} \) for month \( i \), where \( \hat{ET} = K \cdot PET \) and \( K = \frac{ET}{PET} \),

and

\( E \) = Unexplained error.

Separate data sets were used for each province. Variables tried and selected for each model differed according to the climate and agricultural practices of each province. Buenos Aires was the only province for which a trend variable was included.

In developing the models, various procedures of the Statistical Analysis System (SAS Institute Inc., 1979) were used. The procedures used and the operations performed with each are listed in the Appendix. Combinations of variables with the highest \( R^2 \) which included variables significant at (or close to) the 10 percent level and those agronomically meaningful were chosen for the models.

DATA

The Argentina crop data were obtained through the Latin American Branch of the Economic Research Service of the United States Department of Agriculture (M. Mielke, personal communication, 1980. The crop data set used was set up with the year of yield as the year of harvest. The growing season in Argentina may extend into January of the following year before harvest begins. Our interest is in the year of planting and when the weather impacts the crop, which in this case would be year-1.
Meteorological data were prepared using several different sources, including Monthly Climatic Data for the World and the Servicio Meteorológico Nacional in Argentina (R.E. Jensen, C.M. Sakamoto and S.E. Mummert; August 1974). The years between 1950 and 1970 were used to model since the greatest number of stations had the most complete meteorological data for these years. From a general meteorological data file of Argentina stations, separate data sets were created for each of the five wheat provinces. Table 1 lists the stations and weights used to derive each meteorological data set. Groups of stations were weighted according to the contribution of their area to the country's wheat production. Figure 2 shows the location of each station.

YIELD MODELS

Buenos Aires

A plot of yield vs. year for Buenos Aires reveals an increasing trend in technology from 1950 to about 1963 (see Figure 3). Therefore, a "trend variable" was chosen for this period.

The model for Buenos Aires was one of the most difficult to define, probably because this province covers such a large territory. Plots of possible weather variables versus detrended yield did not indicate any significant linear relationships. Variables that one would be inclined to choose on the basis of crop calendar and critical weather during growing season did not show strong correlations with yield. After trying many combinations of variables in regressions, the following model was selected:

- Linear Trend 1950-1963
- ETMETH4
- R7
- ZINDEX8
- TX9
- April ET minus ET
- July total precipitation
- August Z-index
- September average maximum temperature.

The signs of the coefficients of the model seem reasonable. The negative coefficient in July indicates too much rain during planting has a negative
**BUENOS AIRES**

- Pergamino
- Junín
- San Miguel
- Buenos Aires
- Nueve de Julio
- Trenque Lauquen
- Las Flores

- Patagones
- Fortín Mercedes
- Tres Arroyas
- Averaged and weighted 25%
- Trenque Lauquen
- Macachin

- Azul
- Tres Arroyas
- Averaged and weighted 55%
- Balcarce

**CORDOBA**

- Pilar
- Bell Ville
- Averaged
- Rio Cuarto
- Trenque Lauquen

**ENTRE RIOS**

- La Paz
- Concordia
- Averaged
- Parana
- Las Delicias
- Victoria

**LA PAMPA**

- Patagones
- Santa Rosa
- Macachin
- Averaged
- General Acha
- Fortín Mercedes
- Victoria
- Trenque Lauquen

**SANTA FE**

- Ceres
- Esperanza
- Averaged and weighted 23%
- Angel Gallardo
- Bell Ville

- Bell Ville
- Rosario
- Averaged and weighted 77%
- Casilda
- Pergamino

---

Table 1. Meteorological Stations and Weights Used to Develop Regression Models for Argentina Wheat
Figure 2. Five major agricultural provinces in Argentina and locations of meteorological stations used in model development.
STATISTICAL ANALYSIS SYSTEM
PLOT OF YIELD vs YEAR

LEGEND: A = 1 OBS; B = 2 OBS; ETC.

Figure 3. Plot of Yield Versus Year for Province of Buenos Aires.
effect on yield. A large, positive 2-index in August during jointing is favorable to yield. High temperatures in September during heading reduce yield. The statistics of the selected model are summarized in Table 2. A plot of the model's predicted yields and the actual yields for 1950-1970 is shown in Figure 4.

Cordoba

For Cordoba, plots of possible weather variables vs. yield showed that 1951 was a "pivot point" in determining linear relationships for most of the variables. Since yield for 1951 was extremely low, it was decided to plot the variables without 1951. No improvements was seen; there were even fewer linear relationships. Therefore, it was decided to retain 1951.

Initial variables were chosen on the basis of correlation with yield and were tried in regression equations. Models were tried with several combinations and squares of some of the variables. The following variables were significant as a model:

- **ETMETH55**: May ET minus ET squared
- **TX7**: July average maximum temperature
- **P-PET8**: August precipitation minus PET
- **ETMETH90S**: September-October average ET minus ET squared.

The coefficient for ETMETH55 was negative, which reflects the need for drier conditions at planting time. The coefficient for ETMETH90S was also negative. This reflects the detrimental effects of excessive spring rains. High temperatures at early growth (July) reduces yield; favorable rain after planting (August) helps the crop get a good start. The statistics of the selected model are summarized in Table 3. A plot of the model's predicted yields and the actual yields for 1950-1970 is shown in Figure 5.

Entre Rios

Entre Rios was similar to Buenos Aires in that plots of weather variables versus yield did not produce any obvious linear relationships or strong
correlations. Regression equations containing moisture variables consistently produced negative coefficients for August through November. This can be explained agronomically by the fact that Entre Ríos is a very humid province with a high annual rainfall. Rainfall greater than the normal expected value produces disease and fungus problems, thereby reducing yield.

Working with variables chosen on the basis of correlation with yield failed to produce satisfactory results. Therefore, a mechanical process using SAS procedures was used to narrow down possible variables. The best model obtained was:

\[ \text{ETMETH5} = \text{May ET minus ET} \]
\[ \text{ETMETH6} = \text{June total precipitation} \]
\[ \text{ZINDEX8} = \text{August Z index} \]
\[ \text{R11} = \text{November total precipitation} \]

All coefficients were negative for June, August and November, indicating the less rain the better. The statistics of the selected model are summarized in Table 4. A plot of the model's predicted yields and the actual yields for 1950-1970 is shown in Figure 6.

**La Pampa**

For La Pampa, a plot of yield vs. year showed 1965 yield to be extraordinarily high—so high as to be questionable. Correlations and plots of variables with yield were more favorable without 1965. Therefore, 1965 was eliminated from the model data set. The best model had the following variables:

\[ \text{ETMETH4} = \text{April ET minus ET} \]
\[ \text{TX8} = \text{August average maximum temperature} \]
\[ \text{ETMETH9} = \text{September ET minus ET} \]
\[ \text{P-PET10} = \text{October precipitation minus PET} \]
\[ \text{P-PET11} = \text{November precipitation minus PET} \]

The problem with this and the other favorable models is that the coefficient for ETMETH4 was always negative. This cannot be explained agronomically. Therefore, the model was tried in the regression equation without ETMETH4. The R2 was reduced, but all coefficients were reasonable. The
coefficient for the August variable was the only negative. The statistics of the selected model are summarized in Table 5. A plot of the model's predicted yields and the actual yields for 1950-1970 is shown in Figure 7.

Santa Fe

For Santa Fe, 1964 was a year of outstanding yield. Eliminating 1964 from the data set produced better plots and correlations of weather variables to yield.

Santa Fe was the only province for which a satisfactory model was not obtained. Several different approaches were taken to derive a reasonable model, but the only acceptable model was the following:

\[ \text{ETMETH5} \] \text{May ET minus ET} \\
\[ \text{ETMETH7} \] \text{July ET minus ET} \\
\[ \text{ETMETH10} \] \text{October ET minus ET} \\
\[ \text{ETMETH11} \] \text{November ET minus ET}.

In this model, ETMETH10 was significant only at the 20 percent level. It was decided to keep it in the model to reflect conditions at the critical heading period in October. In addition, the \( R^2 \) for the model without ETMETH10 was lower. The only negative coefficient was for the November variable. This reflects the need for drier conditions at harvest time. The statistics of the selected model are summarized in Table 6. A plot of the model's predicted yields and the actual yields for 1950-1970 is shown in Figure 8.

TEST RESULTS

A bootstrap test was run on each model. In this test, the last year of the yield data set was left out and the model was used to predict yield for that year. This process was repeated for the number of years desired. In this case, the number of years used in the test for each province depended on the number of years with complete data. For Santa Fe this was nine years, for the other four provinces six.

For Buenos Aires, Entre Ríos, and La Pampa the bootstrap test adequately predicted yields for 1971 through 1976. There were exceptions (a different
year in each case) where the difference between predicted and actual yield was rather large. For Cordoba, the model predicted yield accurately for three out of the six years and rather poorly for two of the years. In 1972 there was a nine quintal per hectare difference between actual and predicted yield with the predicted yield the lower of the two. In that particular year the beginning of the growing season was extremely dry with increased moisture late in the season, enabling a come-back for the wheat. For Santa Fe, although the model showed actual and predicted yields running fairly close for the modeling years, the bootstrap test failed to predict within five quintals seven of the eight test years. Bootstrap results and plots of model results are printed beginning on page 15.
APPENDIX

Definition of Variables

Three types of indices were used to measure amount of moisture available for plant growth. The first, P-PET, is a measure of precipitation minus potential evapotranspiration. Potential evapotranspiration is determined by the procedures developed by Thornthwaite (1948). It requires temperature only:

\[ \text{PET} = \left( \frac{10 T}{I} \right)^a \]

where \( I = \) heat index, which is the sum of the 12 monthly indices \( i \),
\[ i = \left( \frac{T}{5} \right)^{15} \]
\( T = \) monthly temperature in °C, and
\( a = \) an empirical exponent = \( 6.75 \times 10^{-7} + 7.71 \times 10^{-5} i + 1.79 \times 10^{-2} i + 0.49 \).

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

The second index, Z index, is derived by an algorithm using monthly temperature and precipitation and is defined as

\[ Z = dk \]

where \( d = P - \hat{P} \)  \( P \) is the observed precipitation,
\( P \) is the climatically appropriate precipitation and is equal to \( ET + R + RO + L \).

Evapotranspiration \( \hat{ET} \), recharge \( \hat{R} \), runoff \( \hat{RO} \), and loss \( \hat{L} \) are obtained by multiplying each of their respective potential values (PET, PR, PRO, PL) by the coefficient which is the ratio of their average values to their average potential values; that is, \( \alpha = \hat{ET}/\text{PET}, \ \beta = \hat{R}/\text{PR}, \ \gamma = \hat{RO}/\text{PRO}, \ \text{and } \sigma = \hat{L}/\text{PL}. \)

Climatically appropriate evapotranspiration, recharge, runoff, and loss are then determined as \( \hat{ET} = \alpha \cdot \text{PET}; \hat{R} = \beta \cdot \text{PR}; \hat{RO} = \gamma \cdot \text{PRO}; \) and \( \hat{L} = \sigma \cdot \text{PL}. \)

Recharge, runoff, and loss are determined by a hydrologic procedure developed by Palmer (1965).

The third index is the difference between ET and \( \hat{ET} \). Soil moisture
depletion is based on evapotranspiration (ET) estimates, determined as follows:

\[ (ET)_n = \frac{(S)_{n-1}}{AWC} \left[ \left( (PET)_n - (P)_n \right)^2 + (P)_n \right] \]

where

- \((ET)_n\) = "Actual" evapotranspiration,
- \((S)_{n-1}\) = Available moisture at end of \(n-1\) month,
- AWC = Maximum water holding capacity,
- \((P)_n\) = Precipitation for month \(n\), and
- \((PET)_n\) = Potential evapotranspiration for month \(n\).

\(ET\) measures the difference between the actual evapotranspiration and the "climatically appropriate" evapotranspiration, and hence gives an indication of soil moisture supply and demand.

**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 variables 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, and differs 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 temperatures 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 $E_t$. 

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**STATISTICAL ANALYSIS SYSTEM**

**BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE YIELD**

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**LES IN THE MODEL ARE SIGNIFICANT AT THE 0.1000 LEVEL.**

---

Table 2. Statistics of Model for Province of Buenos Aires.
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All variables entered.

R square = 0.69480993
C(P) = 5.00000000

Backward elimination procedure for dependent variable Yield.

Les in the model are significant at the 0.1000 level.

Table 3. Statistics of Model for Province of Cordoba.
Figure 4. Province of Buenos Aires Wheat Model.
Figure 5. Province of Cordoba Wheat Model.
Table 4. Statistics of Model for Province of Entre Rios.
Figure 6. Province of Entre Ríos Wheat Model.
**Statistical Analysis System**

**Backward Elimination Procedure for Dependent Variable Yield**

- All Variables Entered
- $R^2$ = 0.73084214  \(C(P) = 5.00000000\)

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**Variance Component**

- $\hat{a}^2$ (Intercept) = 31.44103043
- $\hat{e}^2$ (Error) = 0.04160456
- $\hat{p}^2$ (Pesticide) = 0.02426295
- $\hat{p}^2$ (PETII) = 0.0323129

**ANOVA Table**

- Prob>F: 0.0042
- Prob>F: 0.0143
- Prob>F: 0.0231
- Prob>F: 0.0033

**Statistics in the Model are Significant at the 0.1000 Level.**

Table 5. Statistics of Model for Province of La Pampa.
LA PAMPA ACTUAL YIELD AND MODEL PREDICTION 1950-1970

A = ACTUAL YIELD
P = MODELS YIELD

PLOT OF YIELD YEAR
SYMBOL USED IS A
PLOT OF WHAT? YEAR
SYMBOL USED IS P

Figure 7. Province of La Pampa Wheat Model.
STATISTICAL ANALYSIS SYSTEM

BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE YIELD

ALL VARIABLES ENTERED

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Figure 8. Province of Santa Fe Wheat Model.
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Table 8. Results of Jackknife Test for Cordoba Wheat Model.
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Table 9. Results of Jackknife Test for Entre Rios Wheat Model.
Figure 11. Province of Entre Ríos Wheat Model.
### Table 10. Results of Jackknife Test for La Pampa Wheat Model.

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Table 11. Results of Jackknife Test for Santa Fe Wheat Model.
Figure 13. Province of Santa Fe Wheat Model.