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16. Summary/Notes

A multiple regression equation employing a single weather element (the summation of relative humidity from Oct. to Mar.) and a surrogate technology trend variable was developed for corn yield forecasting in DIRA-Ribeirão Preto. This yield-weather-technology model not only provides accurate yield estimation but also pre-dates the official report by at least 3 months.

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CORN YIELD MODEL FOR RIBEIRÃO PRETO, SÃO PAULO STATE, BRAZIL

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ABSTRACT

The weather and technology effects on corn (Zea mays L.) yield in the district of Ribeirão Preto were studied by a correlation analysis. The most important monthly meteorological factor affecting corn yield is total evaporation, which has significant correlation coefficients in five of the six study months. All meteorological factors used for analysis are significant in December, indicating that this is the critical month for corn production. Technology improvement during the period 1957 to 1975 also plays a significant role in corn yield and explains more than 45% of yield variation. The best yield-weather-technology (YWT) model for corn yield prediction employs the summation of relative humidity from October to March, and technology trend as independent variables (predictors). The regression equation of the YWT model, based on the data period of 1957-1975, is relatively stable and the prediction errors range from 1.97% to 4.32% when extrapolating to independent test years after 1975. However, prediction accuracy of the model for a current crop year may be improved by including all the available historic data to the preceding year of forecasting in calculating the regression coefficients. According to the test results, the predicted yield for 1979 is 2527.89 kg/ha, if the summation of relative humidity between October and March is equal to the average of the same term from 1957 to 1978. Each 1% increase or decrease from the average will result in a ± 17.18 kg/ha change in yield. The YWT model gives accurate corn yield information and more importantly pre-dates the available official estimate by at least 3 months.

INTRODUCTION

Reliable crop yield information is needed to estimate production which assists farmers, agribusiness firms and government organs in ~~decision making~~ for efficient resource allocation. In most of the crop yield studies, weather and surrogate technology trend variables have been used as predictors. Thompson (1969a, 1969b) yield models employed linear and quadratic terms of pre-season rainfall, monthly temperature and total precipitation, and three trend variables for corn and wheat. Huda et al. (1976) used weekly meteorological data and crop year number to explain yield variation in corn. Other studies using plant nutrient content (Walker and Peck, 1974) or indices derived from meteorological factors (Baier, 1968; Sakamoto, 1978) as predictors, or substituting trend variable to a direct marker such as nitrogen use (Nelson and Dale, 1978) were also exercised. For further literature on crop-weather analysis modeling the reader is referred to Baier's review (1973).

In this paper, attempts are made to develop a model which predicts corn (<u>Zea mays</u> L.) yield earlier than the Agricultural Economics Institute (IEA) final estimate in July. The application of this modeling approach could lead to early crop forecasting and contribute to market strategy planning in the agribusiness sector.

STUDY AREA

The Regional Agriculture Division (DIRA) in Ribeirão Preto is one of ten agricultural districts in São Paulo State. DIRA-Ribeirão Preto was selected as the study area due to its advanced level of crop technology and relative homogeneous climate, topography, soil types, and above all, as one of the state's major corn producers.

DATA SOURCES

Following soybean, corn is the most important annual crop in the study area. Generally, corn is planted in the months of October and

November and harvested from May to June. In this study, historic yield data are obtained by dividing IEA's final estimates of production (kg) by harvested acreages (ha.). Monthly weather data were provided by the Meteorological Service of the Agricultural Ministry. The data set from 1957 to 1975 were used for yield modeling, while the data after 1975 were tested independently to verify the prediction accuracy of the model selected.

ANALYSIS PROCEDURES

Yield Model Development

(1) The selection of yield predictors (independent variables)

Temperature, solar radiation, precipitation and nutrient applications are important factors influencing crop growth and their yields. For yield predictor selection simple correlation analyses were carried out between historic yields and data of monthly weather variables which are readily accessible and would be expected to affect crop yield. Any long term increase in yield attributed to non-weather factors, such as improved disease resistant varieties, fertilizer and defensive chemical applications, were designated to the surrogate variable "technology trend". Investigations of the yield data series suggested that the technology trend was linear from 1957 to 1975. Consequently, to correlate this variable with historic corn yield, a series of numbers starting from 1 was coded to each year for analysis (i.e., 1957-1, 1958-2 ... 1975-19).

(2) Yield-Weather-Technology (YWT) Modeling

A yield time series is viewed here as a function of weather and technology trend and may be expressed as $Y = a + \Sigma b_i X_i + cT + \varepsilon$ where, Y is the corn yield (kg/ha); X_is' are weather variables; T is technology trend; a is interception; b_is' and c are partial regression coefficients and ε is the random error. In developing the best YWT model, historic corn yields, departures from the 19-year averages (normals) of meteorological data for selected months and technology trend from 1957 to 1975 were used in the regression analysis. The stepwise multiple regression program of the SPSS, Statistical Package for Social Sciences (Nie et al., 1975) was run to select the independent variables according to their statistical significance. Among the various multiple regression yield models generated by the stepwise inclusion approach, the model which contained the least number of predictors and explained a reasonable amount of yield variability was selected for this study.

Yield Model Testing

(1) Stability of regression coefficients

After corn yield modeling, the stability of the regression coefficients in the selected model should be tested. The regression equations of the YWT model were run for periods of one-year increments; 1957-1970, 1957-1971, ... and 1957-1978. The partial regression coefficients of the nine regression equations were then compared in order to observe their variations through time.

(2) Model validation - corn yield prediction accuracy test

The predictive ability of many yield models found in the literature show a lack of testing with independent data. This is normally the case because all of the available historic data were needed to develop a yield model without leaving a time period for a model validation test. In the present study, the stable regression equations of the YWT model were tested for their prediction accuracies. This was accomplished by multiplying the regression coefficients with the meteorological observations and the extrapolated technology variable of the independent year(s), following each corresponding data period used for computing the regression coefficients of the equation. The relative differences between the model predicted corn yields and the IEA's final estimates were calculated.

RESULTS AND DISCUSSION

Yield Model Development

(1) The selection of yield predictors

The correlation coefficients in Table I show that total evaporation was significantly correlated to corn yield in five of the six study months and has a synergistic effect on yield when the summation was used (r = -0.82). Other variables which correlated significantly to yield included total evaporation in January (-0.76), the summation of relative humidity from October to March (0.72) and technology trend (0.68). All the meteorological variables used for analyses are significant in December, confirming this month as critical for corn production. Either higher than normal temperature or lower than normal precipitation in this month (flowering stage) may reduce yield in the region. The positive effects of relative humidity on corn yield and root systems have been demonstrated by Breazeale and McGeorge (1953). The negative correlation of total evaporation and yield may be explained by problems of water stress induced by high evaporation rates. All of the variables which correlated significantly with yield could be used as predictors. However, because of the large number (fourteen) of predictors being considered and the multicollinearity among them, five variables were selected. These predictors were: mean temperature (T_D) and total precipitation (P_D) of December, summations of monthly total evaporation E_{om}) and relative humidity (RH_{om}) from October to March and linear technology trend (TT).

(2) YWT modeling

In yield modeling, rather than using the original meteorological data of the predictors, departures from the 19-year (1957-1975) normals were used. Five yield models were generated by the SPSS program (Table II). Variable E_{om}, which has the highest correlation with yield, was the first predictor selected in the regression and responsible for 67% of the yield variation. Model 3, using the summations of total evaporation and relative humidity from October to March and technology trend as predictors, explained 92% of the fluctuation in yield. A further investigation revealed that E_{om} could be deleted from model 3 and still explain a reasonable amount of ~~yield variation~~ (91%). Thus, the YWT model for corn yield was chosen and expressed as $Y = a + b$ (DFN of RH_{om})+ cTT.

Model Testing

(1) Stability of regression coefficients

Regression coefficients and R^2 values of the YWT model for nine different data periods are shown in Table III. The addition of 1971, a poor crop year (1725.93 kg/ha), modified the regression coefficients of the 1957-1970 equation from 17.62 to 18.08 for variable RH_{om} and from 39.82 to 36.31 for variable TT. These modifications remained relatively stable until 1974. Corn yield of 1975 was 22.45% higher than the previous 18-year yield normal, but 3.33% lower than the RH_{om} normal. This abnormal data substantially changed the coefficients of the 1957-1974 equation. Any additional years beyond 1975 did not change the regression coefficients in the model. For the purposes of this study it is concluded that to construct a YWT model at least a 19-years data period, from 1957 to 1975, should be used.

(2) Model validation

The stable regression equation of the YWT model based on three different data periods (1957-1975, 1957-1976 and 1975-1977) were tested for their yield prediction accuracies using meteorological data of the year(s) following each data period. Comparisons of the model predictions to the IEA final estimates are presented in Table IV. The relative differences between model predictions and IEA estimates for the six independent tests ranged from 1.97% to 4.32%. The smallest differences for the test years 1976, 1977 and 1978 in the diagonal of the table, suggest that the best current yield prediction can be achieved by applying all the available historic data to the preceding prediction year in computing the regression coefficients.

— CONCLUSIONS

Multiple regression techniques were applied to historic meteorological data and technology trend for corn yield prediction in the Ribeirão Preto Agricultural District. The study period from 1957 to 1978 includes three abnormal weather years; 1964, 1969 and 1971. The range of corn yields vary from 1195.98 kg/ha for 1964 to 2713.05 kg/ha for 1976. In this study, a YWT (Yeild-Weather-Technology) model was developed using a single meteorological variable, summation of monthly relative humidity from October to March, and a linear technology trend as predictors. This model not only accurately represents yield fluctuations during the data period from 1957 to 1975, but also in the three successive independent test years from 1976 to 1978 (Fig. 1). However, the results suggest that for an operational yield prediction all the available historic data should be included in calculating the regression coefficients of the multiple regression equation. The YWT model predicted normal corn yield for 1979 is 2527.89 kg/ha, assuming that relative humidity between October and March is equal to the 1957-1978 average. Any positive or negative 1% departure from the previous 22-year RH_{om} average will cause a $\pm$ 17.18 kg/ha change in normal yield. Caution should be taken in applying the model if there is a levelling off of the technology trend. In this case, other time trend variables could be added to the model.

The growing season for corn is from October to May and the IEA final estimate is made available in July, several months following the harvest. The YWT model relies on monthly relative humidity through March thus pre-dating the yield information by at least 3 months. This timely and accurate yield data would greatly benefit agricultural decision makers.

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TABLE I

Correlation coefficients of corn yield with monthly meteorological variables and technology trend in DIRA-Ribeirão Preto (data base : 1957 - 1975)

Variable	Symbol	Months						
		O	N	D	J	F	M	O-M
Mean temp. (^{o}C)	T	-0.33	-0.38	-0.57*	-0.33	-0.04	0.20	-0.41
Total precip. (mm.)	P	0.28	0.29	0.47*	0.06	0.11	-0.01	0.56*
Solar radiation (cal. cm^{-2} day^{-1})	SR	0.02	-0.03	-0.57*	0.02	0.31	-0.25	-0.13
Total evaporation (mm.)	E	-0.66**	-0.51*	-0.68**	-0.76**	-0.50*	-0.20	-0.82**
Relative humidity (%)	RH	0.56*	0.37	0.64**	0.30	0.06	0.25	0.72**
Pre-season precip. (precip. July-Sept.)	PP	r = 0.01						
Linear technology trend	TT	r = 0.68**						

* significant at p = 0.05

** significant at p = 0.01

TABLE II

Constants and coefficients of corn yield models for DIRA - Ribeirão Preto (data base : 1957-1975)

Variable	Normal	Model no.				
		1	2	3	4	5
Constant		1902.85	1902.85	1384.31	1351.55	1336.63
E_{om} (DFN)	664.83	-2.23	-1.67	0.54	0.87	0.90
RH_{om} (DFN)	439.89		7.75	20.14	19.22	19.48
TT				51.85	55.14	56.64
T_D (DFN)	23.24				- 87.94	-109.90
P_D (DFN)	269.69					-0.25
Stand. error of estimation		229.80	217.47	119.31	102.37	102.75
Coeff. of determination		0.67	0.85	0.92	0.95	0.95

E_{om} = summation of total evaporation from Oct. to Mar., RH_{om} = summation of relative humidity from Oct. to Mar., T_D = mean temp. of Dec., P_D = precip. in Dec. and DFN = departure from 1957-1975 normal.

TABLE III

Regression coefficients and R^2 values of the selected YWT model* based on different data periods

Data period	Coefficient a	b	c	R^2
1957-1970	1493.90	17.62	39.82	0.92
1957-1971	1497.63	18.08	36.31	0.91
1957-1972	1511.42	18.13	36.69	0.93
1957-1973	1519.32	18.14	36.83	0.93
1957-1974	1516.98	18.18	38.28	0.94
1957-1975	1466.39	16.98	43.64	0.91
1957-1976	1468.66	17.27	45.21	0.93
1957-1977	1468.29	17.32	46.10	0.93
1957-1978	1454.25	17.18	46.68	0.94

* Estimated corn yield = a + b (DFN of RH_{om}) + c TT

TABLE IV

Comparisons of estimated corn yield by YWT model and IEA

Test year	IEA	YWT model estimate using the data period of 1957-1975	YWT model estimate using the data period of 1957-1976	YWT model estimate using the data period of 1957-1977
1976	2713.05	2595.76(-4.32%)*		
1977	2615.70	2520.54(-3.64%)	2544.99(2.70%)	
1978	2320.42	2241.51(-3.40%)	2261.98(-2.52%)	2274.69(-1.97%)

Estimated corn yield (kg/ha)

* Relative difference in percentage.

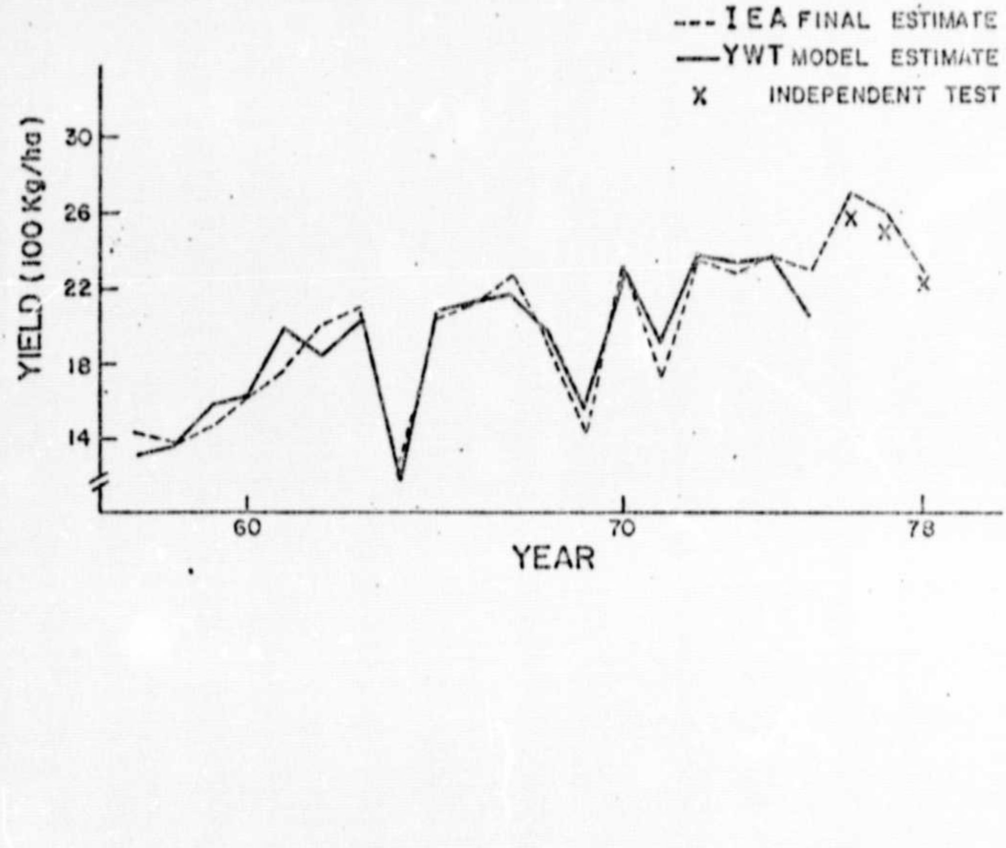

Fig. 1 - Comparison of estimated corn yield by IEA and YWT model based on data period 1957-1975.