A Crop–Weather Model for Prediction of Rice (Oryza sativa L.) Yield Using an Empirical-Statistical Technique

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Short Communication

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A Crop–Weather Model for Prediction of Rice (*Oryza sativa* L.) Yield Using an Empirical-Statistical Technique

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With 1 figure and 1 table

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Abstract

Rice is the staple food in many countries and is grown in varied climates from per-humid to semiarid areas. Crop–weather models were used to predict rice yield in India. However, in spite of a significant influence of solar radiation on rice yield, none of these models used solar radiation as one of the predictors. In this paper, an attempt was made to predict the first season (June–September) rice yield at Coimbatore, Tamil Nadu, India by including solar radiation as one of the predictors. Ten years (1987/88–1996/97) data were used for the study. Seven predictors viz., percentage of rice area during first season (X_1), number of days with minimum temperature below 22 °C in August and September (X_2), average daily maximum temperature for three months (July, August and September; X_3), average daily minimum temperature for three months (July, August and September; X_4), total of average sunshine hours in August and September (X_5), and total rainfall of July, August and September (X_6) total average solar radiation of August and September (X_7) were selected based on earlier report. Full model and stepwise regression analysis were performed using MSTAT computer package. The full model regression without solar radiation as predictor (Model I) recorded comparatively less R^2 (0.6292). Inclusion of solar radiation (Model II) enhanced the R^2 value considerably ($R^2 = 0.9464$). Seven variables were further subjected to stepwise regression analysis and only four predictors were retained in the final model (Model III) with an R^2 value of 0.9234. The model III with minimum parameters $Y = 22119.5758 + 19.6898$, $X_1 - 150.9261$, $X_2 - 1126.7501$, $X_4 + 0.7179$ X7 can be used to predict the first season rice yield (Y) at Coimbatore, India.

Key words: crop–weather model — *Oryza sativa* L. — rice — solar radiation weighing factor — yield prediction

Introduction

Agriculture is the exploitation of solar energy in the presence of an adequate water supply and sufficient plant nutrients to maintain plant growth (Monteith 1958). Climate determines what crops the farmers can grow and weather influences the yield and thus the farmers profit (Watson 1963). A crop–weather model is a simplified representation of the complex relationships between weather and climate and crop performance by using established mathematical or statistical techniques (Baier 1979). The effects of meteorological factors on crop production and yield can be assessed in two different ways (van Keulen 1987). First, location or periods with different weather conditions can be compared and second, 'sensitivity analysis' in which, one individual factor is changed in a systematic way and the effect on final result is analysed. Once the detailed knowledge has been acquired of how, and at what growth stages, climatic factors influence the yield, it is possible to derive complex variates that give appropriate weight to the different factors for correlation with yield in naturally varying climates, and use them to predict yield from meteorological records (Watson 1963).

The temperature, solar radiation and rainfall influence the rice yield directly by affecting the physiological processes involved in grain production and indirectly through diseases and insects (Yoshida 1981). However, many rice yield prediction models in India used any one or combination of the following weather variables as predictor(s):

temperature, temperature difference, growing degree days, rainfall, rainy day, drought, cloud amount, relative humidity, evaporation, sunshine hours and evaporation and technological trend (Huda et al. 1975, Sreenivasan 1980; Chowdhury and Sarkar 1981, Shanker and Gupta 1988, Gopalaswamy 1994 and Kalubarme and Ahuja 1997). In the tropics and temperate regions, the level of incident solar radiation primarily determines rice yield per hectare (Yoshida 1981) but none of the above models have included the solar radiation as a predictor. This may be because of nonavailability of the data for the estimation. Thiyagarajan et al. (1993), Mohandas et al. (1995) and Ramasamy et al. 2000) have used simulation models to estimate rice yield in Tamil Nadu, India. Crop simulation models with sound physical and physiological bases are better research tools to quantify the effects of weather variables on crop growth and development. However, the relatively simpler data requirements of the regression type model make it simple to use in large-scale yield prediction. In this paper an attempt was made to estimate the rice yield by including solar radiation as one of the predictors in the regression model.

Materials and Methods

The regression-type models require only a moderate amount of historical data on crop yield and weather. We have selected the Coimbatore district, Tamil Nadu, India for the study, where rice is being cultivated under irrigated conditions. The area, production and productivity for 10 years (1987/88–1996/97) were collected from a season and crops report, Government of Tamil Nadu, Chennai. The annual rice area in Coimbatore was 19 644 ± 4 330 ha. Out of which 11 936 ha (60.76 %) was in second season, 4013 ha (20.43 %) in third season and 3695 ha (18.81 %) was in first season (June planting). The yield per hectare was high (4105 kg ha^{-1}) in first season followed by 3755 kg ha^{-1} in second season and 3645 kg ha^{-1} in third season. We have estimated the yield for the first season. The assumption made in the study was that the crop was sown in June and harvested in September. In general, crop duration varies between 100 and 120 days. The weather data for 10 years were collected from the Department of Agricultural Meteorology, Tamil Nadu Agricultural University, Coimbatore. The multiple regression model fitted was of the form

$$Y = a_o + \sum a_i x_i \quad i = 1$$

where Y = estimated rice yield (kg ha^{-1}), a_o = regression constant, a_i = estimated regression coefficients for meteorological predictor variables, and $x_i = i^{th}$ meteorological predictor variables.

The selection of variables for the study was similar to that of da Mota and de Silva (1980). The selected variables for the study are given in Table 1. These variables were used to fit full model regression and stepwise regression with the help of an MSTAT computer package.

Results and Discussion

The correlation coefficient of predictors used in the study is given in the Table 1. It indicates that solar radiation alone significantly correlated (r = 0.591) with rice yield during the first season. The model I without solar radiation as a predictor gave $R^2 = 0.6292$, while model II with all the seven variables (i.e. inclusion of solar radiation also in the model I) enhanced the R^2 value ($R^2 = 0.9464$). The stepwise regression retains only minimum variables, which could reasonably explain the yield variability, is given in model III.

Model I

$$Y = 12363.48 + 9.0399X_1 - 25.6084X_2 - 792.35X_3 + 532.8538X_4 + 22.8037X_5 + 1.6386X_6 \; (R^2 = 0.6292)$$

Table 1: Variables used for the model estimation and their correlation coefficient (r) with yield

Code	Variable details	Mean	S.D.	r
X_1	Percentage of rice area during first season	19.15	6.87	− 0.217
X_2	Number of days with minimum temperature below 22 °C in Aug. and Sept.	6.4	4.09	− 0.503
X_3	Average daily maximum temperature (°C) for July, Aug. and Sept.	31.12	0.36	− 0.051
X_4	Average daily minimum temperature (°C) for July, Aug. and Sept.	22.73	0.35	0.360
X_5	Average sunshine hours total of Aug. and Sept. (h)	173.1	20.7	0.473
X_6	Total rainfall (mm) of July, Aug. and Sept.	138.3	56.9	0.011
X_7	Monthly average solar radiation total of Aug. and Sept. (MJ m^{-2})	11266	771	0.591
Y	Rice yield (kg ha^{-1})	4001	503	1.0

S.D., standard deviation.

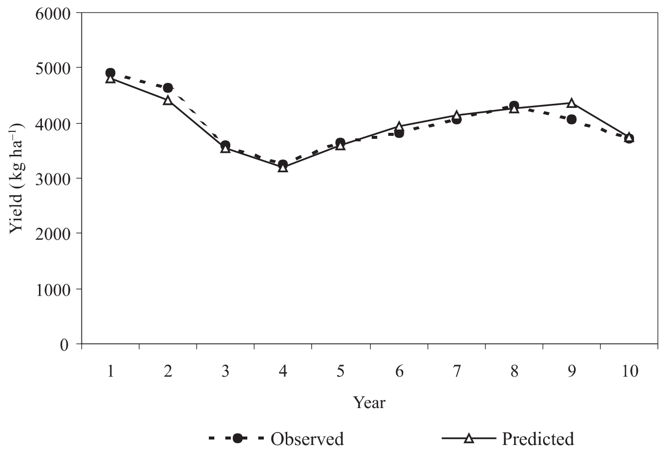

Fig. 1: Observed and predicted rice yield

Model II

$$Y = 8529.0625 + 19.8814X_1 - 172.4337X_2 + 679.8065X_3 - 1494.8067X_4 - 8.6259X_5 + 2.3625X_6 + 0.9044X_7 \quad (R^2 = 0.9464)$$

Model III

$$Y = 22119.5758 + 19.6898X_1 - 150.9261X_2 - 1126.7501X_4 + 0.7179X_7 \quad (R^2 = 0.9234)$$

Model III was used to estimate the yield and compared with observed values. The predicted values did not differ much from those observed (Fig. 1) and the year-to-year fluctuations are in the same direction. The regression models developed in this study by including solar radiation were better ($R^2 = 0.9464$ and 0.9234, respectively) compared to many earlier models especially those of Sreenivasan (1980) ($R^2 = 0.882$) and Gopalaswamy (1994) ($R^2 = 0.798$) given for Tamil Nadu. It indicates that inclusion of solar radiation as one of the predictors enhances the effectiveness of the prediction. Growth and yield of irrigated rice is determined largely by temperature and solar radiation (Yoshida 1977). Solar radiation has the greatest influence on the reproductive stage, followed by the ripening stage. The overall effect of solar radiation during the vegetative stage on the grain yield is extremely small (Yoshida 1981). Temperature correlates positively at the vegetative stage and negative and higher magnitude at a later stage when temperature ranges from 18–35 °C for warm temperature cultivars (Yoshida 1977). The ideal temperature for yield during the reproductive stage is in the diurnal range of 31–22 °C under high levels of sunshine (Munakata 1976). In the absence of instruments to measure solar radiation, an empirical equation can be used successfully to estimate the solar radiation. Goodin et al. (1999) have used daily air temperature for the calculation of solar radiation by using the modified Bristow–Campbell method.

The usefulness of empirical-statistical models representing crop–weather relationships has been demonstrated especially in regional crop-yield assessments, agro-climatic analysis of crop production, evaluation of crop responses to weather elements and assessment of the impact of natural or man-induced variability on crop production (Baier 1977). Information gained from this study supports the use of an empirical-statistical approach for estimating rice yield. The regression model may not be appropriate to extrapolate to another agro-climatic zone; if needed it should be done with much caution and care. Similar models can be employed for different seasons and regions or zones for yield prediction. There is also the possibility to improve the accuracy of the model by proper field experimentation at different regions/zones for a greater number of years.

Zusammenfassung

Ein Wettermodell zur Voraussage des Bestandesertrages von Reis (*Oryza sativa* L.) unter Verwendung einer empirischen, statistischen Technik

Reis ist die Hauptfrucht in vielen Ländern und wird unter verschiedenen klimatischen Bedingungen von humiden bis semiariden Gebieten angebaut. Das Bestandes-Wettermodell wurde verwendet, um den Reisertrag in Indien vorauszusagen. Trotz der signifikanten Beeinflussung durch die Einstrahlung auf den Reisertrag nutzte keines der Modelle die solare Einstrahlung für Voraussagen. In der vorliegenden Veröffentlichung wird der Versuch gemacht, den Reisertrag der ersten Saison (Juni–September) in Coimbatore, Tamil Nadu, Indien unter Berücksichtigung der solaren Einstrahlung als ein Voraussagekriterium zu bestimmen. In 10 Jahren (1987/88 bis 1996/97) wurden Daten für diese Untersuchung benutzt. Sieben Voraussagen wurden hinsichtlich des Anteils der Reisanbaufläche während der ersten Saison (X_1), die Anzahl der Tage mit Minimumtemperaturen unterhalb von 22 °C im August und September (X_2), die durchschnittliche tägliche Maximumtemperatur für drei Monate (Juli, August und September) (X_3), die durchschnittliche Minimumtemperatur für drei Monate (Juli, August und September (X_4), der durchschnittlichen Anzahl Sonnenstunden im August und September (X_5), der durchschnittlichen Einstrahlung im August und September (X_6) und dem Gesamtregenfall im

Juli, August und September (X_7) ausgewählt als Grundlage der Untersuchungen. Gesamtmodelle und schrittweise Regression ohne solare Einstrahlung als Voraussage (Modell I) ergaben einen vergleichsweise geringen R^2 (0,6292). Wurde die solare Einstrahlung (Modell II) verwendet, konnte der R^2-Wert beträchtlich ($R^2 = 0{,}9464$) erhöht werden. Sieben Variable wurden ferner einer schrittweisen Regressionsanalyse unterzogen, wobei nur vier Voraussagen in dem abschließenden Modell (Modell III) mit R^2-Wert von 0,9234 nachgewiesen wurden. Das Modell III mit Minimalparametern $Y = 22119{,}5758 + 19{,}6898X1 - 150{,}9261 \quad X_2 - 1126{,}7501X_4 + 0{,}7179X7$ kann verwendet werden, um die erste Saison der Reisproduktion (Y) in Coimbatore, Indien, vorauszusagen.

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