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Statistical Analysis of Crop-Weather Regression Model for Forecasting Production Impact of Aus Rice in Bangladesh

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Abstract

This study is an endeavor to evaluate statistically predicts a weather-crop yield-forecasting model to generate early crop production estimates. The weather-crop yield-forecasting model was applied to estimate prospective production of Aus rice in Jessore and Rajshahi districts of Bangladesh. This model is the relationship between the crop yield and input weather parameters influencing the crop yield (Aus rice). The model evaluated using a multiple regression and ridge regression techniques. Ridge regression simulation study is used to perform sensitivity analysis. The agro climatic variables and others non-climatic variables were used in the study. The climatic data (1980-2000) were collected and transformed to the model specified from Bangladesh Meteorological Department (BMD) and yield data (1980-2000) were collected from various issues Bangladesh Bureau of Statistics (BBS) and Department of Agricultural Extension (DAE). Thus, compared to the actual production of local variety (LCV), the predicted production of local variety (LCV) Aus was lower in Jessore and Rajshahi districts; the predicted production of high yielding variety (HYV) Aus was lower in Jessore district but same in Rajshahi district; and the predicted production of total (All) Aus was lower in Jessore and Rajshahi districts. However, the predicted production was closer to actual production in both Jessore and Rajshahi districts. The results showed that the yields varied from stage to stage of crop growth. That is climate factor is playing an important role for yield and production level of the Aus crop. This study suggests that global warming might affect not only food grain production but also the distribution and species composition of grasslands. Forecasting of food grain production reliable comprehensive and timely information on the food situation and similar assessment of the prospects may contribute to the government policies. Finding of this study will serve as a basis for making decision by the higher authorities, in the procurement of food grains internally, whenever, harvest is good. Also, it will allow them to maintain a stable price by distribution of food grains from its store if prospects of poor harvests are likely to occur in order to mitigate the suffering of the rural poor.

Keywords and Phrases: Multiple regression, Ridge regression, Biasing parameter, Crop yield parameter, Agro-climate and Global Warming.

AMS Classification: 62M10

1 Introduction

Bangladesh is situated between latitudes 20 degrees 34' and 26 degree 38' north and longitudes 88 degree 01' and 92 degree 41' east, with an area of about 144,000 sq km and nearly 150 million people. Bangladesh is one of the most densely populated and least developed nations. The economy is largely agricultural, with the cultivation of rice the single most important activity. Major impediments to growth include frequent cyclones and floods, a rapidly growing labor force that cannot be absorbed by agriculture, inadequate power supplies, and slow progress towards various necessary reforms. Natural hazards remain a major worry. In the previous year 1988 and 1998, severe floods endangered the livelihood of more than 20 million people. Recently, severe floods lasting from July to August, 2004 endangered the livelihood of more than 30 million people (Rahman and Sumi, 2004).

The pressure of the population on the country's resources makes planning an economic imperative. Crop production in Bangladesh is largely governed by the vagaries of nature. From the time of sowing to harvesting, a crop passes through different growth stages and can reach the genetically determined yield potential only when all environmental and other input factors remain optimal during each of the phases of the growth cycle. If a certain growth stage is not completed satisfactory, the potential yield is reduced and such reduction is either not recovered or recovered only partially. The final yield obtained as thus determined by the interaction of a host of agro-climatic, environmental and input factors, which affect plant physiology in manners during the crop cycle. These circumstances offer scope of evaluating the yield performances at different stage of growth of the crops (Hossain, 1984). Food grains primarily rice and wheat account for about two third of the country's agricultural production. Food-grain is the main food consumption item in Bangladesh, accordingly for about 60 percent of the total calorie intake (Doorenbos and Puritt, 1977). Thus, food grain production is also a major determinant of the level of nutrition.

Climate variables affect a crop in different ways during its stages of development. The different stages of growth and yields of crops are affected by weather fluctuations that deviate from optimum. The effects of climate parameters at different growth stages of the crop may lead towards understanding this response in terms of the final yield and also provide a forecast of crop yield in advance of harvest (Jain et al., 1980). Climate plays very significant role in the yield of rice. Rice is produced in several distinct-cropping seasons including Aus rice, which is the pre-monsoon crop, Aman rice, which is the main monsoon crop, and Boro crop, which is the winter crop. In Bangladesh about 15% of the rice hectare is under irrigation; any further increase will be rather slow. In rainfed agriculture, rainfall is the greater source for crop transpiration. Rainfall also influences soil properties, which determine a field's suitability for tillage and other field operations and for seed emergence. Agriculturists have keen interests in seasonal and spatial distribution of rainfall (Stansel and Fries, 1980). Deficiency in rainfall creates problems right from sowing to physiological maturity stage (Ahmed et al., 2000). Temperature is a dominant climatic factor, which affects the growth of rice plant and yield of rice. Growth and maturity of rice plants at different stages are governed by certain critical levels of low and high temperatures, normally below 20^0C and above 30^0C. Rice yield can be correlated with maximum, minimum, mean and range of temperatures during the cycle of rice plants (Robertson, 1970; Yoshida, 1978).

Climate plays a dominant role in agricultural production systems, it tends to define the bounds within which the physiological growth of crop occurs. Consequently cultural practices are influenced extensively by climatic factors (Bhuiyan and Galang, 1987). Several studies indicate that weather during cropping season strongly influences the crop growth and accounts for two-third (67%) of the variation in productively while other factors accounts for only one-third (33%). So, the growth and development of a plant at any given time can be described as the net result of the interactions of the lives (Shu Geng and Auburn, 1987; White et al., 1993; Singh, 2000).

Simulation is a useful tool for estimating possible future impacts of climate change on crop and the use of simulation models to predict the likely effects of climate change on crop production is an evolving science. It seems very probable that simulation will be used extensively in future to assess impacts of climate change on agriculture (Curry et al., 1990 and Whistler et al., 1995).

Aus rice is grown in 3.0 million hectares mostly as an upland crop directly seeded from March-May with the onset of pre-monsoon rainfall. Seeding starts earlier in the east than in the west. The crop is harvested from June-September. Traditional varieties are of short duration, photosensitive and drought tolerant. In some areas Aus rice is transplanted when late rainfall does not permit timely direct seedling. The entire growth period has high temperature and the crop suffers from drought at early growing stages and low solar radiation at later growth stages. The crop also can suffer from submergence at ripening due to heavy rainfall (Rekabdar et al., 1984). Aus yield varies from 1 to 2 t/ha.

To predict the effects of global warming on grasslands, it is necessary to understand the climate factors controlling grassland productivity under climate conditions (Ohsawa et al., 1998). The IPCC Working Group II (1996) reported in their review that there was a strong linear relationship between above ground net primary productivity and annual precipitation in grasslands, with typically 90% of the variance in primary production accounted for by annual precipitation.

The objective of this paper was to develop a relationship between the crop yield and input climate parameters influencing the crop yield. The model was applied to estimate production impact of Aus rice. It will serve as a basis for making decision by the higher authorities, in the procurement of food grains internally, whenever harvest is good. Also it will allow them to maintain a stable price by distribution of food grains from its store if prospects of poor harvests are likely to occur in order to mitigate the suffering of the rural poor.

2 Data and Sources of Variables

The study was conducted in two purposely-selected district, Jessore and Rajshahi. The study was limited to some climatic factors and non-climatic factors. The selected climatic variables were maximum temperature (MAX), minimum temperature (MIN), average temperature (AVR), diurnal temperature (DUR), total rainfall (TRN), cumulative rainfall (CRN), net solar radiation (NSR), and water balance index (WBI). Time (YAR) and dummy variable (DMY) are the non-climatic variables. Estimation of the model required two sets of data

(a) Historical crop yield data from period 1980 to 2000 and

(b) Historical data on a number of agro-climatic variables from period 1980 to 2000.

Data relating to these agro-climatic variables were obtained from the Bangladesh Meteorological Department (BMD) Bangladesh Bureau of Statistics (BBS) and the Department of Agricultural Extension (DAE). The model is based on the assumption that there exist a quantitative relationship between periodic values of agro-climatic variables and final crop yields. The two important aspects considered are the spatial and temporal dimensions of the models. Data is generally available at the district level and second, since many agricultural policies are implemented at district level, the exercise may provide useful inputs for district level planning.

3 Methodology and Models

3.1 Multiple Regression Model

The yield forecasting model has been used in this sudy was specified as:

$$y_i = \beta_0 + \sum_{i}^{n} \sum_{j}^{k} \beta_j w_{ij} + u_i \qquad i = 1, 2, 3, \cdots\cdots, n$$

$$j = 1, 2, 3, \cdots\cdots, k$$

where, y_i is the yield of the Aus rice crop, w is the agro-climatic variables, b are the coefficients of the relevant variables, β_0 is the constant and u_i is the disturbance term.

The explicit formulation of the model was:

$$\begin{aligned} y &= \beta_0 + \beta_1\text{YAR} + \beta_2\text{MAX} + \beta_3\text{MIN} + \beta_4\text{AVR} + \beta_5\text{DUR} + \beta_6\text{TRN} \\ &+ \beta_7\text{CRN} + \beta_8\text{NSR} + \beta_9\text{WBI} + \beta_{10}\text{DMY} + \epsilon \end{aligned} \quad (1)$$

where,
y = Area/yield/production of Aus rice (Mt/ha)
MAX = Maximum temperature (^{0}c)
MIN = Minimum temperature (^{0}c)
AVR = Average temperature (^{0}c)
DUR = Diurnal temperature (^{0}c)
TRN = Total rainfall of the week (mm)
CRN = Cumulative rainfall for the seasons unto the week (mm)
NSR = Net solar radiation (cal/cm2/day)
WBI = Water balance index
YAR = Time
DMY = Dummy variable $\left[\begin{array}{ll} 1 & 1 = \text{favorable environmental condition for production} \\ 0 & 0 = \text{unfavorable environmental condition for production} \end{array}\right.$
ϵ = Stochastic term/residual term/error term [$\epsilon \sim$ NID(0,σ^2)]

The models for least square were used to estimate the regression coefficients in equation (1) by SPSS Software. The model was estimated for early reproductive stages of Aus rice crop growth, corresponding to weeks 26 (2nd week of July) and week 29 (1st week of August) of the year 2001. For this stage of crop growth models were estimated for LCV (Local variety), HYV (High yielding variety) and All (Total) Aus rice.

3.2 Regression Diagnostic and Simulation Study

Regression analysis is a statistical technique for investigating and modeling the relationship between variables (Montgomery and Peck, 1982). In fact, regression analysis may be the most widely used statistical technique. Regression analysis based on time series data implicitly assumes that underlying time series are stationary. The classical t-test and F-tests are based on this assumption using the unit root test showing that the time series data is stationary (Gujarati, 1995; Yin and Maddala, 1996a,b; Franses and Haldrup, 1994).

3.2.1 Multicollinearity and its Diagnostics

Multicollinearity is a serious problem in estimating the regression coefficients and violates the classical linear regression assumptions and thus results in the loss of precision of estimation (Montgomery and Peck, 1982). A very simple measure of multicollinearity is inspection of the off-diagonal elements r_{jj} in $(X^T X)$ (Montgomery and Peck, 1982). The multicollinearity detects by using examination correlation matrix, variance inflation factors and eigen system analysis of variance-covariance matrix.

3.3 Methods for Dealing with Multicollinearity

3.3.1 Biased Regression Method

Multicollinearity is the serious problem in estimating the regression assumptions (Achen, 1982). Several biased regression method have been proposed as solution to the collinearity problem, these include Stein shrinkage (Stein, 1960), Ridge regression (Hoerl and Kennard, 1970a, 1970b). While ridge regression has received the greatest acceptance, all have been used with apparent success in various problems.

3.3.2 Ridge Regression Techniques

When the method of least squares is applied to non-orthogonal data, poor estimates of the regression coefficients are usually obtained. The variance of the least squares estimates of the regression coefficients may be considerably inflated and the length of the vector of least squared parameter estimates is too long on the average. This implies that the absolute value of the least squares estimates is too large. The Gauss-Markov property referred that the least squares estimator has minimum variance but there is no guarantee that this variance will be small. Ridge regression is a statistical tool, which is particularly suited to answering the first question and also gives a partial solution to the second question (Katz, 1979). Hoerl and Kennard (1970a, 1970b) have suggested that, if one used the criterion of mean square error, a biased estimation method they have developed called "ridge regression" may be wide variety of situations. Ridge regression is based on altering the ridge K. The parameter estimates in this procedure will be biased but may be more precise (Tamarkin, 1982).

The least square estimators $\hat{\beta}$ of β is

$$\hat{\beta} = (X^T X)^{-1} X^T Y \tag{2}$$

It is well known that the LS-estimator is unstable (in the sense of large variance) when the matrix X'X is linearly singular. One technique for coping with this obstacle is so called ridge regression, which is found by solving a slightly modified version of the equations. Specifically, we define the ridge estimator $\hat{\beta}_R$ as the solution to

$$(X^T X + KI)\hat{\beta}_R = X^T Y \tag{3}$$

$$or, \quad \hat{\beta}_R = (X^T X + KI)^{-1} X^T Y \tag{4}$$

where, $K \geq 0$ is a constant selected by the analyst.

The sensitivity analysis using ridge regression requires an issue of some concern of (best) selecting a value for K, which is called the biasing parameter selected by analyst. When K=0 the ridge estimator is the least squares estimator i.e., $\hat{\beta}_0 = \hat{\beta}$.

Several authors have proposed procedures for choosing $'K'$ that are more analytical. Hoerl et al., (1975) have suggested that an appropriate choice for K is

$$K = \frac{P\hat{\sigma}^2}{\hat{\beta}^T\hat{\beta}} \tag{5}$$

where, $\hat{\beta}$ = standardized regression coefficient and

$\hat{\sigma}^2$ = mean square error and is found from the least squares estimator of the standardized regression coefficients and analysis of variance table.

Hoerl et al., (1975) showed that an iterative estimation procedure based on K via simulation that the resulting ridge estimator had significant improvement in MSE over least squares. Specially, they suggested the following sequence of estimates of β and K;

$$\begin{array}{ll} \hat{\beta} & K_0 = \dfrac{P\hat{\sigma}^2}{\hat{\beta}^T\hat{\beta}} \\ \hat{\beta}_R(K_0) & K_1 = \dfrac{P\hat{\sigma}^2}{\hat{\beta}_g^T(K_0)\hat{\beta}_g(K_0)} \\ \hat{\beta}_R(K_1) & K_2 = \dfrac{P\hat{\sigma}^2}{\hat{\beta}_g^T(K_1)\hat{\beta}_g(K_1)} \end{array} \tag{6}$$

The procedure is terminated until $K_{i-1} = K_i$ for some $(i,\ i \neq j)$

The procedure is terminated until when $K_{i-1} = K_i$ for some $(i,\ i \neq j)$ an appropriate value of K may also be determined by inspection of the ridge trace (frequently employed method for determing the value of K). The ridge trace is a plot of the elements of $\hat{\beta}_R$ versus K, for values of K usually in the interval 0 to 1. As the biasing parameter K is in increased, the estimate becomes less variable with the trade-of -increased biases. If the predictor variables are highly correlated, the estimates will change rapidly (usually decreasing absolute value) for small value of K, coefficients will frequently change their relative magnitudes and sometimes even their signs, indicating the relative instability of the OLS estimates. Eventually, the coefficients will appear to stabilize for large values of K.

4 Results and Discussions

The study is an endeavor to statistically predict a weather-crop yield forecasting model to generate early crop production estimates. The weather-crop yield forecasting model was applied to estimate prospective production of Aus rice in two districts of Bangladesh. An attempt was made to estimate yields and production of local Aus, HYV Aus, and all Aus of two districts taken from 23 BBS locations for 2001-2002 seasons by making use of the estimated coefficients of the crop yield-weather regression model.

Table 1. Summary statistics and estimated values of the ridge regression coefficients of the Crop-Weather Regression Model for Aus Rice, 2001-2002 season, Jessore and Rajshahi (Week 26, Early Reproductive Stage) using stable K values.

		Jessor			**Rajshahi**		
		K=0.24037 for local Aus K=0.168745 for HYV Aus K=0.117413 for All Aus			K=0.008379 for local Aus K=0.07046 for HYV Aus K=0.054633 for All Aus		
Equation	Variables/ Constants	Coeffs. of Regression	t-statistics	$\frac{R^2}{F}$	Coeffs. of Regression	t-statistics	$\frac{R^2}{F}$
LCV Aus	Const.	-0.01957	-0.5321		-0.02261	-0.5650	
	YAR	-0.01009	-0.9632		0.00592	0.9665	
	MIN	0.01552	0.7915	$R_2 = 0.9088$	−0.07572**	-2.0671	$R_2 = 0.9501$
	DUR	0.02717	0.4061		−0.06117**	-2.8805	
	TRN	0.001173	0.9271	F=27.428	0.00205**	2.0735	F=52.332
	CRN	-1.5E-05	-0.0810		-0.00017	-0.5537	
	NSR	-6.8E-05	-0.0754	Sig. F=	0.00138	1.9460	Sig. F=
	WBI	0.16606	0.4437	1E-09	2.54009**	2.6469	1.51E-12
	DMY	0.50719**	4.7169		0.30554**	4.1443	
HYV Aus	Const.	-0.02655	-0.5651		-0.01698	-0.6441	
	YAR	-0.00345	-0.5776		-0.00329	-0.9081	
	MIN	0.05381**	3.1289	$R_2 = 0.9850$	0.05309**	4.1644	$R_2 = 0.9941$
	DUR	0.02166	0.6573		-0.00084	-0.0661	
	TRN	0.00023	0.2262	F=180.753	0.00129	1.9700	F=465.516
	CRN	-0.00018	-0.9451		-0.00025	-1.2947	
	NSR	0.00048	0.6627	Sig. F=	3.05E-05	0.0676	Sig. F=
	WBI	0.32472	0.9266	2.98E-18	0.31769	1.0075	1.02E-22
	DMY	0.35811	5.2150		0.38364**	9.3289	
ALL Aus	Constant	-0.00745	-0.3251		-0.00733	-0.3496	
	YAR	0.02639**	5.9932		0.02449**	4.4022	
	MIN	0.00803	0.8688	$R_2 = 0.9899$	0.03178**	2.9916	$R_2 = 0.9912$
	DUR	0.02582	1.6259		-0.00569	-0.5594	
	TRN	0.00161**	3.2001	F=180.753	0.00017	0.3265	F=310.048
	CRN	-0.00014	-1.4736		5.74E-06	0.0391	
	NSR	0.00093**	2.6370	Sig. F=	-0.00029	-0.8451	Sig. F=
	WBI	0.14359	0.7140	3.76E-20	0.08970	0.3375	8.59E-21
	DMY	0.05289	0.90089		0.19296**	3.0457	

**$p < 0.001$statistically highly significant

The correlation matrix indicates that some independent variables have high correlation. Thus inspection of the correlation matrix indicates that there are several linear dependencies in the data and that the multicollinearity is a serious problem. Therefore multicollinearity is suspected and the least square estimates of the regression coefficients may be poor. This may seriously limit the usefulness of the regression model for inference and prediction.

Estimation of the biasing parameter K was derived from regression simulations using the iteration technique. The ridge trace is shown from Fig. 1 to 6 for early reproductive stage of local, HYV and all Aus in Jessore and Rajshahi district. Also Fig. 7 to 12 showed the ridge trace for early maturity stage of local, HYV and all Aus in Jessore and Rajshahi district. The ridge trace (Fig. 1 to 12) showed that the instability in the regression coefficients was due to multicollinearity (Marquardt and Snee, 1975) which indicated that there are violations of the Gauss-Markov property. However, the ridge regression coefficients stabilize rapidly as K increases (Fig. 1 to 12). The estimated results for Jessore and Rajshahi are presented in Tables 1 to 3 respectively.

The fitted ridge regression ($K = 0.24037$) simulation output (Table 1) of LCV Aus for early reproductive stage of Jessore district showed that the minimum temperature, diurnal temperature, total rainfall, water balance index and dummy variable had positive impact on LCV Aus yield, whereas time variable, cumulative rainfall and net solar radiation had negative impact on LCV Aus yield. Only the dummy variable was statistically highly significant. F values and $R^2 = 0.91$ were significantly improved over the simulation study and overall regression coefficients were statistically highly significant.

Table 1 showed the fitted ridge regression ($K = 0.168745$) simulation output of HYV Aus for early reproductive stage of Jessore district; the minimum temperature, diurnal temperature, total rainfall, net solar radiation, water balance index and dummy variable had positive impact on HYV Aus yield, whereas, time variable and cumulative rainfall had negative impact on HYV Aus yield. Only the minimum temperature was statistically highly significant. F values and $R^2 = 0.98$ were significantly improved over the simulation study and overall regression coefficients were statistically highly significant.

In Jessore district the fitted ridge regression ($K = 0.117413$) simulation output (Table 1) of All Aus for early reproductive stage showed that the time variable, minimum temperature, diurnal temperature, total rainfall, net solar radiation, water balance index and dummy variable had positive impact on All Aus yield, whereas, cumulative rainfall had negative impact on All Aus yield. The time variable, total rainfall and net solar radiation were statistically highly significant. F values and $R^2 = 0.99$ were significantly improved over the simulation study and overall regression coefficients were statistically highly significant.

In Rajshahi district the fitted ridge regression ($K = 0.008379$) simulation output (Table 1) of LCV Aus for early reproductive stage showed that the time variable, total rainfall, net solar radiation, water balance index and dummy variable had positive impact on LCV Aus yield, whereas, minimum temperature, diurnal temperature and cumulative rainfall had negative impact on LCV Aus yield. The minimum temperature, diurnal temperature, total rainfall, water balance index and dummy variable were statistically highly significant. F values and $R^2 = 0.95$ were significantly improved over the simulation study and overall regression coefficients were statistically highly significant.

Table 1 also showed the fitted ridge regression ($K = 0.07046$) simulation output of HYV Aus for early reproductive stage of Rajshahi district; the minimum temperature, total rainfall, net solar radiation, water balance index and dummy variable had positive impact on HYV Aus yield, whereas, time variable, diurnal temperature and cumulative rainfall had negative impact on HYV Aus yield. The minimum temperature and dummy variable were statistically highly significant. Simulation study also showed that the F values and $R^2 = 0.99$ were significantly improved and overall regression coefficients were statistically highly significant.

The fitted ridge regression ($K = 0.054633$) simulation output (Table 1) of All Aus for early reproductive stage of Rajshahi district showed that the time variable, minimum temperature, total rainfall, cumulative rainfall, water balance index and dummy variable had positive impact on All Aus yield, whereas, diurnal temperature and net solar radiation had negative impact on All Aus yield. The time variable, minimum temperature and dummy variable were statistically highly significant. Simulation results indicated that F values and $R^2 = 0.99$ were significantly improved and overall regression coefficients were statistically highly significant.

Table 2 . Summary statistics and estimated values of the ridge regression coefficients of the Crop-Weather Regression Model for Aus Rice, 2001-2002 season, Jessore and Rajshahi (Week 29, Early Maturity Stage) using stable K values.

		Jessore			Rajshahi		
		K=0.24355 for local Aus K=0.132885 for HYV Aus K=0.136163 for All Aus			K=0.445672 for local Aus K=0.070402 for HYV Aus K=0.078395 for All Aus		
Equation	Variables/ Constants	Coeffs. of Regression	t-statistics	$\frac{R^2}{F}$	Coeffs. of Regression	t-statistics	$\frac{R^2}{F}$
LCV Aus	Const.	-0.03104	-0.5539		-0.01471	-0.27096	
	YAR	-0.01169	-1.2056		0.005237	0.653248	
	MIN	0.01873	0.9381	$R_2 = 0.9167$	0.026296	1.52541	$R_2 = 0.9129$
	DUR	-0.04444	-0.7680		-0.01933	-0.35975	
	TRN	0.00195	1.5570	F=30.260	-0.00014	-0.14641	F=28.832
	CRN	-3.8E-05	-0.1700		7.96E-05	0.374104	
	NSR	0.00084	0.7998	Sig. F=	9.75E-05	0.137353	Sig. F=
	WBI	0.13765	0.3921	3.83E-10	0.089707	0.254679	6.17E-10
	DMY	0.56279**	5.4631		0.234049**	2.278503	
HYV Aus	Const.	-0.01802	-0.4517		-0.0142	-0.51242	
	YAR	-0.00497	-0.9759		-0.00499	-1.4688	
	MIN	0.07801**	4.5279	$R_2 = 0.9892$	0.058102**	4.248045	$R_2 = 0.9936$
	DUR	0.00195	0.0469		-0.00408	-0.15133	
	TRN	0.00107	1.0182	F=251.180	0.000334	0.651641	F=424.344
	CRN	-0.00030	-1.9246		9.91E-07	0.008851	
	NSR	-0.00038	-0.4949	Sig. F=	7.52E-06	0.021713	Sig. F=
	WBI	0.17019	0.4489	8.46E-20	0.191817	0.595255	2.81E-22
	DMY	0.35334**	5.6859		0.341232**	6.847229	
ALL Aus	Const.	-0.00720	-0.2738		-0.00576	-0.27544	
	YAR	0.02767**	5.0715		0.025364**	4.230974	
	MIN	0.02114**	2.0229	$R_2 = 0.9867$	0.031437**	2.915948	$R_2 = 0.9913$
	DUR	0.00435	0.1599		-0.00693	-0.33027	
	TRN	0.00153**	2.5477	F=205.240	0.000496	1.181724	F=313.279
	CRN	-5.1E-05	-0.5014		1.12E-05	0.110887	
	NSR	0.00040	0.7996	Sig. F=	-0.00021	-0.77994	Sig. F=
	WBI	0.06426	0.2948	7.55E-19	0.062053	0.230986	7.68E-21
	DMY	0.09229	1.4475		0.145118	1.938896	

$^{**}p < 0.001$ statistically highly significant

The fitted ridge regression ($K = 0.24355$) simulation output (Table 2) of LCV Aus for early maturity stage of Jessore district showed that the, minimum temperature, total rainfall, net solar radiation, water balance index and dummy variable had positive impact on LCV Aus yield, whereas, time variable, diurnal temperature and cumulative rainfall had negative impact on LCV Aus yield. Only the dummy variable was statistically highly significant. Simulation results indicated that F values and $R^2 = 0.92$ were significantly improved and overall regression coefficients were statistically highly significant.

In Jessore district the fitted ridge regression ($K = 0.132885$) simulation output (Table 2) of HYV Aus for early maturity stage showed that the minimum temperature, diurnal temperature, total rainfall, water balance index and dummy variable had positive impact on HYV Aus yield, whereas, time variable, cumulative rainfall and net solar radiation had negative impact on HYV Aus yield. The minimum temperature and dummy variable were statistically highly significant. F values and $R^2 = 0.99$ were significantly improved over the simulation study and overall regression coefficients were statistically highly significant.

Table 2 showed the fitted ridge regression ($K = 0.136163$) simulation output of All Aus for early maturity stage of Jessore district; the time variable, minimum temperature, diurnal temperature, total rainfall, net solar radiation, water balance index and dummy variable had positive impact on All Aus yield, whereas, only cumulative rainfall had negative impact on All Aus yield. The time variable, minimum temperature and total rainfall were statistically highly significant. F values and $R^2 = 0.99$ were significantly improved over the simulation study and overall regression coefficients were statistically highly significant.

In Rajshahi district the fitted ridge regression ($K = 0.445672$) simulation output (Table 2) of LCV Aus for early maturity stage showed that the time variable, minimum temperature, cumulative rainfall, net solar radiation, water balance index and dummy variable had positive impact on LCV Aus yield, whereas, diurnal temperature and total rainfall had negative impact on LCV Aus yield. Only the dummy variable are statistically highly significant. Simulation results indicated that F values and $R^2 = 0.91$ were significantly improved and overall regression coefficients were statistically highly significant.

Table 2 also showed the fitted ridge regression ($K = 0.070402$) simulation output of HYV Aus for early maturity stage of Rajshahi district and the minimum temperature, total rainfall, cumulative rainfall, net solar radiation, water balance index and dummy variable had positive impact on HYV Aus yield, whereas, time variable and diurnal temperature had negative impact on HYV Aus yield. The minimum temperature and dummy variable were statistically highly significant. F values and $R^2 = 0.99$ were significantly improved over the simulation study and overall regression coefficients were statistically highly significant.

The fitted ridge regression ($K = 0.078395$) simulation output (Table 2) of All Aus for early maturity stage of Rajshahi district showed that the time variable, minimum temperature, total rainfall, cumulative rainfall, water balance index and dummy variable had positive impact on All Aus yield, whereas, diurnal temperature and net solar radiation had negative impact on All Aus yield. The time variable and minimum temperature were statistically highly significant. Simulation results indicated that F values and $R^2 = 0.99$ were significantly improved and overall regression coefficients were statistically highly significant.

Table 3 . Estimated Yields and production of Aus Rice in Jessore and Rajshahi for 2001-2002 season, as obtained from the Crop-Weather Regression Model

Districts	**Categories**	**Yield per hectare (metric tons)**		Area of Aus (0.000 hectare)	**Production of Aus (metric tons)**	
		Week 26 (Early Reproductive Stage)	Week 29 (Early Maturity Stage)		Week 26 (Early Reproductive Stage)	Week 29 (Early Maturity Stage)
Jessore	LCV Aus	1.0137	0.9977	57.360	58.1458	57.2280
	HYV Aus	2.0908	2.1727	32.025	70.1604	69.5807
	ALL Aus	1.4572	1.4950	89.385	130.2518	133.6306
Rajshahi	LCV Aus	1.0922	1.0606	34.730	37.9231	36.8346
	HYV Aus	1.9552	1.9234	30.435	59.5065	58.5386
	ALL Aus	1.4901	1.4737	35.165	97.0958	96.0337

It is evident from Table 3 that the yields of LCV, HYV and ALL Aus estimated at early reproductive stage were 1.0137, 2.0908 and 1.4572 metric tons (Mt's) per hectare respectively. Similarly, in early maturity stage these were 0.9977, 2.1727 and 1,4950 Mt's per hectare respectively for Jessore district. Again, it can be seen from Table 3 that the yields of LCV, HYV and ALL Aus estimated at the early reproductive stage were 1.0922, 1.9552 and 1.490 Mt's per hectare respectively. Similarly, in early maturity stage these were 1.0606, 1.9234 and 1.4737 Mt's per hectare respectively for Rajshahi district. The result showed that the yields were varied from stage to stage of crop growth. That is, climatic factors are playing an important role for yield and production level of the Aus crop.

5 Conclusions

Finding of this study will serve as a basis for making decision by the higher authorities in the procurement of food grains internally, whenever harvest is good. Also, it will allow them to maintain a stable price by distribution of food grains from its store if prospects of poor harvests are likely to occur in order to mitigate the suffering of the rural poor.

The predicted yield of LCV Aus for early reproductive stage in Jessore is lower than the national average yield of 1.026 Mt's per hectare for Aus in the preceding year, but in Rajshahi district it is greater than the national average yield of 1.026 Mt's per hectare for Aus of the preceding year. Similarly, the predicted yield of earlymaturity stage in Jessore district is lower than the national average, but in Rajshahi district it is greater than the national average. The HYV Aus both for early reproductive and early maturity stage in the Jessore and Rajshahi districts are greater than the national average yield of 1.798 Mt's per hectare. The ALL Aus, both for early reproductive and early maturity stage in the Jessore and Rajshahi districts are greater than the national average yield of 1,283 Mt's per hectare.

Thus, compared to the actual production of LCV, the predicted production of LCV Aus was lower in Jessore and Rajshahi districts; the predicted production of HYV Aus was lower in Jessore district but same in Rajshahi district; and the predicted production of All Aus was lower in Jessore and Rajshahi districts. However, the predicted production was closer to actual production in both the districts. Forecasting of food grain production, reliable comprehensive and timely information on the food situation and similar assessment of the prospects may contribute to the government policies. This study suggests that global warming might affect not only food grain production but also the distribution and species composition of grasslands.

Abbreviations:

ALL- Total
HYV- High Yield Variety
LCV- Local
MAX- Maximum Temperature
MIN- Minimum Temperature
AVR -Average Temperature
DUR- Diurnal Temperature
TRN- Total Rainfall
CRN- Cumulative Rainfall
NSR -Net Solar Radiation
WBI- Water balance index
YAR- Time
DMY- Dummy Variable
BMD- Bangladesh Meteorological Department
BBS- Bangladesh Bureau of Statistics
DAE- Department of Agricultural Extension
Mt-Metric Ton

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