Measuring Climatic and Hydrological Effects on Cash Crop Production and Production Forecasting in Bangladesh Using ARIMAX Model

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Abstract
The objective of this study is to measure the climatic and hydrological effects on cash crop productions in Bangladesh using Box-Jenkins Auto-Regressive Integrated Moving Average (ARIMA) model with external regressor variables, that is, ARIMAX model. At the same time, forecasting cash crop production using the same model under consideration of the climatic and hydrological effects. It is not very easy to measure the climatic and hydrological effects on different types of agricultural crop production in as usual regression model because of time sequence dataset. Because of time sequence data, Box-Jenkins ARIMAX model is used in this study to measure the climatic and hydrological effects on different major cash crop production in Bangladesh, where climatic and hydrological variables are used as external regressor variable. This is the new study to measure climatic and hydrological effects on crop production using ARIMAX model. The best fitted ARIMAX model for Sugarcane, Tea, Tobacco and Cotton production are ARIMAX(0,1,1), ARIMAX(0,1,1), ARIMAX(0,1,1), ARIMAX(1,1,0) respectively.
Keywords: Climate, Hydrology, Cash Crop, ARIMAX Model, Forecasting, Bangladesh.

1. Introduction

Bangladesh has a large agrarian base country with 76 percent of total population is living in the rural areas and 90 percent of the rural population directly related with agriculture. Agriculture is the single largest producing sector of the economy since it comprises about 18.6% (data released on November, 2010) of the country's GDP and employs around 45% of the total labor force. Considering the climatic conditions Jute, Tabaco, Sugarcane, Cotton, Tea, etc. are the major cash crop productions in Bangladesh.

Tea is an important export item in Bangladesh. Bangladesh ranks tenth among the ten largest tea-producing and exporting countries in the world. In the year 2000, the country’s tea production was 1.80% of the 2,939.91 million kg produced worldwide. Most of the 163 tea estates in Bangladesh are located in the North-eastern region of Bangladesh-Maulvi Bazar, Hobiganj, Sylhet, Brahmanbaria districts. There are a few number of tea estates in Panchagar District and in Chittagong and South-eastern district (rasheeka.wordpress.com, Archive for Tea Industry)

In Bangladesh, particularly in Kushtia, Chakaria upazila of Cox’sbazar and Bandarban, farmers have experienced expansion of tobacco cultivation. According to the official Agricultural Statistics (Bangladesh Bureau of Statistics, Ministry of Planning, GOB, August 2010) three varieties of tobacco - Jati, Motihari and Virginia - are grown in different districts of Bangladesh. Jati and Motihari are mostly grown in Rangpur and Bandarban, while Virginia is mostly grown in Kushtia, Rangpur, Jessore and Dhaka. In terms of land area covered by all three kinds of tobacco, Rangpur still remains highestwith 40345 acres during 2008-09 followed by Kushtia 22241 and Bandarban 4678 acres of land. Besides tobacco is extending to Jessore, Jhenaidah, Nilphamari, Lalmonirhat and even in Manikganj and Tangail.

Cotton is commonly known is kapas tula in Bangladesh. Cotton is one of the important cash crops in Bangladesh. It is the main raw materials of textile industry. Annual requirement of raw cotton for textile industry of Bangladesh is estimated around 2.5 million bales. Local production is only about 0.1 million bales. Around 4-5% of the national requirement is fulfilled through the local production, remaining 95-96% is fulfilled by importing raw cotton from USA (40%), CIS (35%), Australia, Pakistan, South Africa and other country producing countries (25%) (BTMA, March, 2002). (BBS, 2000, Statistical Year book of Bangladesh).In Bangladesh Garments Industries contribute 27% of GDP, due to low labor costs and quota free export to the

European market. The Garments industry has been flourishing in Bangladesh, Readymade garments (RMG) accounts for about 75% of the total export earnings.

Sugarcane is another important cash crop in Bangladesh. It is considered as one of the most efficient converters of solar energy. It is very important industrial crops; accounting for 66% of sugar production in the world. It is also known as "ikshu" in Bangladesh and is the main source of sugar and gur. The contribution of sugarcane to national GDP is about 0.78%. about 5 million people depend on sugarcane cultivation in Bangladesh.

Climate change in Bangladesh is an extremely crucial issue and according to National Geographic, Bangladesh ranks first as the nation most vulnerable to the impacts of climate change in the coming decades. Climate change and agriculture are interrelated processes, both of which take place on a global scale. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run-off, precipitation and the interaction of these elements. These conditions determine the carrying capacity of the biosphere to produce enough food for the human population and domesticated animals. The overall effect of climate change on agriculture will depend on the balance of these effects. Assessment of the effects of global climate changes on agriculture might help to properly anticipate and adapt farming to maximize agricultural production.

2. Review of Literature

There are not enough review of the literature for measuring the climatic and hydrological effects on agricultural crop productions such as Cash crop productions using ARIMAX model. But some of such works in the other relevant fields by using ARIMAX model has been done such as **Julio J. Lucia and hipolit torro** (2005) have conducted an analysis with the title "short term electricity future prices at Nord Pool forecasting power and risk premiums". This study analyses how weekly prices at Nord pool are formed. Forecasting power of future prices is compared with an ARIMAX model in the spot prices. The time series model contains external lagged variable like temperature, precepitation, reservoious level and the basis (future price less the spot price.

3. Objectives of the Study

The main objective of this study is to develop an ARIMAX model for measuring the climatic and hydrological effects on major cash crop production in the Bangladesh and production forecasting using the same model. The specific objective of the study is to develop an Autoregressive Integrated Moving Average with external regressors (ARIMAX) model for different types of cash crop productions such as Sugarcane, tobacco, Tea and Cotton in Bangladesh and forecasting these cash crop production considering the climatic and hydrological effects.

4. Reasons for Using ARIAMX model

To measure any cause-effect relationship among the variables, generally, we use Multiple Regression Model but this model is a suitable model for cross-sectional dataset. The dataset used in this study is a time sequence data set, that is, it has time effects on the variable under study which should be considered. We don't avoid the problem of time effects on the variable under study, that's why, we try to fit the model using Box-Jenkins (Box and Jenkins, 1970) ARIMA approach with external regressors, that is, ARIMAX model. By ARIMAX model, we can overcome time effects problem by adding some Auto-Regressive and/or Moving Average term in the model to adjust these time effects. Definitely, in as usual Regression model, we don't consider these time effects, so ARIMAX model is the best model for considering time effects in this study.

5. Methodology

A time series is a set of numbers that measures the status of some activity over time. It is the historical record of some activity, with measurements taken at equally spaced intervals with a consistency in the activity and the method of measurement.

The Box and Jenkins (1970) procedure is the milestone of the modern approach to time series analysis. Given an observed time series, the aim of the Box and Jenkins procedure is to build an ARIMA model. In particular, passing by opportune preliminary transformations of the data, the procedure focuses on Stationary processes.

In this study, it is tried to fit the Box-Jenkins Autoregressive Integrated Moving Average (ARMIA) model with external regressor, that is, ARIMAX model. This model is the generalized model of the non-stationary ARMA model denoted by ARMA(p,q) can be written as

$$Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \cdots + \Phi_p Y_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} \ldots \ldots \ldots . -\theta_q e_{t-q} \quad (1)$$

Where, Y_t is the original series, for every t, we assume that e_t is independent of $Y_{t-1}, Y_{t-2}, Y_{t-3}, \ldots, Y_{t-p}$.
And it consists of the combination of Auto-Regressive series, AR(p) and Moving Average series, MA(q) , where AR(p) can be defined as $Y_t = \Phi_1 Y_{t-1} + \cdots + \Phi_p Y_{t-p} + e_t$; and MA(q) can be defined as $Y_t = e_t - \theta_1 e_{t-1} \ldots - \theta_q e_{t-q}$

A time series $\{Y_t\}$ is said to follow an integrated autoregressive moving average (ARIMA) model if the d^{th} difference $W_t = \nabla^d Y_t$ is a stationary ARMA process. If $\{W_t\}$ follows an ARMA (p,q) model, we say that $\{Y_t\}$ is an ARIMA(p,d,q) process. Fortunately, for practical purposes, we can usually take d = 1 or at most 2. Consider then an ARIMA (p,1,q) process. with $W_t = Y_t - Y_{t-1}$, we have

$$W_t = \Phi_1 W_{t-1} + \Phi_2 W_{t-2} + \cdots + \Phi_p W_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} \ldots \ldots \ldots . \theta_q e_{t-q} \quad (2)$$

Again ARIMA model with external regressor, that is, ARIMAX model with d=1 can be written as

$$W_t = \Phi_1 W_{t-1} + \Phi_2 W_{t-2} \ldots + \Phi_p W_{t-p} + e_t - \theta_1 e_{t-1} - \theta_q e_{t-q} + \cdots \beta_1 X_{t1} + \beta_2 X_{t2}, \ldots, \beta_m X_{tm} \quad (3)$$

Where X's are regressor variables and β's are the coefficients of regressor variable

Box and Jenkins procedure's steps

1. **Preliminary analysis:** create conditions such that the data at hand can be considered as the realization of a stationary stochastic process.
2. **Identification**: specify the orders p, d, q of the ARIMA model so that it is clear the number of parameters to estimate. Recognizing the behavior of empirical autocorrelation functions plays an extremely important role.
3. **Estimate:** efficient, consistent, sufficient estimate of the parameters of the ARIMA model (maximum likelihood estimator).
4. **Diagnostics:** check if the model is a good one using tests on the parameters and residuals of the model. Note that also when the model is rejected, still this is a very useful step to obtain information to improve the model.
5. **Usage of the model:** if the model passes the diagnostics step, then it can be used to interpret a phenomenon, forecast.

5.1. Procedure of Maximum Likelihood Estimation (MLE) Methods

The advantage of the method of maximum likelihood is that all of the information in the data is used rather than just the first and second moments, as is the case with least squares. Another advantage is that many large-sample results are known under very general conditions. For any set of observations, $Y_1, Y_2, \ldots, Y_n$ time series or not, the likelihood function L is defined to be the joint probability density of obtaining the data actually observed. However, it is considered as a function of the unknown parameters in the model with the observed data held fixed. For ARIMA models, L will be a function of the ϕ's, θ's, μ, and σ_e^2 given the observations $Y_1, Y_2, \ldots, Y_n$. The maximum likelihood estimators are then defined as those values of the parameters for which the data actually observed are most likely, that is, the values that maximize the likelihood function.

We begin by looking in detail at the AR (1) model. The most common assumption is that the white noise terms are independent, normally distributed random variables with zero means and common variance, σ_e^2. The probability density function (pdf) for each e_i is then

$$(2\pi\sigma_e^2)^{-(1/2)}\, exp^{(-[\frac{e_2^2}{\sigma_e^2}])}, for \; -\infty < e_t < \infty$$

and, by independence, the joint pdf for $e_1, \ldots, e_n$ is

$$(2\pi\sigma_e^2)^{-(\{n-1\}/2)}\, exp^{(-[\Sigma\frac{e_2^2}{\sigma_e^2}])}, for \; -\infty < e_t < \infty \quad (4)$$

Now consider

$$\begin{aligned} Y_2 - \mu &= \phi\,(Y_1 - \mu) + e_2 \\ Y_3 - \mu &= \phi\,(Y_2 - \mu) + e_3,.. \\ \dots\ Y_n - \mu &= \phi\,(Y_{n-1} - \mu) + e_n \end{aligned} \tag{5}$$

If we condition on $Y_1 = y_1$ Equation (5) defines a linear transformation between $e_2, e_3, \dots, e_n$ and $Y_2, \dots, Y_n$ (with Jacobian equal to 1). Thus the joint pdf of $Y_2, \dots, Y_n$ given $Y_1 = y_1$ can be obtained by using Equation (5) to substitute for the e's in terms of the Y's in Equation (4). Thus we get

$$f(Y_2, \dots, Y_n | Y_1) = (2\pi\sigma_e^2)^{-(\{n-1\}/2)} \exp\left[-\frac{1}{2\sigma_e^2}\sum_2^n \{(Y_t - \mu) - \phi(Y_{t-1} - \mu)\}^2\right] \tag{6}$$

Now consider the (marginal) distribution of Y_1. It follows from the linear process representation of the AR(1) process that Y_1 will have a normal distribution with mean μ and variance $\sigma_e^2/(1-\phi^2)$. Multiplying the conditional pdf in equation (6) by the marginal pdf of Y_1 gives us the joint pdf of $Y_1, Y_2, \dots, Y_n$ that we require. Interpreted as a function of the parameters φ, μ and σ_e^2, the likelihood function for an AR(1) model is given by

$$L(\phi, \mu, \sigma^2) = (2\pi\sigma_e^2)^{-\left(\frac{\{n-1\}}{2}\right)} (1 - \phi^2) \exp\left[-\frac{1}{2\sigma_e^2} S(\phi, \mu)\right] \tag{7}$$

Where, $S(\phi, \mu) = \sum_2^n \{(Y_t - \mu) - \phi(Y_{t-1} - \mu)\}^2 + (1 - \phi^2)(Y_1 - \mu)$

The function S(φ,μ) is called the unconditional sum-of-squares function. As a general rule, the logarithm of the likelihood function is more convenient to work with than the likelihood itself. For the AR (1) case, the log-likelihood function, denoted by (ϕ, μ, σ^2) , is given by

$$l(\phi, \mu, \sigma^2) = -\frac{n}{2}\log(2\pi) - \frac{n}{2}\log(\sigma_e^2) + \frac{1}{2}\log(1 - \phi^2) - \frac{1}{2\sigma_e^2}\ S(\phi, \mu) \tag{8}$$

For given values of φ and μ, $l(\phi, \mu, \sigma^2)$ can be maximized analytically with respect to σ_e^2 in terms of the yet to be determined estimators of φand μ. We obtain

$$\widehat{\sigma_e^2} = \frac{S(\phi, \mu)}{n} \tag{9}$$

As in many other similar contexts, we usually divide by n −2 rather than n (since we are estimating two parameters, ϕ and μ) to obtain an estimator with less bias. For typical time series sample sizes, there will be very little difference.

Consider now the estimation of φ and μ. A comparison of the unconditional Sum of Squares function S(ϕ,μ) with the conditional Sum of Squares function $Sc(\phi, \mu) = \sum_2^n \{Y_t - \mu) - \phi(Y_{t-1} - \mu)\}^2$ of AR process reveals one simple difference. Since $S_c(\phi,\mu)$ involves a sum of n −1 components, whereas $(1 - \phi^2)(Y_1 - \mu)^2$ does not involve n, we shall have $S(\phi, \mu) \approx Sc(\phi, \mu)$. Thus the values of φ and μ that minimize S(ϕ,μ) or $S_c(\phi,\mu)$ should be very similar, at least for larger sample sizes. The effect of the rightmost term in Equation (9) will be more substantial when the minimum for ϕ occurs near the stationarity boundary of ±1.

5.2. Diagnostic Tests of Residuals

5.2.1. Jarque-Bera Test

We can check the normality assumption using Jarque-Bera (Jarque & Bera, 1980) test, which is a goodness of fit measure of departure from normality, based on the sample kurtosis(k) and skewness(s). The test statistics Jarque-Bera(JB) is defined as

$$JB = \frac{n}{6}\left(s^2 + \frac{(k-3)^2}{4}\right) \sim \chi^2_{(2)}$$

Where n is the number of observations and k is the number of estimated parameters. The statistic JB has an asymptotic chi-square distribution with 2 degrees of freedom, and can be used to test the hypothesis of skewness being zero and excess kurtosis being zero, since sample from a normal distribution have expected skewness of zero and expected excess kurtosis of zero.

5.2.2. Ljung-Box Test

Ljung-Box (Box and Ljung, 1978) Test can be used to check autocorrelation among the residuals. If a model fit well, the residuals should not be correlated and the correlation should be small. In this case the null hypothesis is $H_0 : \rho_1(e) = \rho_2(e) = \ldots\ldots = \rho_k(e) = 0$ is tested with the Box-Ljung statistic

$$Q^* = N(N+1) \sum_{i=1}^{k} (N-k)\, \rho^2_k(e)$$

Where, N is the no of observation used to estimate the model. This statistic Q* approximately follows the chi-square distribution with (k-q) df, where q is the no of parameter should be estimated in the model. If Q* is large (significantly large from zero), it is said that the residuals autocorrelation are as a set are significantly different from zero and random shocks of estimated model are probably auto-correlated. So one should then consider reformulating the model.

6. Used Software

This analysis has completely done by statistical programming based open source Software named as **R**, (version **2.15.1).** The additional library packages used for analysis are **forecas**t, **tseries** and **TSA**.

7. Data Source and Data Manipulation

The climatic datasets are available from the Bangladesh Government's authorized websites www.barc.gov.bd. The crop data-sets are also available from Bangladesh Agricultural Ministry's websites named as www.moa.gov.bd. These data-set are available from the year1972 to 2006. Climatic information was in the original form such that it is arranged in the monthly average information corresponding to the years from 1972 to 2006 according to the 30 climatic stations. The name of these stations are Dinajpur, Rangpur, Rajshahi, Bogra, Mymensingh, Sylhet, Srimangal, Ishurdi, Dhaka, Comilla, Chandpur, Josser, Faridpur, Madaripur, Khulna, Satkhira, Barisal, Bhola, Feni, MaijdeeCourt, Hatiya, Sitakunda, Sandwip, Chittagong, Kutubdia, Cox's Bazar, Teknaf, Rangamati, Patuakhali, Khepupara, Tangail, and Mongla. We take the month October, November, December, January and February as a "dry season" and March, April, May, June, July, August, September as a "summer season" considering the weather and climatic conditions of Bangladesh. Then, finally we take average seasonal climatic information of 30 climatic stations corresponding to the year from 1972 to 2006 for the purpose of observing seasonal effects of Climatic and hydrological variable. We take the average of 30 climatic areas because of focusing the overall country's situation and overall model fitting for whole Bangladesh.

To serve our research objective, we divide the dataset two parts, where the first part is made of initial 31 years (1972-2001) to fit the model and second part contain last five years (2002-2006) dataset, from which climatic and hydrological variable are used to forecast five years forward forecasting considering the demand of ARIMAX model (because we have to give input as regressor variables to forecast using the ARIMAX model).

8. Climatic and Hydrological Variables Used in This Study

sun.sum = Sunshine of the Summer Season, sun.dry = Sunshine of the Dry Season , clo.sum = Cloud Coverage of the Summer Season, clo.dry = Cloud Coverage of the Dry Season, max.tem.dry = Maximum Temperature of the Dry Season, max.tem.sum = Maximum Temperature of the Summer Season, min.tem.dry = Minimum Temperature of the Dry Season, min.tem.sum = Minimum Temperature of the Summer Season, rain.dry= Ammount of Rainfall of the Dry Season, rain.sum= Amount Rainfall of the Summer Season, rh.dry = Relative Humidity of the Dry Season, rh.sum= Relative Humidity of the Summer Season, wind.dry = Wind Speed of the Dry Season and wind.sum = Wind Speed of The Summer Season.

9. ARIMAX Modeling for Different Cash Crop Production(Analysis)

9.1 ARIMAX Modeling for Sugarcane Production

Dickey-Fuller unit root test is used to check whether time sequence sugarcane production data satisfies the sationarity conditions. It is found that stationarity condition satisfied at the difference order one with p-value =

0.01 which suggests that there is no unit root at the first order difference of sugarcane production at 1% level of significance. The graphical stationarity test using ACF and PACF is shown in the Figure-1

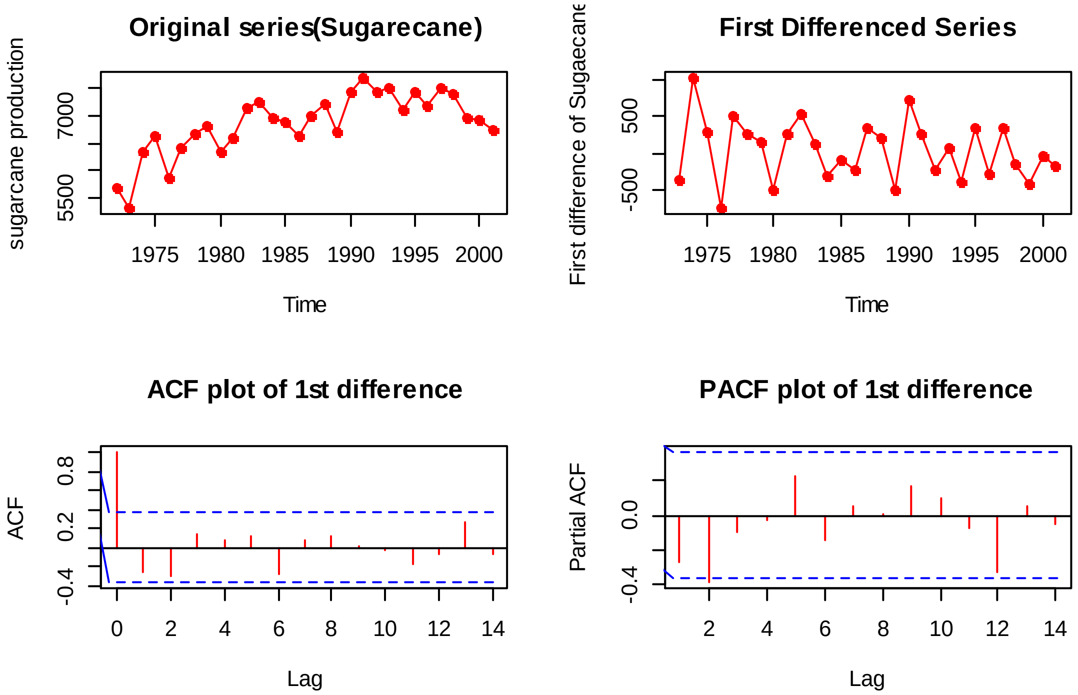


Figure 1: *Graphically Stationarity Checking for Sugarcane Production*

From the Figure 1, it is clear that original series does not show a constant variance and slightly shows an increasing trend but first order differenced series shows a more stable variance than the original series. Again, from the ACF and PACF, it is clear that there is no significant spike in the first order differenced series which also tell us that the series is stationary with first order difference and at the same time, there are no significant effects of Autoregressive and Moving Average order at first order difference series, which also implies stable variance.

From the tentative order analysis, the best selected ARIMAX model for measuring the climatic and hydrological effects on Sugarcane production in Bangladesh is ARIMAX (0,1,1) with the AIC = 433.73 and BIC = 455.61. The parameter estimates of the fitted ARIMAX (0,1,1) are given in the Table 1.

Table 1: *Summary Statistics of the ARIMAX Model for Sugarcane Production*

Coefficients	**Estimates**	**Std. Error**	**t-value**	**p-value**
ma1	-1	0.0895	-11.1754	0.0284
sun.sum	-95.7717	446.4682	-0.2145	0.4327
sun.dry	-900.8863	259.5937	-3.4704	0.0893
clo.sum	-182.1219	587.544	-0.31	0.4043
clo.dry	-480.9725	579.3279	-0.8302	0.2794
max.tem.dry	-449.0541	328.4169	-1.3673	0.201
max.tem.sum	625.7998	583.4032	1.0727	0.2388
min.tem.dry	737.8143	366.7051	2.012	0.1468
min.tem.sum	-639.0952	461.7818	-1.384	0.1992
rain.dry	-3.8714	4.0049	-0.9667	0.2554
rain.sum	-3.4251	2.0106	-1.7035	0.169
rh.dry	-107.816	75.8186	-1.422	0.1951
rh.sum	256.4301	149.6737	1.7133	0.1682
wind.dry	294.5875	1062.5695	0.2772	0.4139
wind.sum	530.4545	481.0136	1.1028	0.2345

From the Table 1, it is clear that Sugarcane production depends on the first order Moving Average Lag, which has statistically significant effects at 3% level of significance. At the same time, sun.dry has statistically significant effects on Sugarcane production at 10% level of significance. Again, sun.sum, sun.dry, clo.sum, clo.dry, max.tem.dry, min.tem.sum, rain.dry, rain.sum and rh.dry have negative and max.tem.sum, min.tem.dry, rh.sum, wind.dry and wind.sum have positive effects on Sugarcane production

To check Autocorrelation assumption, "Box-Ljung test" is used. From the test, it is found that the $\Pr(|\chi^2_{(1)}| \geq 0.1286) = 0.7199$, which suggests that we may accept the assuption that there is no autocrrelation among the residuals of the fitted ARIMAX(0,1,1) for Sugarecane production model at 5% level of significance. Again, to check the normality assumption, "Jarque-Bera test" is uesd, from which, we find the $\Pr(|\chi^2_{(2)}| \geq 1.0401) = 0.5945$, which refers to accept the norality assumpytion that the residuals are from normal distribution. Graphical Residuals Diagnostics are shown in the Figure 2.

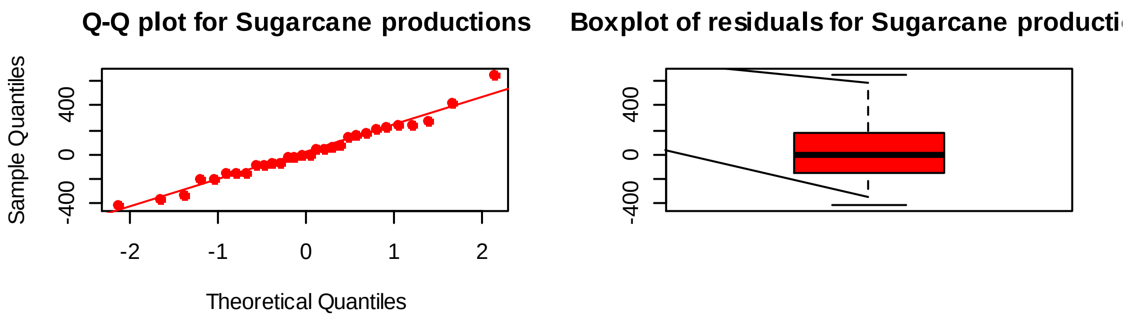


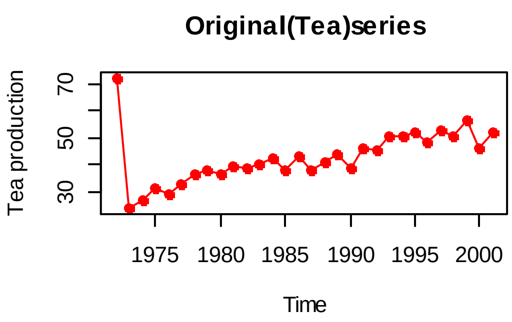
Figure-2: *Graphical Diagnostics Checking for ARIMAX Model of Sugarcane Production*

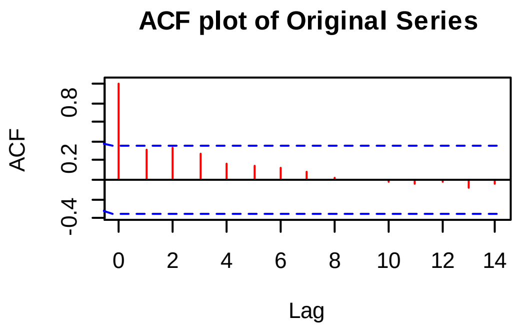
From the Figure 2, it is clear that almost all of the points are very closed to the Q-Q line or on the Q-Q line, which indicates that residuals are normally distributed of the Sugarcane production model. At the time, from the Boxplot, it is clear that residuals are symmetrically (normally) distributed and there is no unusual or outlier observation, that is, this model is going to make a good inference.

Finally, considering all of the Graphical and Formal test, it is obvious that our fitted model ARIMAX (0,1,1) is the best fitted model for measuring the Climatic and hydrological effects on Sugarcane production in the Bangladesh.

9.2 ARIMAX Modeling for Tea Production

Dickey-Fuller unit root test is used to test whether time sequence tea production data series are stationary or not. It is found that stationarity condition satisfied without any difference with the $\Pr(|t| \geq -13.9946) = 0.01$, which suggests that there is no unit root in the original series at 5% level of significance. The graphical stationarity test is shown in the Figure-3





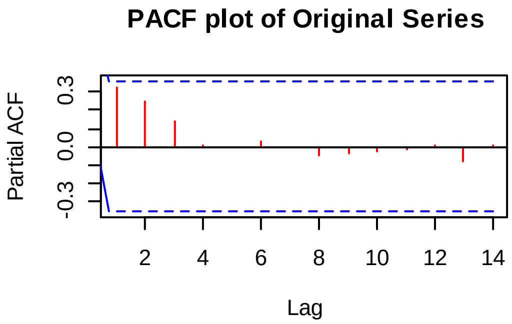


Figure 3: *Graphically Stationarity Checking for Tea Production*

From the Figure 3, it is clear that original tea production series shows a constant variance. Again, from the ACF and PACF, it is clear that there is no significant spike in the original series which also indicates that there are no significant effects of Auto-Regressive and Moving Average in the original series, that is, the tea production series is stationary without any difference.

From the tentative order analysis, our finally, the best selected ARIMAX model for measuring the climatic and hydrological effects on tea production in Bangladesh is ARIMAX (1,0,0) with the AIC = 206.63 and BIC = 230.45. The parameter estimates of the fitted ARIMAX (1,0,0) model are given in the Table-2.

Table 2: *Summary Statistics of ARIMAX Model for Tea Production*

Coefficients	**Estimates**	**Std.Error**	**t-value**	**p-value**
ar1	-0.7907	0.1404	-5.6321	0.0559
intercept	1040.9484	294.4137	3.5357	0.0877
sun.sum	-36.273	8.6402	-4.1982	0.0744
sun.dry	12.3276	4.8729	2.5298	0.1198
clo.sum	-53.5081	12.2081	-4.383	0.0714
clo.dry	65.9457	14.5708	4.5259	0.0692
max.tem.dry	36.1332	7.5984	4.7554	0.066
max.tem.sum	-46.988	12.4349	-3.7787	0.0823
min.tem.dry	-40.2493	7.7132	-5.2182	0.0603
min.tem.sum	35.9612	9.4144	3.8198	0.0815
rain.dry	-0.2993	0.076	-3.9366	0.0792
rain.sum	-0.1409	0.0456	-3.0917	0.0996
rh.dry	5.5314	1.2996	4.2563	0.0735
rh.sum	-9.0652	2.539	-3.5704	0.0869
wind.dry	-22.7006	18.5342	-1.2248	0.2179
wind.sum	-34.3451	8.3034	-4.1363	0.0755

From the Table 2, it is clear that tea production depends on the first order Autoregressive Lag, which has statistically significant effects at 6% level of significance. At the same time, sun.dry, clo.sum, clo.dry, max.tem.dry, max.tem.sum, min.tem.dry, min.tem.sum, rain.sum,rain.sum, rh.dry, rh.sum and wind.sum have statistically significant effects on tea productions at 10% level of significance. Again, sun.dry, clo.dry, max.tem.dry, min.tem.sum and rh.dry have positive and sun.sum, clo.sum, max.tem.sum, min.tem.dry, rain.dry, rain.sum, rh.sum, wind.dry and wind.sum have negative effects on tea production in Bangladesh.

To check the Autocorrelation assumption, "Box-Ljung test" is used. From the test, we find the $\Pr(|\chi^2_{(1)}| \geq 1.1773) = 0.2779$, which suggests that we may accept the assuption that there is no autocrrelation among the residuals. Again, to check the normality assumptions, "Jarque-Bera test" is used, which gives the $\Pr(|\chi^2_{(2)}| \geq 0.0552) = 0.9728$, which suggests to accept the norality assumption, that is, residuals follow normal distribution. Graphical Residuals Diagnostics are shown in the Figure 4.

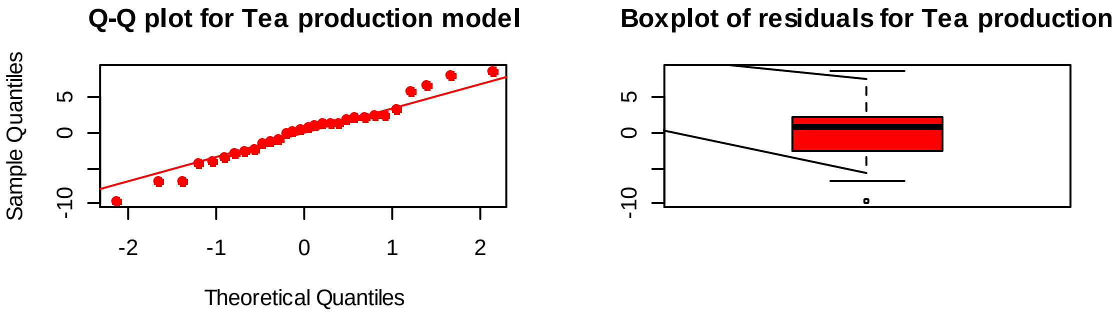


Figure 4: *Graphical Diagnostics Checking for ARIMAX Model of Tea Production*

From the Figure 4, it is clear that almost all of the points are very closed to the Q-Q line or on the Q-Q line, which suggests that residuals are normally distributed of the Tea production model. At the time, from the Boxplot, it is clear that residuals are slightly negatively skewed and it contains single outlier.

Finally, considering all of the Graphical and Theoretical test, it is clear that our fitted model ARIMAX (1,0,0) is the best fitted model for measuring the climatic and hydrological effects on tea production in Bangladesh.

9.3 ARIMAX Modeling for Cotton Production

Dickey-Fuller unit root test is used to test whether the time sequence cotton production series is stationary or not. It is found that stationarity condition satisfied at first order difference with the p-value = 0.01, which suggests that there is no unit root in the first order difference at 5% level of significance, that is, the series is stationary. The graphical stationarity test is shown in the Figure 5.

From the Figure 5, it is clear that at the first difference cotton production series shows a constant variance but in the original series is not stationary, that is, our difference order is one to make the cotton production series stationary. Again, from the ACF and PACF, it is clear that there is no significant spike in the first order difference series, which also indicate that there are no significant effects of Auto-Regressive and Moving Average in the first order difference, that is, the cotton production series is stationary at the first order difference.

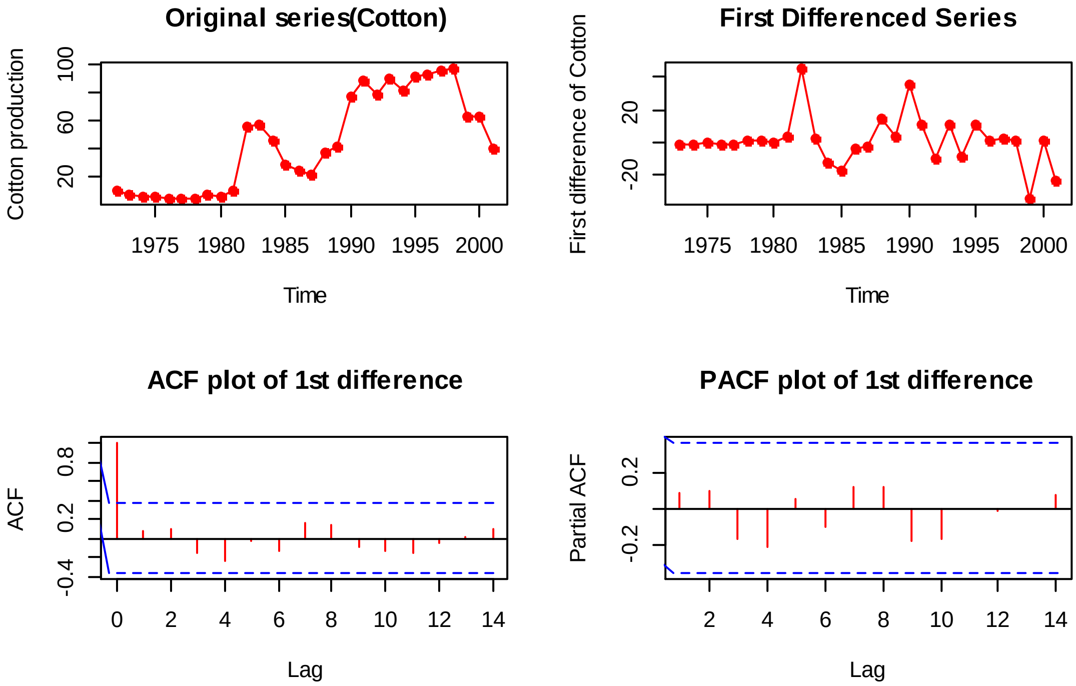


Figure-5: *Graphically Stationarity Checking for Cotton Production*

From the tentative order analys, the best selected ARIMAX model for measuring the climatic and hydrological effects on cotton production is ARIMAX (1,1,0) with the AIC = 237.95 and BIC = 259.82. The parameter estimates of the fitted ARIMAX (1,1,0) are shown in the Table 3.

Table 3: *Summary Statistics of the ARIMAX Model for Cotton Production*

Coefficients	**Estimates**	**Std.Error**	**t-value**	**p-value**
ar1	0.5749	0.1859	3.0931	0.0995
sun.sum	6.7974	11.5496	0.5885	0.3307
sun.dry	-31.7327	9.0473	-3.5074	0.0884
clo.sum	-7.3014	16.3115	-0.4476	0.366
clo.dry	-24.7835	11.1699	-2.2188	0.1348
max.tem.dry	-17.5668	7.3996	-2.374	0.1269
max.tem.sum	28.5494	19.6168	1.4553	0.1916
min.tem.dry	30.2768	8.6389	3.5047	0.0885
min.tem.sum	-36.0005	13.393	-2.688	0.1134
rain.dry	0.0887	0.0857	1.0343	0.2446
rain.sum	0.0064	0.0441	0.1439	0.4545
rh.dry	-3.4872	2.0874	-1.6706	0.1717
rh.sum	9.2769	4.6811	1.9818	0.1488
wind.dry	-50.5128	29.3197	-1.7228	0.1674
wind.sum	38.5358	18.4037	2.0939	0.1418

From the Table 3, it is obvious that first order Auto-Regressive Lag has significant effects on cotton production at 10% level of significance. Again, the regressor variables sun.dry, and min.tem.dry have a significant effects on cotton production at 8% level of significance. Similarly, sun.sum, max.tem.sum, min.tem.dry, rain.dry, rain.sum, rh.sum and wind.sum have positive and sun.dry, max.tem.dry, min.tem.sum, clo.dry, clo.sum, rh.dry and wind.dry have negative effects on cotton production.

To check Autocorrelation assumption, "Box-Ljung test" is used. From the test, it is obtained that the $\Pr(|\chi^2_{(1)}| \geq 1.0272) = 0.3108$, which suggests that we may accept the assuption that there is no autocrrelation among the residuals at 5% level of significance. Again, to check the normality assumptions, "Jarque-Bera" test is used.

From the test, we get the Pr($|\chi^2_{(2)}| \geq 0.6803$) = 0.7117, which stongly suggests to accept the norality assumpytion such that the residuals are follow normal distributin. Graphical Residuals Diagnostics are shown in the Figure-6.

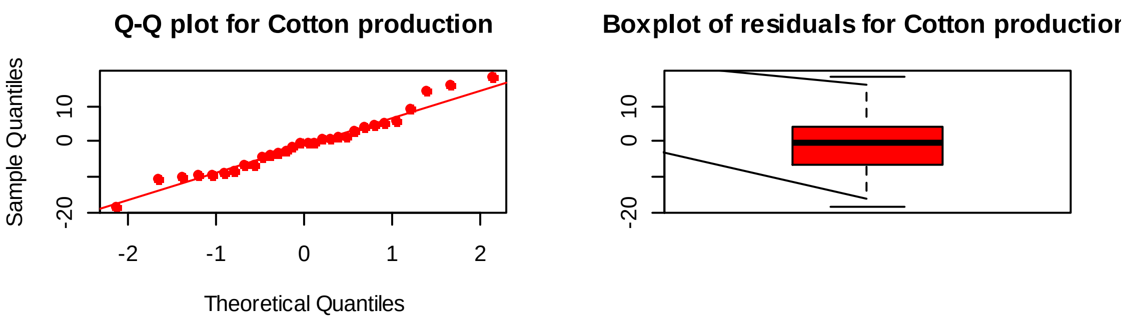


Figure 6: *Graphical Diagnostic Checking for ARIMAX Model of Cotto Production*

From the Figure 6, it is clear that almost all of the points are very closed to the Q-Q line or on the Q-Q line, which suggests that residuals are normally distributed of the cotton production model. At the time, from the boxplot, it is clear that there is no unusual or outlier observation, that is, this model is going to make a good inference.

Finally, considering all of the Graphical and Theoretical test, it is clear that our fitted model ARIMAX (1,1,0) is the best fitted model for measuring the Climatic and hydrological effects on cotton production in the Bangladesh.

9.4 ARIMAX Modeling for Tobacco Production

Dickey-Fuller unit root test is used to test whether the time sequence tobacco production series is stationary or not. It is found that stationarity condition satisfied at the difference order one with the p-value < 0.01, which suggests that there is no unit root in the first order difference at 1% level of significance, that is, the tobacco production series become stationary at first order difference. The graphical stationarity test is shown in the Figure 7

From the Figure 7, it is obvious that at the first difference tobacco production series shows more stable variance than the original series, that is, our difference order is one to make the cotton production series as stationary. Again, from the ACF and PACF, it is clear that there is no significant spike in the first order difference series, which also indicate that there are no significant effects of Auto-Regressive and Moving Average in the first order difference, that is, the cotton production series is stationary at the first order difference.

From the tentative order analysis, the best selected ARIMAX model for measuring the climatic and hydrological effects on tobacco production is ARIMAX (0, 1,1) with the AIC = 194.93 and BIC = 216.8. The parameter estimates of the fitted ARIMAX model for tobacco production are given in the Table 4.

From the Table 4, it is obvious that first order Moving Average Lag has significant effects on Tobacco production at 3% level of significane. Similarly, sun.dry, clo.dry, max.tem.sum, min.tem.dry, rh.sum and wind.sum have positive and sun.sum, clo.sum, max.tem.dry, min.tem.sum, rain.dry, rain.sum, rh.dry, and wind.dry have negative effects on cotton production. At the same time, max.tem.dry has statistically significant effects on Tobacco productions at 11% level of significance.

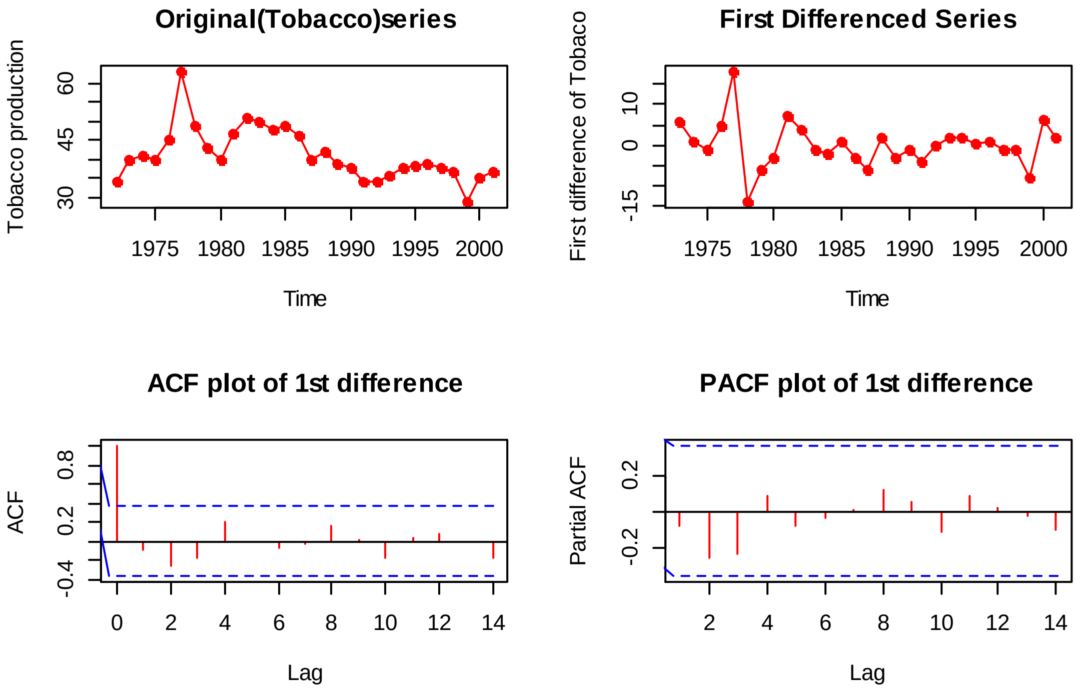


***Figure 7:** Graphically Stationarity Checking for Tobacco Production*

***Table 4:** Summary Statistics of the ARIMAX Model for Tobacco Production*

Coefficients	Estimates	Std. Error	t-value	p-value
ma1	1	0.093	10.7527	0.0295
sun.sum	-7.5628	6.8696	-1.1009	0.2347
sun.dry	2.4157	5.0897	0.4746	0.3589
clo.sum	-15.2521	7.73	-1.9731	0.1493
clo.dry	6.5076	4.5953	1.4161	0.1957
max.tem.dry	-10.2569	3.8105	-2.6918	0.1132
max.tem.sum	7.4327	11.0168	0.6747	0.3111
min.tem.dry	6.6123	4.1402	1.5971	0.1781
min.tem.sum	-1.5544	7.3401	-0.2118	0.4336
rain.dry	-0.0728	0.0513	-1.4182	0.1955
rain.sum	-0.0084	0.0243	-0.3462	0.3939
rh.dry	-0.0062	1.1931	-0.0052	0.4983
rh.sum	4.5699	2.4324	1.8788	0.1557
wind.dry	-5.5083	16.9135	-0.3257	0.3998
wind.sum	1.3588	11.9038	0.1141	0.4638

To check Autocorrelation assumption, “Box-Ljung test” is used. From the test, it is obtained the $\Pr(|\chi^2_{(1)}| \geq 0.1198) = 0.7293$, which suggests that we may accept the assuptions that there is no autocrrelation among the residuals at 5% level of significance. Again, to check the normality assumptions, “Jarque-Bera ” test is used. From the test, we get the $\Pr(|\chi^2_{(2)}| \geq 2.0714) = 0.355$, which refers to accept the norality assumpytion such that the residuals are follow normal distributin.

Finally, considering all of the Graphical and Formal test, it is clear that our fitted model ARIMAX (0, 1, 1) is the best fitted model for measuring the Climatic and hydrological effects on tobacco production in the Bangladesh.

10. Forecasting Cash Crop Production Using Fitted ARIMAX Model

After, selecting the best model, now we are going to use these models to forecast cash crop production in Bangladesh. To forecast the following modern "Forecasting Criteria" are considered. The most useful forecast evaluation criteria are Root Mean Square Error (RMSE) proposed by Ou and Wang (2010), Mean Absolute Error(MAE), Root Mean Square Error Percentage(RMSPE), Mean Absolute Percentage Error (MAPE) proposed by Sutheebnjard and Premchaiswadi (2010). The results of these criteria for forecasting cash crop production in Bangladesh are shown in the Table 5.

Table 5: *Forecasting Criteria for the Best Selected Model*

Cash Crop	Selected Model	Forecasting Criterion			
		ME	RMSE	MAPE	MAE
Cotton	ARIMAX(1,1,0)	-0.6321079	8.2321	35.28611	6.347396
Sugarcane	ARIMAX(0,1,1)	24.59022	228.5847	2.625375	176.2629
Tea	ARIMAX(1,0,0)	0.1937676	4.228393	8.277093	3.289199
Tobacco	ARIMAX(0,1,1)	-0.0987441	3.854004	7.292685	3.062968

11. Comparison between Original and Forecasted Series

It is tried make a comparison between the original series and forecasted series from the fitted ARIMAX model. These forecasted results are shown in the Figure 8.

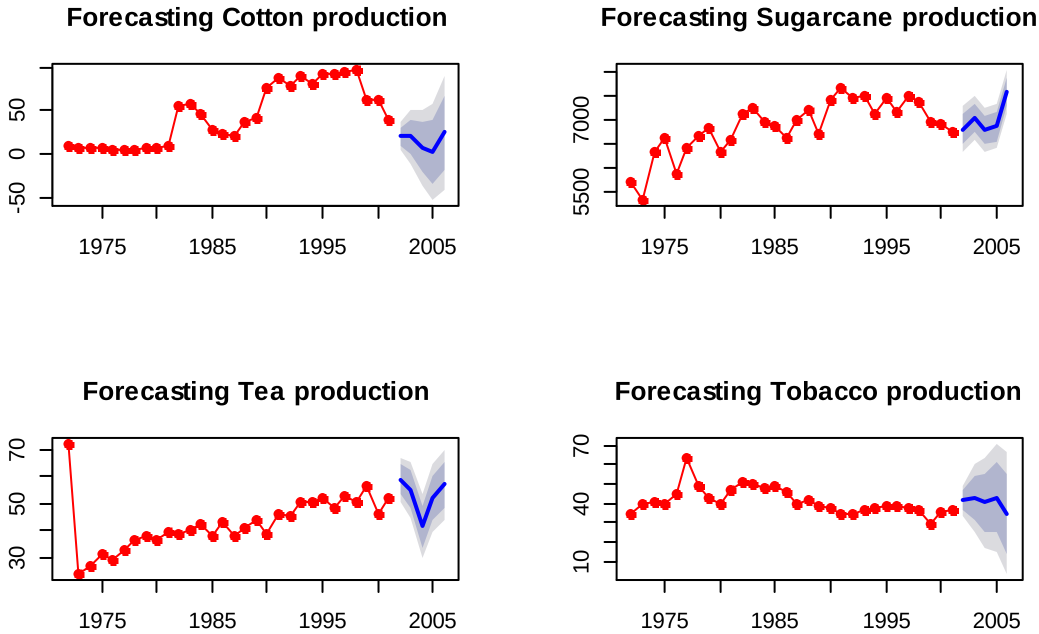


Figure 8: *Graphical Comparison between Original and Forecasted Series*

From the Figure 8,

- It is clear (top-left) that the original series of the cotton production (red color), which show initially almost constant tendency, after sometimes it increases and decreases consecutively and the forecasting series (blue color) also shows the same manner. That is, forecasting cotton productions may be good under consideration of climatic and hydrological effects.
- It is clear (top-right) that the original series of the Sugarcane productions (red color), which shows an upward production tendency and the forecasting series also shows similar pattern (blue color). In the forecasting plot, in sample forecasting part shows an upward trend and similarly, the out sample forecasting part also shows almost an upward tendency. That is, forecasting Sugacane productions may be good under consideration of climatic and hydrological effects.
- It is clear (left-bottom) that the original series of the tea production (red color), which shows an upward production tendency and the forecasting series also shows an upward production tendency (blue color). In the forecasting plot, in sample forecasting part shows an upward trend and similarly, the out sample

forecasting part also shows an upward trend under consideration of climatic and hydrological effects. That is, forecasting tea productions may be good.

- It is clear (bottom-right) that the original series of the tobacco production (red color), which shows a downward production tendency and the forecasting series also shows a downward production tendency (blue color). In the forecasting plot, in sample forecasting part shows a downward trend and similarly the out sample forecasting part also shows a downward trend under consideration of climatic and hydrological effects. That is, forecasting Tobacco productions may be good.

Finally, all of the fitted models clearly explain the practical situation which implies that these fitted models are statistically good fitted model for measuring climatic and hydrological effects in cash crop production and forecasting the cash crop under consideration of these effects covering the Bangladesh area.

12. Conclusion and Recommendations

In this study, it is tried to fit an ARIMAX model because of time sequence cash crop data set, where climatic and hydrological variables are used as a regressor variable. In this study, it is tried to fit the best model to measure the Climatic and hydrological effects on different types of cash crop productions named as Sugarcane, Cotton, Tobacco and Tea, covering the whole Bangladesh. To select the best model for measuring the climatic and hydrological effects on different types of Cash crop productions, the latest available model selection criteria such as AIC, BIC, ACF and PACF are used. Again, to select the fitted model, it is tried to fit the best simple model because the model contains less parameters give the good representative results. The best selected Box-Jenkins ARIMAX model for measuring the climatic and hydrological effects on Cash crop production are ARIMAX (1,1,0), ARIMAX (1,0,0), ARIMAX (0,1,1) and ARIMAX (1,1,0) for Sugarcane, Tea, Tobacco and Cotton production respectively. From the analysis, sun.dry for Sugarcane production; sun.dry, clo.sum, clo.dry, max.tem.dry, max.tem.sum, min.tem.dry, min.tem.sum, rain.sum,rain.sum, rh.dry, rh.sum and wind.sum for Tea production; max.tem.dry has statistically significant effects on Tobacco productions; and sun.dry and min.tem.dry for Cotton production have significant effects. The main objective of this study is to fit an appropriate model and we are interested to forecast. At the same time, to forecast ARIMAX model, there are need to future input variable which is not available base on which we can forecast for long time. We are tried to forecast five years forward by using our dataset in which we used thirty one year's data to fit model and remaining five years dataset (for regressor variable) are used as input variable to forecast. From the Comparison between original series and forecasted series, it is clear that each of the model are good to forecast because in sample and out sample forecasting shows the same manner which implies the best representation of empirical situation. Again, all of the formal and graphical tests show that they are very well managed to fit the ARIMAX model for specific cash crop production. These selected models are the best selected model to measure climatic and hydrological effects and forecasting cash crop in Bangladesh.

After conducting these analyses, the following recommendations can be made such as

- The policy makers and researchers could use these model to make a decision for agricultural productions under consideration of climatic and hydrological effects on agricultural productions.
- Similar regional models could be further studied to find variations of the models.
- The climatic zone similar to Bangladesh could also be compared in the future studies.

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