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The Best-Fitted Model for Analyzing Climatic Impact on Crop Production: A Comparative Study of ARIMA and ARIMAX Models

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ABSTRACT

The agriculture sector is highly vulnerable to weather variations. Agricultural output is influenced by several climate-related phenomena, including changes in temperature and rainfall patterns. The main objective of this study was to investigate the impact of climatic parameters on cotton and sugarcane production using Autoregressive Integrated Moving Average (ARIMA) and ARIMAX models. Annual data on mean maximum temperature (YMMTX), mean minimum temperature (YMMTN), and total rainfall for 1981–2021 at the Bahawalnagar and Bahawalpur stations was obtained from the Pakistan Meteorological Department (PMD), Karachi. Time-series data on crop production and cultivated area was obtained from the Pakistan Bureau of Statistics. Stationarity of data was assessed using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Based on the minimum values of the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Root Mean Square Error (RMSE), the best-fitted ARIMAX models for cotton and sugarcane production in Bahawalnagar and Bahawalpur were ARIMAX (1,1,0), (1,0,0), (1,1,0), and (3,1,0), respectively. The results indicated that climatic factors significantly affect cotton and sugarcane production. These findings may be useful for planning and development departments, farmers, and other stakeholders.

Keywords: ARIMAX, climate change, cotton, mean maximum temperature, sugarcane

Highlights

- Climatic impact on agricultural production in Bahawalpur and Bahawalnagar.
- ARIMA and ARIMAX models were compared using historical data for the time period (1981-2021).
- ARIMAX demonstrated better forecasting performance than ARIMA based on AIC, BIC, and RMSE.

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1.INTRODUCTION

Pakistan is an agricultural country where agriculture plays a key role in the national economy, contributing 22.7% to Gross Domestic Product (GDP) and reducing 37.4% of the labor force [1]. Approximately, 60%–70% of the country's population depends on agriculture for its livelihood. Globally, approximately 99.9% of food is produced on land, whereas only 0.01% comes from the oceans [2]. According to the 2017 census, the population of Pakistan is growing at an annual rate of 2.4% [3]. This rapid population growth accelerates the demand for food and agricultural products, placing considerable pressure on limited resources. Consequently, it may contribute to food insecurity, inflation, hunger, inadequate nutrition, and undernutrition among the population [2].

Many factors affect crop production. Among these, climatic factors play a key role in influencing crop production, such as sugarcane and cotton. Researchers have highlighted approximately 60 factors that may affect sugarcane production. This is because sugarcane usually remains in the field for 12–24 months, making its growth and yield sensitive to changing environmental and climatic conditions [4]. It has been observed that the ideal temperature for sugarcane growth ranges from 26°C to 27°C [5]. In Punjab Province, variations in sugarcane production have been associated with high temperatures, decreased precipitation, and variations in relative humidity [6]. Furthermore, low temperatures and inadequate water availability may adversely affect sugarcane growth and reduce its production [7]. Crops, such as rice, wheat, sugarcane, and maize play a vital role in the national economy of Pakistan. These crops contribute 3.5% and 3.4%, respectively, to agricultural value addition and 0.6% and 0.7%, respectively, to the GDP of Pakistan.

In the 21st century, climate change and variability have emerged as serious environmental problems worldwide [8]. The global climate is shifting rapidly, with increasing temperatures being observed in various regions of the world. Pakistan is also facing significant temperature variations with overall warming trend in the country. These climate changes have adversely affected the arid and semi-arid regions of the Punjab Province. In Punjab, rising temperatures and changing climatic conditions tend to pose substantial challenges to agricultural productivity and water availability. The United Nations Framework Convention on Climate Change (UNFCCC) describes climate change as a change that has a direct

or an indirect impact on human activity. Furthermore, it also alters the composition of the global atmosphere. Climate change refers to long-term variations in climatic conditions. This includes changes in the mean and variability of climatic variables, such as temperature and precipitation that continue for decades or longer [9]. Previous studies have also observed temperature fluctuations in various parts of Pakistan which are highly vulnerable to changes in climate. As indicated by the Global Climate Risk Index 2014, Pakistan was ranked fifth in terms of the impacts of weather events [10]. During the Kharif rice-growing season, mean maximum temperature is expected to increase by 2–2.5°C. Positive trends observed in weather indices in the Indus Basin have contributed considerably to the country's agricultural economy, while negative trends have been reported in the northern part of the country [11]. The province of Punjab alone occupies more than 69% of Pakistan's total irrigated area [12]. Hamjah et al. [13] reported that the best-fitted ARIMAX models for tobacco, cotton, and sugarcane production in Bangladesh were ARIMAX (0,1,1), (0,1,1), and (1,1,0), respectively, in their assessment of the effects of climatic factors on cash-crop yield. Tyagi et al. [14] employed time-series models, including ARIMAX and naïve models, to investigate the relationship between climate change and sugarcane yield. It was found that climate change was one of the factors affecting crop yield. An ARIMAX model was also used to analyze the relationship between historical influenza trends and weather data [15].

2.METHODOLOGY

This study covered the Bahawalnagar and Bahawalpur stations in Punjab Province and used time-series data for the time period (1981–2021). Yearly mean maximum temperature ($YMMT_X$), mean minimum temperature ($YMMT_N$), and total rainfall data for both stations were obtained from the Pakistan Meteorological Department (PMD), Karachi and the Punjab Bureau of Statistics. Crop-production and cultivated-area data were obtained from the Pakistan Bureau of Statistics. Figure 1 presents the data acquisition for study framework.

For stationary time-series modeling, the Box–Jenkins method is commonly used to describe a series in relation to its previous observations. In this approach, the response variable is modelled using its own lagged values and a stochastic error term [16]. The Autoregressive Integrated Moving average (ARIMA) model developed by Box and Jenkins is widely

used for time-series forecasting. In univariate time-series analysis, forecasts are generated from past observations of a single variable. ARIMAX extends ARIMA by incorporating exogenous variables to improve the model's explanatory capability. It combines regression analysis with ARIMA modelling.

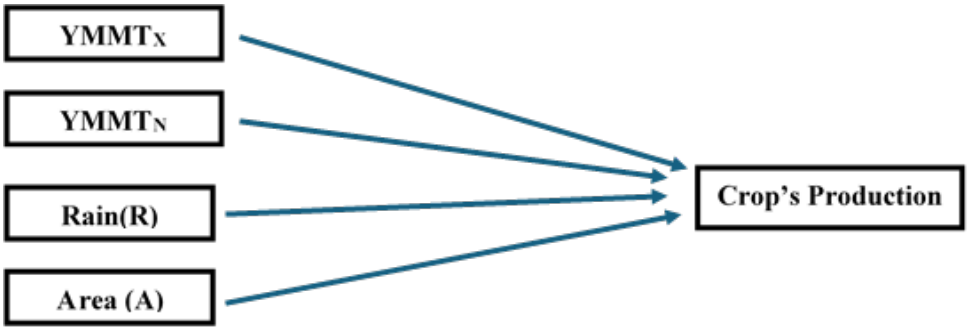


Figure 1. Data Usage Study Framework

The general equations for the ARIMA and ARIMAX models can be expressed as follows:

$$y_t = \sigma_1 y_{t-1} + \sigma_2 y_{t-2} + \cdots + \sigma_p y_{t-p} + \varepsilon_t - \emptyset_1 \varepsilon_{t-1} - \emptyset_2 \varepsilon_{t-2} - \cdots - \emptyset_q \varepsilon_{t-q}$$

$$y_t = \propto x_i + \sum_{j=1}^{p} \sigma_j y_{t-j} + \varepsilon_t + \sum_{j=1}^{q} \emptyset_j \varepsilon_{t-j}$$

The variables $YMMT_X$, $YMMT_N$, rainfall (R), and cultivated area (A) for the corresponding period are used as exogenous variables in the ARIMAX model.

The Box–Jenkins procedure consists of the following steps:

Step 1: Model Identification. Before applying a time-series model, a non-stationary series must be transformed into a stationary series. The model order can then be identified using appropriate diagnostic tools.

Step 2: Estimation. Estimate the model parameters and use criteria, such as AIC and BIC to select the best-fitted model.

Step 3: Diagnostic Test. Determine whether the residuals of the fitted model are stationary. If the model does not satisfy the diagnostic criteria, select an alternative model based on the model-selection criteria.

Step 4: Forecasting. Use the selected model to forecast the series after assessing the residuals. In ARIMAX or ARMAX modelling, explanatory variables are incorporated into the ARIMA or ARMA framework, and the same four steps are followed to identify the most suitable model.

3.RESULTS

3.1. Analysis for ARIMA

Two different unit-root tests, the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test, were applied to assess the stationarity of the time-series data, as shown in Table 1. Both tests indicated that the yearly mean maximum and minimum temperatures, total rainfall, and sugarcane production in Bahawalnagar (BG_YMMT_X, BG_YMMT_N, BG_R, and BG_PS) were stationary at level. In contrast, the cultivated cotton area, cultivated sugarcane area, and cotton production in Bahawalnagar (BG_CA, BG_SA, and BG_PC) became stationary at the 5% significance level after first-order differencing.

The main objective was to identify the most suitable ARMA or ARIMA model by determining the parameters p, d, and q. This was done using the ARIMA tool's automatic-selection procedure and was verified through a random model-search approach. Models up to order 5 were evaluated, and the most suitable model was selected using AIC and BIC (Bayesian Information Criterion). ACF and PACF plots were also considered when identifying ARMA model orders [17].

Figure 2 indicates that ARIMA (1,1,0), ARMA (1,0,0), ARIMA (1,1,0), and ARIMA (1,1,3) are the most suitable models for BG_PC, BG_PS, BP_PC, and BP_PS, respectively. These models were selected using the AIC and BIC criteria and were verified with the ARIMA function.

The equations for the selected ARIMA or ARMA models for both stations are presented below.

$$B_{PC} = 0.0432 + 0.2633y_{t-1} \quad (1)$$

$$B_{PS} = 1103.36 + 0.5655y_{t-1} \quad (2)$$

$$\mathbf{B}P_{PC} = 0.0341 + 0.453y_{t-1} \quad (3)$$

$$BP_{PS} = 14.58 + 0.864_{t-1} - 0.654_{\epsilon_{t-1}} - 0.495_{\epsilon_{t-2}} \quad (4)$$

Table 1. Summary of Unit Root Test by using ADF and Phillips-Perron (PP) Tests

Parameters	ADF					Phillips Perron (PP)				
	Level		First Difference		Integration	Level		First Difference		Integration
	Critical Value (-2.9389)	*p*- value 5%	Critical Value (-2.9411)	*p*- value 5%		Critical Value (-2.9389)	*p*- value 5%	Critical Value (-2.9411)	*p*- value 5%	
LNBG_PC	-2.1981	0.2102	-7.8672	0.000	I(1)	-2.3326	0.1670	-7.8672	0.0000	I(1)
LNBP_PC	-2.9665	0.0470	-	-	I(0)	-3.4527	0.0149	-6.5200	0.0000	I(1)
LNBG_PS	-3.7651	0.0067	-	-	I(0)	-3.7651	0.0067	-	-	I(0)
LNBP_PS	-0.4309	0.8933	-6.7712	0.000	I(1)	-1.3469	0.5980	-	-	I(0)
BG_YMMT_X	-3.6228	0.0097	-	-	I(0)	-3.5807	0.0108	-	--	I(0)
BP_YMMT_X	-4.7148	0.0005	-	-	I(0)	-4.7260	0.0005	-	-	I(0)
BG_YMMT_N	-4.8895	0.0003	-	-	I(0)	-4.7958	0.0004	-	-	I(0)
BP_YMMT_N	-1.8482	0.3524	-12.5762	0.000	I(1)	-3.9164	0.0045	-	-	I(0)
BG_R	-5.0385	0.0002	-	-	I(0)	-5.1806	0.0001	-	-	I(0)
LNBG_SA	-0.2147	0.1723	-6.4665	0.000	I(1)	-1.5051	0.2015	-35.8243	-	I(1)
LNBG_CA	-1.8581	0.3480	-7.8267	0.000	I(1)	-2.0546	0.2634	-8.3069	0.0000	I(1)

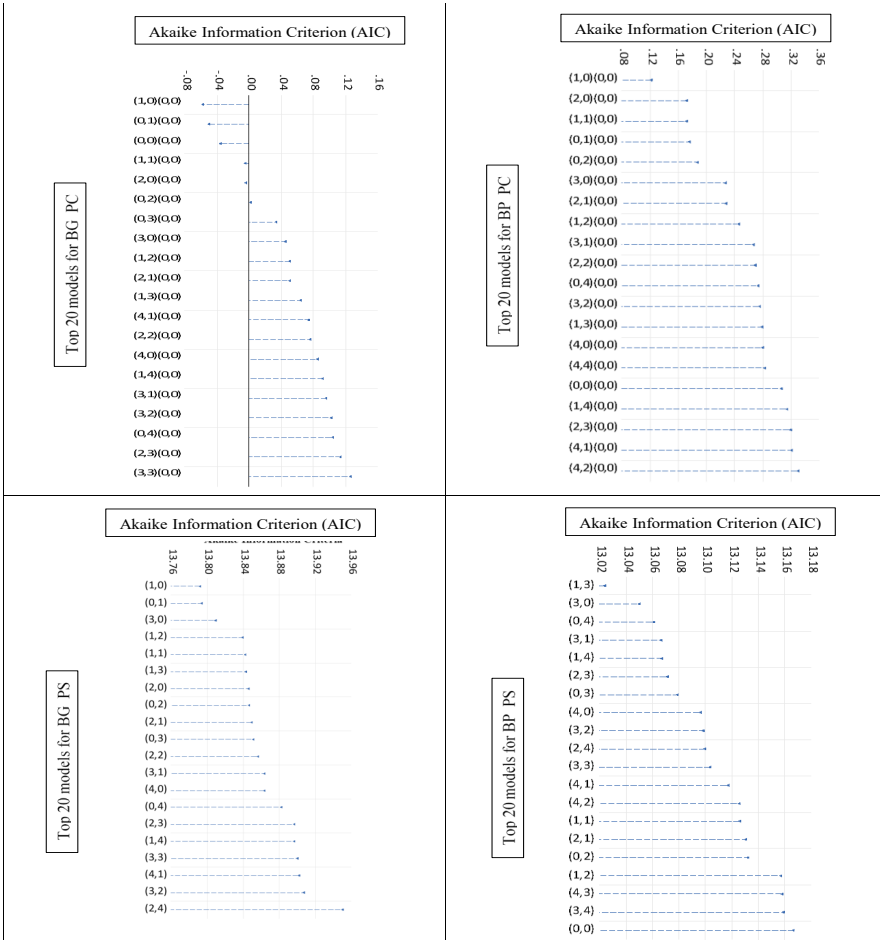


Figure 2. Comparison of AIC-based Selection of the Best-Fitted ARIMA Models

3.2. Analysis for ARIMAX

The best-fitted ARIMAX and ARMAX models were selected using AIC, BIC, and RMSE to forecast cotton and sugarcane production through 2030. Regressors were forecasted using the ARIMA function. All possible combinations of the ARIMAX model orders p and q were calculated for the specified lag values, and the parameters were then estimated. The most suitable models were selected based on AIC, BIC, and RMSE as measures of goodness-of-fit. A model was considered to provide a better fit when these values were lower, as shown in Table 2 for Bahawalpur and Bahawalnagar.

Table 2. Summary of Selection of the Best-Fitted Models Across Different AR And MA Orders

Bahawalnagar							
Cotton				Sugarcane			
Models	AIC	BIC	RMSE	Models	AIC	BIC	RMSE
ARIMAX (1,1,0)	-0.33	-0.03	0.21	ARMAX (1,0)	13.39	13.69	154.64
ARIMAX (0,1,1)	-0.28	0.01	0.21	ARMAX (0,1)	13.52	13.82	230.07
ARIMAX (1,1,1)	-0.29	0.049	0.21	ARMAX (1,1)	13.41	13.76	161.04
ARIMAX (1,1,2)	-0.3	0.05	0.21	ARMAX (1,2)	13.46	13.6	153.59
ARIMAX (1,1,3)	-0.3	0.05	0.21	ARMAX (1,3)	13.46	13.9	193.31
ARIMAX (1,1,4)	-0.29	0.04	0.21	ARMAX (1,4)	13.42	13.91	160.53
ARIMAX (2,1,0)	-0.08	0.2	0.19	ARMAX (2,0)	13.42	13.78	162.73
ARIMAX (2,1,1)	-0.29	0.05	0.18	ARMAX (2,1)	13.46	13.85	159.52
ARIMAX (2,1,2)	-0.04	0.3	0.19	ARMAX (2,2)	13.51	13.95	151.95
ARIMAX (2,1,3)	-0.03	0.3	0.19	ARMAX (2,3)	13.46	13.95	171.89
ARIMAX (2,1,4)	-0.04	0.3	0.19	ARMAX (2,4)	13.45	13.98	185.47
ARIMAX (3,1,0)	-0.02	0.28	0.17	ARMAX (3,0)	13.44	13.84	144.77
ARIMAX (3,1,1)	-0.19	0.14	0.18	ARMAX (3,1)	13.5	13.5	144.79
ARIMAX (3,1,2)	-0.04	0.3	0.16	ARMAX (3,2)	13.37	13.86	180.45
ARIMAX (3,1,3)	-0.02	0.32	0.17	ARMAX (3,3)	13.41	13.94	173.79
ARIMAX (3,1,4)	0.009	0.4	0.17	ARMAX (3,4)	13.45	14.02	181.09
ARIMAX (4,1,0)	-0.02	0.28	0.17	ARMAX (4,0)	13.5	13.94	144.83
ARIMAX (4,1,1)	-0.24	0.1	0.17	ARMAX (4,1)	13.55	14.03	140.77
ARIMAX (4,1,2)	-0.04	0.3	0.164	ARMAX (4,2)	13.39	13.92	178.08
ARIMAX (4,1,3)	0.4	0.2	0.17	ARMAX (4,3)	13.43	14.01	189.48
ARIMAX (4,1,4)	-0.07	0.27	0.16	ARMAX (4,4)	13.5	14.11	167.08
Bahawalpur							
Cotton				Sugarcane			
Models	AIC	BIC	RMSE	Models	AIC	BIC	RMSE
ARIMAX (1,1,0)	0.508	0.816	0.304	ARIMAX (1,1,0)	13.36	13.67	625.63
ARIMAX (0,1,1)	0.66	0.97	0.204	ARIMAX (1,1,1)	13.13	13.49	734.42
ARIMAX (1,1,1)	0.63	0.98	0.309	ARIMAX (1,1,2)	13.17	13.57	698.95
ARIMAX (1,1,2)	0.72	1.12	0.201	ARIMAX (1,1,3)	12.87	13.3	489.59
ARIMAX (1,1,3)	0.55	0.99	0.323	ARIMAX (1,1,4)	12.94	13.43	522.86
ARIMAX (1,1,4)	0.57	1.04	0.335	ARIMAX (0,1,1)	13.13	13.44	905.99
ARIMAX (2,1,0)	0.63	0.98	0.313	ARIMAX (0,1,2)	13.11	13.47	719.38
ARIMAX (2,1,1)	0.55	0.94	0.31	ARIMAX (0,1,3)	13.01	13.41	474.51
ARIMAX (2,1,2)	0.41	0.85	0.218	ARIMAX (0,1,4)	12.89	13.32	520.28
ARIMAX (2,1,3)	0.58	1.06	0.356	ARIMAX (2,1,0)	13.39	13.74	570.28
ARIMAX (2,1,4)	0.48	1	0.188	ARIMAX (2,1,1)	13.11	13.5	683.31
ARIMAX (3,1,0)	0.66	1.05	0.349	ARIMAX (2,1,2)	13.11	13.56	750.01
ARIMAX (3,1,1)	0.4	0.58	0.306	ARIMAX (2,1,3)	12.92	13.41	481.44
ARIMAX (3,1,2)	0.46	0.94	0.216	ARIMAX (2,1,4)	12.94	13.47	539.33
ARIMAX (3,1,3)	0.48	1	0.207	ARIMAX (3,1,0)	13.08	13.48	505.87
ARIMAX (3,1,4)	0.54	1.1	0.201	ARIMAX (3,1,1)	13.13	13.57	506.66

Bahawalpur							
Cotton				Sugarcane			
Models	AIC	BIC	RMSE	Models	AIC	BIC	RMSE
ARIMAX (4,1,0)	0.71	1.14	0.341	ARIMAX (3,1,2)	13.02	13.50	659.87
ARIMAX (4,1,1)	0.61	1.09	0.285	ARIMAX (3,1,3)	12.87	13.40	465.69
ARIMAX (4,1,2)	0.65	1.17	0.298	ARIMAX (3,1,4)	12.9	13.4	474.86
ARIMAX (4,1,3)	0.66	1.22	0.355	ARIMAX (4,1,0)	13.14	13.58	504.54
ARIMAX (4,1,4)	0.65	1.26	0.385	ARIMAX (4,1,1)	13.17	13.66	509.3

The AIC and BIC values of −0.33 and −0.03, respectively, are lower than those of the other candidate AR and MA orders. The general equation for the ARIMAX (1,1,0) model for BG_PC is presented below.

$$B_{PC} = c + \sigma_1 y_{t-1} + \propto_1 B_{YMMTX} + \propto_2 B_{YMMTN} + \propto_3 B_{R} + \propto_4 B_{AC} \quad (5)$$

The general equation for the ARMAX (1,0) model for BG_PS is presented below.

$$B_{PS} = c + \sigma_1 y_{t-1} + \propto_1 B_{YMMTX} + \propto_2 B_{YMMTN} + \propto_3 B_{R} + \propto_4 B_{CA} \quad (6)$$

Table 3. Summary Statistics of the ARIMAX (1,1,0) and ARMAX (1,0,0) Models for Cotton and Sugarcane

ARIMAX (1,1,0) Modelling for Cotton		
Variables	Coefficients	*p*-value
AR (1)	0.045	0.0001
BG_ $YMMT_X$	-0.076	0.1004
BG_ $YMMT_N$	0.004	0.421
BG_R	-0.002	0.674
BG_CA	1.417	0.004
ARMAX (1,0,0) Modelling for Sugarcane		
_BG_ $YMMT_X$	-0.77	0.98
BG_ $YMMT_N$	2.50	0.24
BG_R	0.11	0.65
BG_SA	497.39	0.000
AR (1)	0.86	0.0000

Table 3 presents the estimated effects of the variables on cotton and sugarcane production. For sugarcane production, the first-order autoregressive lag, BG_YMMTN, BG_R, and BG_SA have positive coefficients, whereas BG_$YMMT_X$ has a negative coefficient. For cotton

production, BG_YMMT_N, AR(1), and BG_CA have positive coefficients, whereas BG_YMMT_X and BG_R have negative coefficients. Non-significant factors were excluded from the forecasting equations. The parameters were estimated using EViews, yielding the equations presented below;

$$B_{PC} = 1.4976 - 0.5359y_{t-1} + 1.3421B_{AS} - 0.04546B_{YMMTX} \quad (7)$$

The general equation for the ARIMAX (1,1,0) model for BG_PC is presented below;

$$B_{PS} = 1107.045 + 0.7928y_{t-1} + 537.08B_{AS} \quad (8)$$

Similarly, the most suitable models for BP_PC, and BP_PS are ARIMAX (1,1,0) and ARIMAX (3,1,0), respectively, based on their AIC and BIC values.

The general equations for both models are presented below;

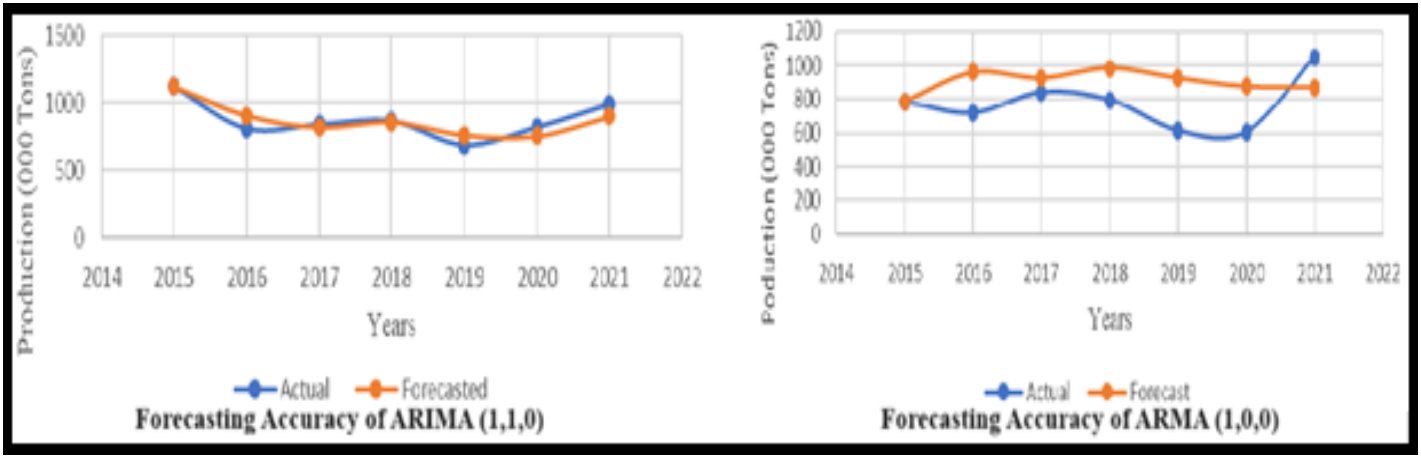
$$BP_{PC} = 0.3196 - 0.5176y_{t-1} + 0.51BP_{AS} \quad (9)$$

$$B_{PS} = 1107.045 + 0.7928y_{t-1} + 537.08B_{AS} \quad (10)$$

Diagnostic tests were used to assess the selected models. The absolute t-statistics exceed the corresponding critical values, indicating that the model residuals are stationary at level. Table 4 presents the results of the ADF diagnostic tests for the selected models.

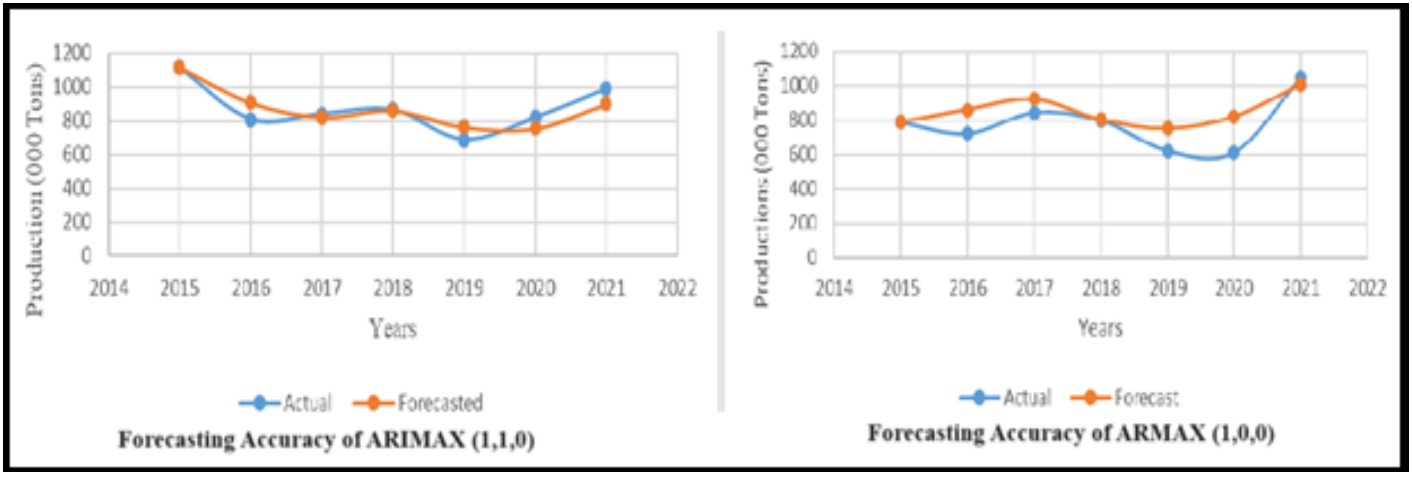
Table 4. Summary of Diagnostic Test Results for the Selected Models using the ADF Test

Models	ADF			Integration
	Level			
	t-statistics	Critical Value	*p*-value (5%)	
ARIMA(1,1,0)	-5.8623	-2.9145	0.0000	I(0)
ARMA(1,0,0)	-6.8629	-2.9458	0.0000	I(0)
ARIMA(1,1,0)	-5.8623	-2.9415	0.0000	I(0)
ARIMA(1,1,3)	-6.7440	-2.9411	0.0000	I(0)
ARIMAX(1,1,0)	-6.0875	-2.9484	0.0000	I(0)
ARMAX(1,0,0)	-6.8393	-2.9411	0.0000	I(0)
ARIMAX(1,1,0)	-6.7440	-2.9411	0.0000	I(0)
ARIMAX(3,1,0)	-6.6275	-2.9484	0.0000	I(0)



Forecasting Accuracy of ARIMA (1,1,0)

Forecasting Accuracy of ARMA (1,0,0)



Forecasting Accuracy of ARIMAX (1,1,0)

Forecasting Accuracy of ARMAX (1,0,0)



Figure 3. Comparison of Actual and Predicted Cotton and Sugarcane Production

3.3. Forecasting Accuracy of Models

The annual data was divided into training and testing sets. The training set covered 1981-2015, while the testing set covered 2016-2021. Forecast performance was evaluated using the testing set. Figure 3 compares the actual and predicted values; the blue line represents the actual values and the brown line represents the predicted values. The two series display similar patterns, and the RMSE is lower than that of the alternative models. Root Mean Square Error (RMSE), as discussed by Ou and Wang [18], is one of the criteria used to evaluate forecast performance. These results suggest that the selected model can predict future production with reasonable accuracy.

3.4. Comparative Study of ARIMA and ARIMAX

The results were used to compare the forecasting performance of ARMA and ARMAX models. The AIC, BIC, and RMSE were used to compare the performance of ARMA (1,1) and ARMAX (1,0), as shown in Table 5. These model-selection criteria have also been used in previous studies [19, 20].

Table 5. Results of Comparative Analysis for Various Models based on AIC, BIC, and RMSE for Cotton and Sugarcane Production

Crops	Methods	Parameters			AIC	BIC	RMSE
		P	d	q			
Bahawalnagar							
Cotton	ARIMA (1,1,0)	1	1	0	-0.05	0.07	0.199
	ARIMAX (1,1,0)	1	1	0	-0.36	-0.06	0.108
Sugarcane	ARMA (1,0,0)	1	-	0	13.79	13.92	233
	ARMAX (1,0,0)	1	-	0	13.39	13.69	154
Bahawalpur							
Cotton	ARIMA (1,1,0)	1	1	0	0.06	0.25	0.144
	ARIMAX (1,1,0)	1	1	0	-0.04	0.26	0.09
Sugarcane	ARIMA (1,1,0)	1	1	3	13	13.39	636.8
	ARIMAX (3,1,0)	3	1	0	12.9	13.23	505.9

The ARMAX model generally produces lower AIC, BIC, and RMSE values than the corresponding ARMA model. This indicates better fit or forecast accuracy according to these criteria. Using the fitted model equations (1)–(10), cotton and sugarcane production were forecasted for the

Bahawalpur station. According to Table 6, cotton and sugarcane production in the study region are projected to increase over the forecast period.

Table 6. Results of Production Forecasts (thousand tons) from the ARIMAX or ARMAX Models for Cotton and Sugarcane Production

Crops	Cotton		Sugarcane	
Stations	Bahawalnagar	Bahawalpur	Bahawalnagar	Bahawalpur
Models	ARIMAX (1,1,0)	ARIMAX (1,1,0)	ARMAX (1,0,0)	ARIMAX (3,1,0)
2022	1005.61	1060.11	610.56	1343.6
2023	1059.15	1065.24	611.02	1352.15
2024	1103.64	1116.2	612.54	1562.27
2025	1713.71	1141.98	613.58	1569.29
2026	1789.44	1215.79	617.56	1579
2027	1868.89	1259.97	621.97	1580.12
2028	1951.78	1351.35	626.98	1590.2
2029	2038.43	1451.79	631.18	1623.4
2030	2128.86	1594.56	635.8	1642.04

4.DISCUSSION

Climatic variables play an important role in agricultural productivity, particularly in the semi-arid regions of Southern Punjab, Pakistan, where cotton and sugarcane are important cash crops. Changes in temperature and precipitation can influence crop growth, water availability, and yield stability. This study examined agricultural output and the potential effects of climate change on cotton and sugarcane productivity, including the role of possible adaptation measures.

In this study, the ARIMA model was used to examine historical patterns and forecast cotton and sugarcane production in Bahawalpur and Bahawalnagar. The ARIMAX model incorporated climatic variables to assess their additional contribution to variations in production. This approach is consistent with crop-forecasting research indicating the value of incorporating temperature and rainfall into ARIMAX models [21]. Comparing the predictive performance of the two models helps determine whether including climatic information improves forecasting accuracy. According to the ARIMAX (3,1,0), sugarcane production in Bahawalpur would be 1,642,040 tons in 2030. Moreover, the results showed that the lag of first-order autoregressive model had a statistically significant impact on the production of cotton in Bahawalnagar at the 10% significance level.

BG_YMMT_N (yearly mean minimum temperature) and BG_CA (area under cultivation of cotton) had positive coefficients, whereas BG_YMMT_X (annual mean maximum temperature) and BG_R (annual total rainfall) had negative coefficients. This is in line with the studies conducted by Abbas [12] on the association between climate change and cotton production in Pakistan.

Similarly, in the case of Bahawalnagar, BG_YMMT_X (yearly mean maximum temperature) and BG_CA had a statistically significant impact on cotton yield at the 10% significance level. In the case of Bahawalpur, BP_YMMT_N and BP_CA had positive coefficients, while BP_YMMT_X and BP_R had negative coefficients. BP_CA had a statistically significant effect on cotton production at the 10% significance level. Khan [22] reported that changes in temperature and rainfall affected the production of major crops, including cotton and sugarcane, across districts of Punjab, with negative climatic effects observed in Bahawalnagar. Similarly, Ali et al. [23] found that the effects of climatic variables on crop productivity varied across Pakistan's agro-environmental regions. This highlights the importance of considering local climatic conditions when evaluating crop performance. Shahzadi et al. [24] also reported strong effects of rising temperatures, changing rainfall patterns, and other climate-related factors on cotton production in Southern Punjab, Pakistan.

The ARMAX (1,0,0) results indicated that the first-order autoregressive lag had a statistically significant influence on sugarcane production in Bahawalnagar at the 10% significance level. BG_YMMT_N, BG_R, and BG_SA had positive coefficients, whereas BG_YMMT_X had a negative coefficient. The result of BG_SA model had a statistically substantial effect on sugarcane yield in Bahawalnagar at the 10% significance level. In the same way, the ARIMAX (3,1,0) model results illustrated that the first-order autoregressive lag significantly affected sugarcane production in Bahawalpur at the 10% significance level. Moreover, the models BP_YMMT_N and BP_SA had positive coefficients. However, BP_YMMT_X and BP_R had negative coefficients. These results indicated that both BP_SA and BP_YMMT_N had a statistically significant impact on sugarcane production in Bahawalpur at the 10% significance level. These outcomes are associated with Ali et al. [23], who stated that maximum temperature was statistically significant and positively linked with cotton production.

Additionally, Ali et al. [25] studied an association between sugarcane

production, temperature, rainfall, and agricultural influences in Pakistan. This emphasizes the necessity to measure climatic impacts together with other production factors. Changes in model performance and assessed climatic coefficients between Bahawalpur and Bahawalnagar may provide valuable insights into local fluctuations in crop productions. In general, incorporating climatic variables into time-series models may improve crop-production forecasting and support evidence-based decisions on irrigation management, crop planning, and climate-adaptation policies.

4.1. Conclusion

The increasing frequency of extreme weather events, particularly changes in temperature and rainfall, poses significant challenges to agricultural production in Pakistan and threatens regional food security. This study aimed to identify suitable Box–Jenkins ARIMA and ARIMAX models to assess the effects of climatic variables on cotton and sugarcane production in Bahawalpur and Bahawalnagar, Punjab, Pakistan, for the time period (1981-2021), and to forecast production using the selected models.

The findings indicated that both climatic and non-climatic variables—including annual mean maximum and minimum temperatures, cultivated area, and rainfall—influenced the annual production of cotton and sugarcane at both stations. Annual mean minimum temperature, the autoregressive lag, and cultivated area generally had positive effects on production. On the other hand, annual mean maximum temperature and rainfall had negative effects in the estimated models. Based on RMSE, AIC, and BIC, ARIMAX generally outperformed ARIMA in forecasting performance. ARIMAX (1,1,0) was identified as the most suitable model for cotton production in both Bahawalpur and Bahawalnagar. For sugarcane production, ARIMAX (3,1,0) was selected for Bahawalpur, while ARIMAX (1,0,0) was selected for Bahawalnagar.

This study may help policymakers and researchers make informed decisions about agricultural production by considering the effects of temperature and rainfall, particularly on cotton and sugarcane.

Author Contribution

Sajid Ali Khan: writing - original draft, software. **Muhammad Ali**: conceptualization, methodology, supervision. **Bulbul Jan:** formal analysis, resources, writing-review & editing. **Azhar Iqbal:** resources.

Conflict of Interest

The authors declare that they have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

The data supporting the findings of this study would be made available by the corresponding author upon request.

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