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AN EFFICIENT ADVANCED TIME SERIES MODEL METHODOLOGY FOR PREDICTION OF PADDY PRODUCTION IN TAMIL NADU, INDIA

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Abstract. Predicting crop yield, particularly paddy production, is challenging due to various factors such as crop type, environmental conditions, and management strategies. Although statistical methods have been employed to forecast paddy yield, achieving high accuracy remains difficult. This study, conducted with meticulous attention to detail, aims to provide accurate forecast information for Tamil Nadu. The thoroughness of the research process instills confidence in the results, which will benefit farmers, policymakers, and stakeholders by reducing production risks. The ARIMA models were used to forecast paddy crop production, utilizing annual data from 1966 to 2021 for model fitting and forecasting up to 2030. The performance of the models was evaluated using metrics such as RMSE, MAE, MAPE, and R-squared values. The models showed promising results with high accuracy and low errors, providing valuable insights for decision-making processes.

AMS Mathematics Subject Classification : 62M10, 91B84.
Key words and phrases : ARIMA, model fit, forecast, Paddy yield, performance measures.

1. Introduction

The majority of the population is sustained by the agricultural industry, which is a significant food sector in both India and the rest of the world. It contributes roughly 18% of India's GDP. For people living in rural areas, growing rice is a vital source of income. Three different types of crops are typically grown by many farmers worldwide each year. This includes the spring season from February/March to June/July, the winter crop (Rabi) from October to February/March (the majority of this crop season is affected by high rains), and the summer crop (Kharif) from June/July to September([1]).

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From the total gross harvested area of the state 58.97 Lakh/ha, rice alone was grown on 17.75 Lakh/ha (31%) and is the most cultivated rice crop in Tamil Nadu state in terms of both area and production (source: Policy: Government of Tamil Nadu (2015-16)). As far as calorie consumption and human nutrition are concerned, paddy is the only truly essential food in the entire state.

The agricultural crisis has become significantly worse and more serious over the past few years. Agriculture in Tamil Nadu has remained a risk at the discretion of the monsoon; both inadequate rainfall and excessive rain that led to flooding has had an impact there. Given the significance and necessity of rice in daily life, it is essential to understand its supply both now and, in the years, to come.

This will help forecast demand and enable us to satisfy the needs of a population that is expanding. Based on the demand for rice, we defined the study's goal as developing suitable ARIMA representations for the Time-series data of paddy crop production in Tamil Nadu and producing Ten-year forecasts with suitable prediction intervals.

2. Literature Review

There are many forecasting techniques, thus it's important to understand their usability and accuracy before applying them in a particular situation. Researchers and experts frequently use time series modelling to produce precise forecasts([2]). The primary goal of time series modelling is to analyze past data in order to develop a model that fits the unique dataset and use that model to predict future values for the series([3]). A time series is a collection of observations made about activity and compiled over time periods that are predictable, such as daily, weekly, monthly, quarterly, and yearly.

Crop growth analysis and crop yield predictions are essential steps that support policies for issues including food security, land use allocation, and the environment. Statistical methods can produce accurate crop forecasts well in advance. Particularly in field of Forecasting very useful statistical methods is called 'Autoregressive Integrated Moving Average (ARIMA)' were formed by Box and Jenkins [4] in 1970 for the prediction and forecasting of time series data.

Oza [5] investigated the effectiveness of a study on the rice crop using several Scattrometer dataset types. The exponential smoothing approaches discussed by Makridakis and Hibbon [6]), Granger and Newbold [7], Pankratz [8],Bhola Nath [9] and Kumari [10] were applied to the growth of the rice crop and are the most suitable forecasting methods in the world for rice crop production.

In order to ensure global food security, Sahu [11] researched Modelling and forecasting of rice and wheat land area, production, yield, and total seeds in SAARC countries. Rice production forecasting in Bangladesh was examined by Mohamed Amir Hamjah [12] using the Box-Jenkins ARIMA Model. Modelling and Forecasting of Bangladesh Pulse Production by Niaz [13]. Vishwajith [14] created a time series model and forecast for the output of pulses in India. The study Predicting Oilseeds Prices in India: Case of Groundnut was published by Ashwin Darekar [15]. Muhammad[16] conducted research on a comparative analysis of Pakistan and India to anticipate wheat production.

Using an ARIMA modelling approach, Pant [17] examined forecasting wheat output in India. In addition to applying the ARIMA Model prediction, Patel [18] researched the Economic Analysis of Groundnut Processing Units in Southern Rajasthan and Price Behavior of Groundnut in Gujarat. Anil Kumar [19] statistical analysis in growth of the Chickpea (Cicer arietinum L.) genotypes. Shakila [20] has studied for forecasting of wheat production by using various kind of regression models.

The objective of this research is to choose the optimal ARIMA model for adjusting and forecasting the area, yield, and production of the rice crop in the ceded region, accordingly. Choices are then made and the forecasting process is started. For the growth of the rice crop, Khadar Babu et al. [21, 22] investigated various auto-regressive models. Victor [23] has studied about the rice crop production using new initial value condition in Holt's winter Methods. A discussion of the analysis of rice crop growth using various smoothing techniques was made by Khadar Babu [24] in 2022.

Hemavathi [25] has discussed about the ARIMA models for Prediction of Area, production and yield of paddy its cultivations in Thanjavur District of Tamil Nadu. The research gap between the Hemavathi [25] to be used ARIMA modelling for entire Tamil Nadu state and used R programming for estimating the accuracy and forecasting for the rice crop area, production and Yield.

3. Materials and Methods

3.1. Data Set. This study is based on secondary data on the rice crop in order to forecast the land area, production, and yield of rice in Tamil Nadu. Area, production, and yield data for the rice crop were obtained from the 'Directorate of Economics and Statistics, Season and Crop Report', the Tamil Nadu state website, and sources from 1966-1967 through 2020-21. This data was then used to analyze trends and make predictions for future rice crops in the region.

3.2. Auto Correlation. Auto correlation coefficient is key statistic to show the data having correlation between successive terms of the dataset (or time series). The time series auto correlation coefficient itself lagged by 1,2 and more periods. The notation for correlation coefficient is used in the article as

$$a_k = \frac{\sum_{t=k+1}^{n}(Z_t - \bar{Z})(Z_{t-k} - \bar{Z})}{\sum_{t=k+1}^{n}(Z_t - \bar{Z})^2} \tag{1}$$

a_k indicates how the correlation between successive terms of the Z for a specified time series analysis. a_k shows that how Z values correlates two intervals apart correlating to each other, and so on., together the auto correlation function or ACF make up at lags 1,2 in empirical time series analysis, the concept auto correlation function is a suitable and valuable tool to investigate the properties of the data. In some of the cases a_k is the complicated in some cases it is intractable.

A White noise model: it's random model and it is the combination of two parts in a time series data, an overall level c and the error term e_t, it is defined as follows

$$Z_t = c + e_t \tag{2}$$

one of the fundamental major tasks in time series is a White noise model approach. Every model in time series and forecasting should have an error and it was followed to White noise model.

3.3. Partial Auto Correlation Function (PACF). If the forecast variable Z is regressed with the explanatory variables Y_1 and Y_2, it may be useful to predict how much of the explanatory power Y_1 has if the subsequent term Y_2 is partially affected first. This means that when you regress Z on Y_2, you get White noise in a regression analysis, which is known as the partial auto correlation idea in time series.

3.4. Auto Regression:

$$Z_t = b_0 + b_1 Y_{t-1} + b_2 Y_{t-2} + ... + b_k Y_{t-k} \tag{3}$$

The above model shows that regressing Z_t against Z_{t-1}, Z_{t-2},...Z_{t-k}, which are explanatory variables to the previous value of the forecast variable Z_t. the name auto regression is used to explain the equation 3.

3.5. Non-Stationarity to Stationary Approach. In some cases, trends and non-stationarity accrued in a time series, results the positive correlation might be dominated auto correlation diagram. In such a case it is very important to remove non-stationarity in a time series data. One of the source able removing stationarity methods is of differencing. It is a method to convert the data into less wave length in a diagram between the series.

$$\delta_t^1 = \delta_t - \delta_{t-1} \tag{4}$$

The above delta series have $n-1$ values. Meanwhile the first difference calculation is not possible.

3.6. Time Series ARIMA model: The regression model of the form

$$Z = b_0 + b_1 Y_1 + b_2 Y_2 + \cdots + b_p Y_p + e \tag{5}$$

Where the forecast variable Z, the explanatory variables Y_1 through Y_p, linear regression coefficients b_0 through b_p and e is the White noise term. Let us suppose the variables are defined as $Y_1 = Z_{t-1}, Y_2 = Z_{t-2}, ...Y_p = Z_{t-p}$ equation (5) becomes

$$Z_t = b_0 + b_1 Z_{t-1} + b_2 Z_{t-2} + ... + b_p Z_{t-p} + e_t \tag{6}$$

The above equation is a regression equation. But it differs from the previous equation. These are time lagged forecast variable values. And therefore, auto regression is used to describe in equ. 6 model form. In time series analysis usually, autoregressive models join with moving average models and make a new form of the time series model called auto regressive moving average (ARMA Models).

A special case of time series analysis, in fact all these models are used when the data is stationary. The extension of the model building to non-stationary data by using differencing approach to convert data into minimized variation. Then it will also be a stationary data series. These are called auto regressive integrated moving averages models and it was popularized by Box and Zenkins (1970) [4] ARIMA Models. The usual notation was the ARIMA model is known as ARIMA (p, d, q).
Therefore

AR: p denotes the order of the auto regressive part
I: degree of the first difference
MA: q is the order of moving average part.

The classifications of the models:

ARIMA (0,0,0) – White noise model
ARIMA (0,1,0) – Random walk model
ARIMA (2,0,0) – AR(2) model

The annual statistics on rice crop production, yield, and area seeded in Tamil Nadu from 1966–1967 to 2020–2021 was forecast by using ARIMA methods. The ARIMA procedure is also known as the Box-Jenkins methodology. This method focuses on a Auto-Regressive Integrated Moving Average (ARIMA) model fitting to a given set of data. The core objectives of fitting ARIMA models are the identification of the Stochastic Process underlying the time series and accurate upcoming value prediction.

The use of these methods has been necessary for the creation of models for discrete time series and dynamic systems rather frequently. However, this approach did not work well for seasonal series with a high random component or lead times [7].

George Box and Gwilym Jenkins investigated ARIMA models extensively at the onset, and their names have been used interchangeably with the wider ARIMA process used for time series analysis, forecasting, and control since 1968. However, the stochastic model for that series determines the most accurate forecast of future values for a time series.

A stochastic process is either stationary or not. First, keep in mind that most time series are non-stationary and that the ARIMA model only considers stationary time series. The first stage of the Box-Jenkins model involves reducing non-stationary series to a stationary series by taking first order differences since

the ARIMA methods only relate to stationary time series.
The following are the key steps in creating a Box-Jenkins forecasting model.

(1) Identification of the series
(2) Estimating the parameters of data
(3) Diagnostic checking and
(4) Forecasting

4. Results and Discussion

The ARIMA model is a tool used for analyzing and forecasting time series data through various steps.

4.1. Model Identification. The ARIMA model could forecast paddy area, production, and yield data converting the input variable into a form of stationary series. Any series whose values fluctuate over time primarily in relation to a fixed mean and fixed variance is said to be stationary.

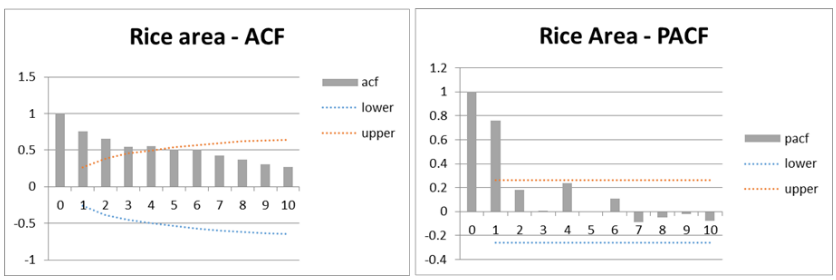


Figure 1. ACF and PACF For Rice Area

There are various techniques to determine this. The most popular technique is to look at the data graph or time plot of the data to see whether or not it is stationary to determine stationarity.

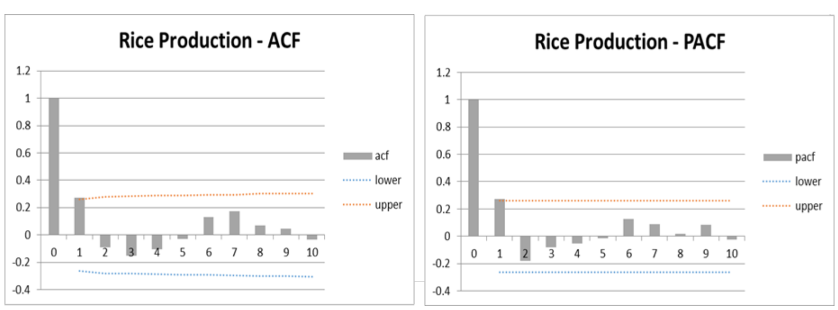
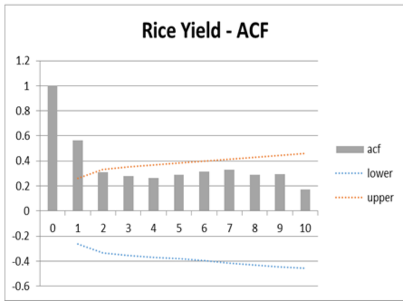


Figure 2. ACF and PACF For Rice Production



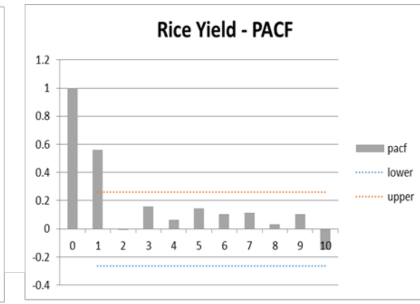


FIGURE 3. ACF and PACF For Rice Yield

TABLE 1. PACF and ACF For Rice Area, Production and Yield

Lags	Area		Production		Yield	
	ACF	PACF	ACF	PACF	ACF	PACF
0	1	1	1	1	1	1
1	0.75938	0.759381	0.272947	0.272947	0.563421	0.563421
2	0.65434	0.1835	-0.09224	-0.18016	0.311316	-0.00898
3	0.54672	0.004044	-0.15243	-0.08212	0.280508	0.159105
4	0.55656	0.235847	-0.10344	-0.05437	0.261565	0.064656
5	0.50388	-0.00529	-0.02972	-0.01611	0.292021	0.146792
6	0.50649	0.110077	0.131612	0.127661	0.316015	0.106455
7	0.42374	-0.09011	0.171701	0.087868	0.327965	0.114371
8	0.37251	-0.04783	0.071112	0.01828	0.290654	0.031114
9	0.30968	-0.02165	0.046803	0.08498	0.296202	0.104039
10	0.2652	-0.07626	-0.03492	-0.02613	0.170041	-0.1501

In this case, differentiating the data wasn't needed as the mean of X_t was steady. This meant that broad patterns, rather than specific data points, were the only focus of the investigation. Finding the values of p and q comes next. To do this, several orders of X_t's autocorrelation and partial auto correlation coefficients are estimated (Table 1). The value of p and q only be at most 0.5, according to the ACF and PACF (Figure. 1, 2, and 3).
The ARIMA forecasting model for area is ARIMA(1,1,1)

$$\Delta X_t = c + 0.3152X_{t-1} + \epsilon_t + 0.7743\epsilon_{t-1}. \tag{7}$$

The ARIMA forecasting model for production is ARIMA(0,0,1)

$$X_t = \epsilon_t - 0.3245\epsilon_{t-1}. \tag{8}$$

The ARIMA forecasting model for yield is ARIMA(0,1,2)

$$\Delta X_t = \epsilon_t + 0.4758\epsilon_{t-1} + 0.2999\epsilon_{t-2}. \tag{9}$$

TABLE 2. AIC values for tentative ARIMA models

Rice Area		**Rice Production**		**Rice Yield**	
ARIMA (2,1,2)	750.5399	ARIMA (2,0,2)	956.785	ARIMA (2,1,2)	Inf
ARIMA (0,1,0)	758.0852	ARIMA (0,0,0)	955.0546	ARIMA (0,1,0)	858.945
ARIMA (1,1,0)	754.2071	ARIMA (1,0,0)	953.2804	ARIMA (1,1,0)	857.7444
ARIMA(0,1,1)	748.8764	**ARIMA (0,0,1)**	**952.3371**	**ARIMA (0,1,2)**	**846.2095**
ARIMA (0,1,0)	756.2266	ARIMA (0,0,0)	1106.868	ARIMA (0,1,0)	857.1499
ARIMA (2,1,0)	755.6903	ARIMA (1,0,1)	954.3277	ARIMA (1,1,1)	Inf
ARIMA (1,1,1)	**747.098**	ARIMA (0,0,2)	954.3168	ARIMA (1,0,1)	Inf
ARIMA (2,1,1)	750.5399	ARIMA (1,0,2)	955.8865	ARIMA (1,1,2)	Inf
ARIMA (1,1,0)	752.5268	ARIMA (0,0,1)	1057.982	ARIMA (0,1,1)	847.7796
ARIMA (2,1,0)	754.0794				
ARIMA (1,1,1)	748.5465				
ARIMA (0,1,1)	748.8764				
ARIMA (2,1,1)	750.5452				
ARIMA (1,1,2)	750.546				
ARIMA (0,1,2)	749.0098				
ARIMA (2,1,2)	750.5399				

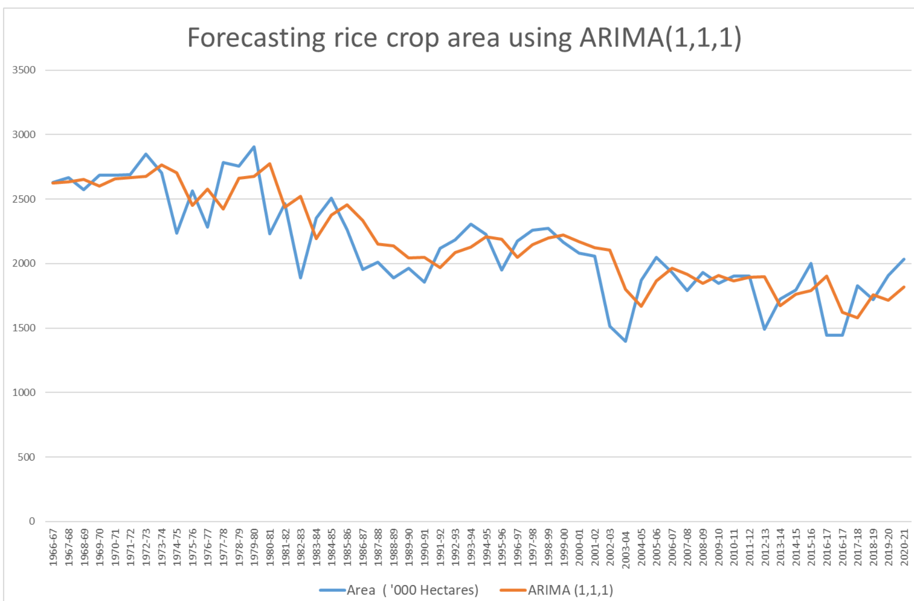


FIGURE 4. Forecasting rice area using ARIMA(1,1,1)

We estimated various ARIMA models and selected the one with the lowest Akaike Information Criterion. Table 2 lists the models and accompanying AIC values.

The model with the lowest AIC values is ARIMA(0, 0, 1) for paddy production, ARIMA(0, 1, 2) for paddy yield, and ARIMA(1, 1, 1) for paddy area.

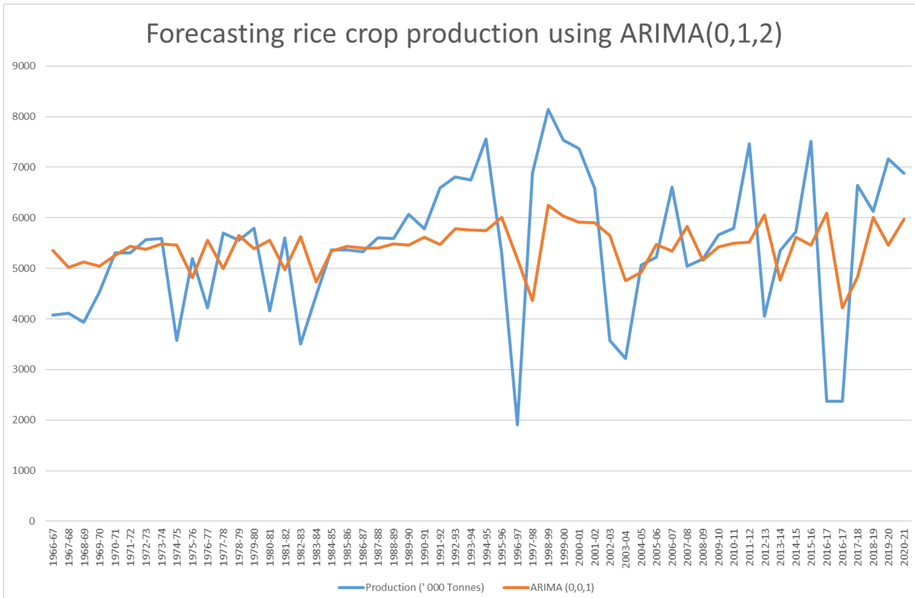


FIGURE 5. Forecasting rice production using ARIMA(0,0,1)

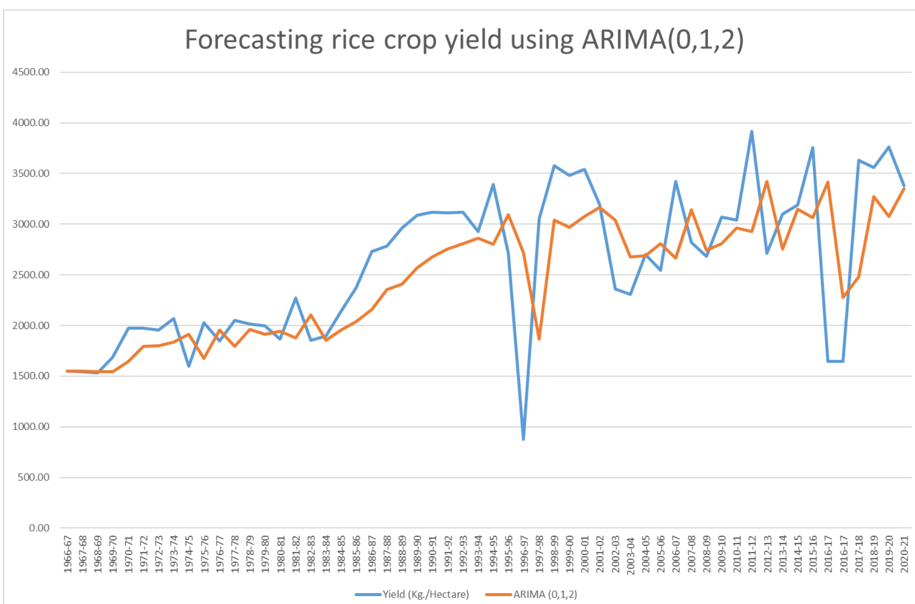


FIGURE 6. Forecasting rice yield using ARIMA (0,1,2)

Table 3. Estimates of ARIMA model for rice Area, Production and Yield

Error Measures	Area	Production	Yield
ME	-600.911	-2071.095	-1167.252
MSE	365561.424	4331291.329	1362802.021
RMSE	604.617	2081.175	1167.391
MAE	600.911	2071.095	1167.252
MPE	-0.337	-0.339	-0.340
MAPE	0.337	0.339	0.340
sMAPE	0.288	0.289	0.290
U_1	0.145	0.145	0.145
U_2	66.558	42.884	39.570
Box- Ljung Test	0.0387	0.0291	0.04801

Table 4. Forecasted values of paddy cultivated area, production and yield with 95% Confidence Level.

Year	Forecasted values for Area ('000 Hectares)	Lower Control Limit	Upper Control Limit	Forecasted values for Production (' 000 Tonnes)	Lower Control Limit	Upper Control Limit	Forecasted values for Yield (Kg. / Hectare)	Lower Control Limit	Upper Control Limit
2021	1815.041	1349.148	2280.935	5996.37	3302.528	8562.123	3303.709	2164.907	4442.512
2022	1787.937	1261.452	2314.422	5959.68	2649.835	8154.308	3333.272	2188.055	4478.489
2023	1779.983	1223.43	2336.537	5985.79	2649.835	8154.308	3362.835	2211.239	4514.431
2024	1777.65	1198.15	2357.149	6030.50	2649.835	8154.308	3392.398	2234.458	4550.338
2025	1776.965	1176.866	2377.064	6080.70	2649.835	8154.308	3421.96	2257.711	4586.21
2026	1776.764	1157.159	2396.369	6132.54	2649.835	8154.308	3451.523	2280.999	4622.047
2027	1776.705	1138.306	2415.104	6184.86	2649.835	8154.308	3481.086	2304.32	4657.852
2028	1776.688	1120.065	2433.31	6237.33	2649.835	8154.308	3510.648	2327.673	4693.623
2029	1776.683	1102.338	2451.027	6289.83	2649.835	8154.308	3540.211	2351.06	4729.363
2030	1776.681	1085.071	2468.291	6342.35	2649.835	8154.308	3569.774	2374.478	4765.07

4.2. Model Estimation and Verification. Using the R programming language, the parameters of the rice production, yield, and cultivated area models were estimated. Tables 3 and 4 present the estimation's findings.

Diagnostic tests like autocorrelation function (ACF) and partial autocorrelation function (PACF) plots, as well as Ljung-Box tests, were used to check how accurate the ARIMA models were. The results showed that the models accurately captured data patterns, with no significant autocorrelation remaining in residuals. The additional analyses confirmed the reliability and effectiveness of the ARIMA models. As a model is being verified, its residuals are examined to determine if any systematic patterns are present that could be eliminated in order to enhance the chosen ARIMA.

5. Conclusion

In this study, ARIMA (1, 1, 1), ARIMA (0, 0, 1), and ARIMA (0, 1, 2), respectively, were found to be the developed models for rice cultivation area, production and yield. This is achieved by looking at the partial and full autocorrelations of the residuals of different orders. A non-significant 'Box L-Jung statistic' result also points to a "good fit of the models". It is evident from the forecast facilitated by the constructed model that over the following ten years, the area, production, and yield of rice cultivations is not enough for future. The anticipated value's accuracy can be confirmed after the data for the lead periods are available. For the study period, the multiple growth rate of paddy had been negative and insignificant for area, production, and yield, representative that the Tamil Nadu state must take the necessary steps to increase rice production.

Conflicts of interest : The authors declare no conflict of interest.

Data availability : Data is available in the referenced article.

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