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RESEARCH ARTICLE

Modelling and forecasting of turmeric in Andhra Pradesh

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Abstract

In India, turmeric holds a special place as both a spice and a medicinal crop, with South India being the leading region for its cultivation and trade. Given its economic importance, the present study examines developments in acreage, output and yield of turmeric in Andhra Pradesh from 1954 to 2023, using data collected from India stats and analyzed through GRETL and MS Excel. The compound annual growth rates (CAGR) were calculated across eight sub-periods to identify cultivation trends. The results indicate that from 1954 to 1993, turmeric area, production and yield showed a steady increase, but began declining thereafter, largely influenced by regional restructuring and the state bifurcation. Furthermore, for forecasting, the Box-Jenkins ARIMA methodology was applied, selecting models based on autocorrelation functions and criteria such as AIC, RMSE, MAE, MAPE (minimum) and R^2 (maximum) values. The ARIMA (1,1,10) model was deemed suitable for forecasting area and yield, while the ARIMA (1, 1, 9) model was appropriate for production, both achieving a 95 % accuracy level. Projections suggest a declining trend in turmeric cultivation, with area and production expected to decrease to 9.33 (000 ha) and 108.12 (000) MT, respectively, by 2030-31. These findings highlight the necessity for strategic interventions to stabilize and enhance turmeric farming in the region, providing a foundation for policymakers to address sustainability and productivity challenges.

Keywords: ARIMA; CAGR; forecasting; modelling; time series; turmeric

Introduction

India, widely recognised as the Spice Bowl of the World, has nurtured a thriving legacy of spice cultivation and trade since ancient times (1). Among its diverse array of spices, turmeric (*Curcuma longa* L.) holds exceptional prominence-praised not only as a culinary staple and natural colourant, but also for its wide-ranging medicinal benefits. The active compound curcumin, known for its anti-inflammatory, antioxidant, antimicrobial and anticancer properties, underpins turmerics' therapeutic appeal in traditional systems like Ayurveda and its growing validation in modern scientific research (2, 3).

India remains the largest producer, consumer and exporter of turmeric globally. In the 2023-24 agricultural year, turmeric was cultivated on approximately 305,000 hectares, yielding about 1.054 million tonnes, with an average productivity of 3.66 t/ha (4). Among the producing states, Telangana leads the country, contributing nearly 14.33 % of the national area and 24.75 % of production, with productivity levels reaching about 6.6 t/ha (5). Telangana's' leadership in turmeric production is primarily due to its favorable warm climate, well-drained loamy soils and a strong, established agricultural base for this specific crop (6). Maharashtra, Tamil Nadu, Odisha and Karnataka also remain major contributors to turmeric output, collectively accounting for a substantial share of the national production (7). In contrast Andhra Pradesh was once a major producer as well in 2013–14, just before the states' bifurcation, it ranked third in the country with nearly 151.9 thousand tonnes of production (8). After the split in 2014, however, turmeric cultivation in Andhra Pradesh declined sharply, falling to around 17 thousand ha and 121 thousand tonnes by 2015–16. The situation later improved, reaching about 74.7 thousand tonnes of production with area cultivation 26 thousand ha in 2021–22, with around 5.6 % of national output, but it again fell to about 22.4 thousand ha area with production 38 thousand tonnes in 2023 –24 (4).

Despite turmeric's' economic and medicinal relevance Andhra Pradesh currently experiences high variability in area, production and yield, driven by policy changes, market uncertainties and structural adjustments after bifurcation. This instability poses challenges for farmers, supply-chain actors and policymakers, particularly in crop planning, input management and marketing. Time-series models, particularly the Box–Jenkins ARIMA framework, are well-suited for capturing historical patterns and generating reliable short-term forecasts. To address this, the present study employs the Box–Jenkins ARIMA model to forecast the area, production and yield of turmeric in Andhra Pradesh. By providing evidence-based insights into future trends, this study aims to guide policymakers, researchers and farmers in formulating strategies to overcome production challenges and enhance the sustainability of turmeric cultivation (9, 10).

Materials and Methods

Data source

The information was collected from online databases. The data on the area, production and yield of turmeric for the last 69 yr, *i.e.*, from 1954 to 2023. To analyse the data, we utilized the statistical software GRETL (Gnu Regression, Econometric and Time-series Library) and MS Excel.

Growth rate

Compound annual growth rate (CAGR) was estimated using the following functional form:

$$\ln Y = a + bt \quad \text{(Eqn. 1)}$$

Where Y is the time series data of area, production, or yield of turmeric, for which the growth rate is calculated, 't' is the trend term and 'a is the constant coefficient. The slope coefficient 'b' measures the relative change in Y for a given absolute change in the value of the explanatory variable 't'. The compound annual growth rate can be calculated from the value.

$$CAGR = [\text{antilog}_e (b) - 1] \times 100 \quad \text{(Eqn. 2)}$$

For analyzing the growth rate of time series data on area, production and yield, the study period was segmented into eight decadal periods the period I (1954-1963), period II (1964-1973), period III (1974 -1983), period-IV (1984-1993), period-V (1994-2003), period-VI (2004-2013), period-VII (2014-2023) and period-VIII (1954-2023).

Modelling and forecasting

Box-Jenkins was used for forecasting the future values of dependent variables such as area, production and yield. The Box-Jenkins methodology is also referred to as the ARIMA methodology (11). The invention of the Box-Jenkins approach for modelling in the 1970s significantly advanced time series forecasting, further enhanced by the advent of computer software. The fundamental premise behind this technique is that the present value of the series is intrinsically linked to its historical values (12, 13).

It is first necessary to note that most time series are non-stationary and the ARIMA models refer only to a stationary time series (11). Since the ARIMA models refer only to a stationary time series, the first stage of the Box-Jenkins model is for reducing a non-stationary series to a stationary series by taking first-order differences. In general, an ARIMA model is characterised by the notation ARIMA (p, d, q) where p, d and q denote orders of auto-regression, integration (differencing) and moving average, respectively. It refers to the number of lags of the difference series is referred to as autoregressive and the lags within predicted data are referred to as moving average (14).

Autoregressive model

ARIMA models stand for autoregressive integrated moving average model. Integrated means the trends have removed; if the series has no important trend, the models are known as ARMA models. The notation AR(p) refers to the autoregressive model of order p. The AR (p) model is written

$$X_t = c + \sum_{i=1}^{P} \alpha_i X_t + \mu_t \quad \text{(Eqn. 3)}$$

Where are the parameters of the model, c is a constant and is it noise (15)

Moving average model

The notation MA (q) refers to the moving average model of order q:

$$X_t = \mu + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} + \varepsilon_t \quad \text{(Eqn. 4)}$$

Where the θ_1, ...,θq are the parameters of the model, μ is the expectation of Xt (often assumed to equal 0) and 'ε_t' is an error term.

The stage shown in Fig. 1 can be used to fit time-series data to an ARIMA model.

The whole period under consideration (1954 - 2015) was distributed as model building for the period of 1954 - 2015 and as model validation for the period of 2016-2023 and forecast up to 2030. Models are compared based on the maximum value of the coefficient of determination (R^2) and the minimum value of root mean square error (RMSE), mean absolute percentage error (MAPE), mean absolute error (MAE) and akaike information criterion (AIC).

Results and Discussion

Growth trend analysis for turmeric in Andhra Pradesh

The growth in the area, production and yield of turmeric is examined to know the pattern of changes taking place in the turmeric in Andhra Pradesh. The period-wise annual compound growth rate in the area, production and yield of turmeric in Andhra Pradesh has been depicted in Table 1. In the early phase (period I: 1954-1963), growth rates for area, production and yield were all negative, with production declining at -7.4 % annually. This early decline is consistent with historical evidence indicating limited access to

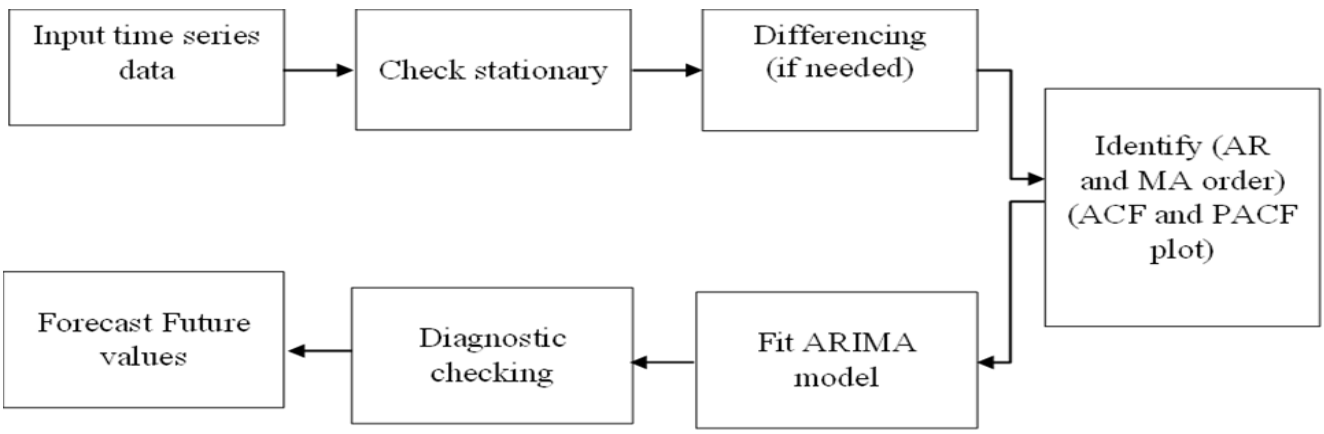

Fig. 1. Flow chart of Box-Jenkins.

Table 1. Growth rate of area, production and yield of turmeric in Andhra Pradesh from 1954 to 2023

PERIOD	Area	Production	Yield
Period-I (1954-1963)	-1.55	-7.4	-5.75
Period-II (1964-1973)	2.11	2.57	0.38
Period-III (1974-1983)	4.72	6.83	2.04
Period-IV (1984-1993)	9.06	12.29	2.98
Period-V (1994-2003)	1.72	-0.12	-1.79
Period-VI (2004-2013)	-6.02	-5.5	0.56
Period-VII (2014-2023)	6.63	-9.05	-14.98
Period-VIII (1954-2023)	1.82	2.93	1.09

improved inputs, poor irrigation coverage and the dominance of traditional farming practices during the mid-20th century (16). In period II (1964-1973), a positive shift occurred, with production growing at 2.57 % annually, largely due to an increase in area (2.11 %), while yield grew minimally (0.38 %). This recovery reflects the broader national improvement in spice cultivation during the green revolution era, largely due to enhanced extension services and gradual adoption of improved agronomic practices (6). This growth trend continued into periods III (1974-1983) and IV (1984-1993), with production rates improving to 6.83 % and 12.29 %, respectively, supported by positive contributions from area and yield, particularly in period IV where yield growth was 2.98 % which corresponds with nationwide technological improvements, increased fertilizer use and gradual integration of irrigation infrastructure in horticultural crops (6). During period V (1994-2003), production declined at -0.12 % annually, primarily driven by a decline in yield (-1.79 %), with a decline in area (1.72 %). In period VI (2004-2013), yield growth (0.56 %) sustained production increases despite a slight decline in area (-6.02 %). Similar stagnation was reported across Indian spice crops during the late 1990s, largely linked to climatic variability, rising input costs and increasing pest and disease pressures.

However, period VII (2014-2023) experienced positive growth in area and negative growth in production and yield, with an annual production decline of -9.05 %, largely due to the bifurcation of Andhra Pradesh and Telangana in 2014, which resulted in the loss of major turmeric-growing regions to Telangana. This structural division significantly reduced cultivated area and disrupted supply chains, contributing to production instability in the reorganised state (8). Across the entire study period (1954-2023), the overall CAGR reflects moderate positive growth in area (1.82 %), production (2.93 %) and yield (1.09 %) as shown in Fig. 2, indicating a general upward trend in turmeric production despite distinct periods of expansion and contraction, particularly influenced by regional restructuring in recent years.

Modelling and forecasting

After the evaluation of the trend each series, our next goal is to forecast the series for the future years. Box–Jenkins methodology was employed, as indicated in the material and methods. Data from 1954 to 2015 were used to create the model and data from 2016 to 2023 were used to validate it. The best fitting models are used to forecast the area, production and yield series in the future. To forecast, first check the stationarity, in which the ACF and PACF graphs from the original series clearly reveal that none of them are steady in nature, but after first-order differencing are sufficient to make them stationary. So it was discovered that ARIMA models ranging from (0, 1, 0) to (1, 1, 10) are appropriate for forecasting the area production and yield of turmeric, starting with the model-building technique mentioned in the material and method.

The study then uses the differenced series to estimate ARIMA equations for all parameters using data from 1954 to 2023 and provides forecasts up to 2030, through the Gretl software and MS Excel. ARIMA models were tested and the best models were chosen among the competing models based on the smallest value of RMSE, MAE, MAPE, AIC and the highest value of R^2, but basic objectives were not followed and the best-fitted model was selected based on the model that satisfies the majority of the objectives. However, residuals are also subjected to diagnostic checks using ACF and PACF graphs. The graph clearly illustrates that the acreage, production and yield of turmeric in Andhra Pradesh are expected to decrease in the future were quite clearly in Fig. 3-5. In the turmeric area, production and yield data from none of the series are stationary in Andhra Pradesh. Thus, first differencing with the original data makes all the series stationary, i.e. constant mean and constant variance.

The ACF and PACF plot of first difference, the value of area

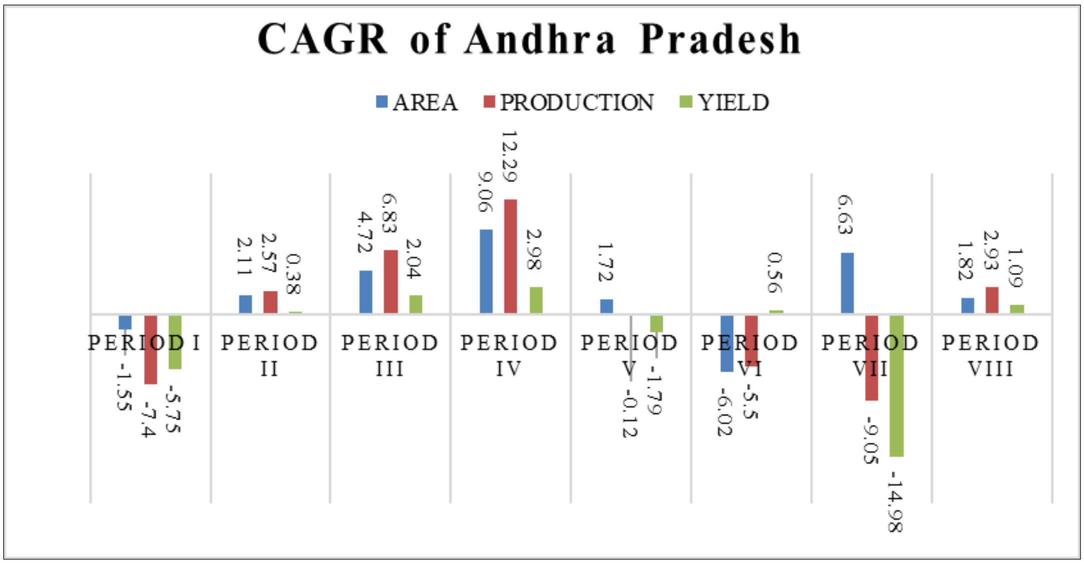

Fig. 2. Decadal growth trend in area production and yield of turmeric in Andhra Pradesh in 1954-2023.

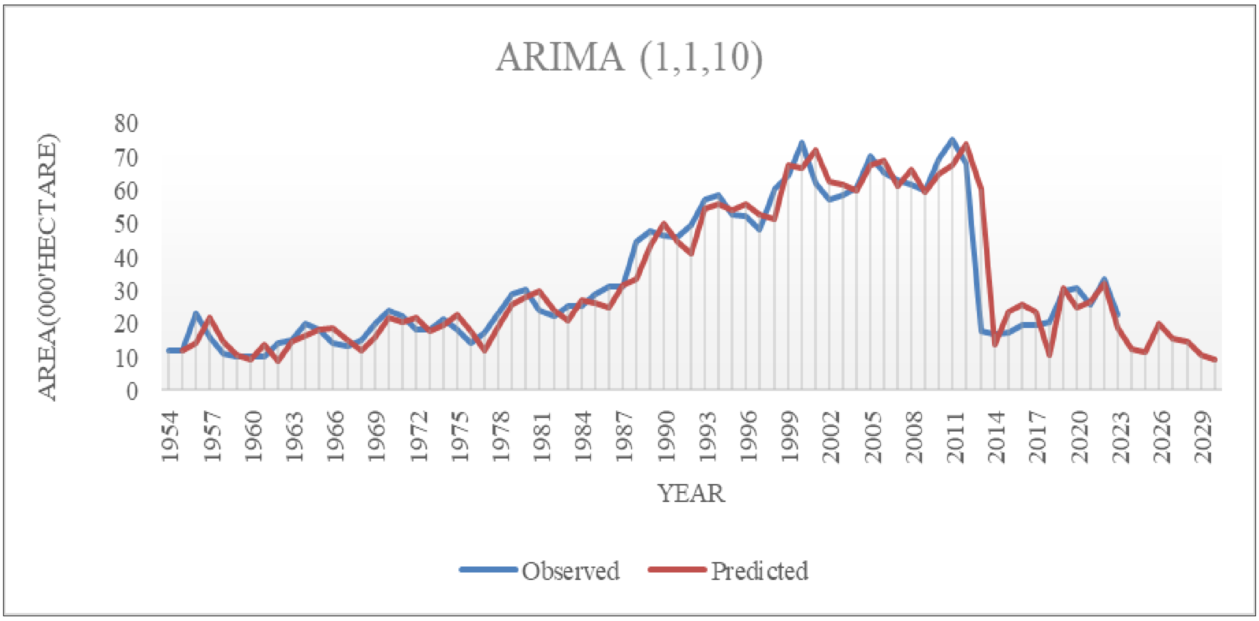

Fig. 3. Observed and forecasting area under turmeric in Andhra Pradesh.

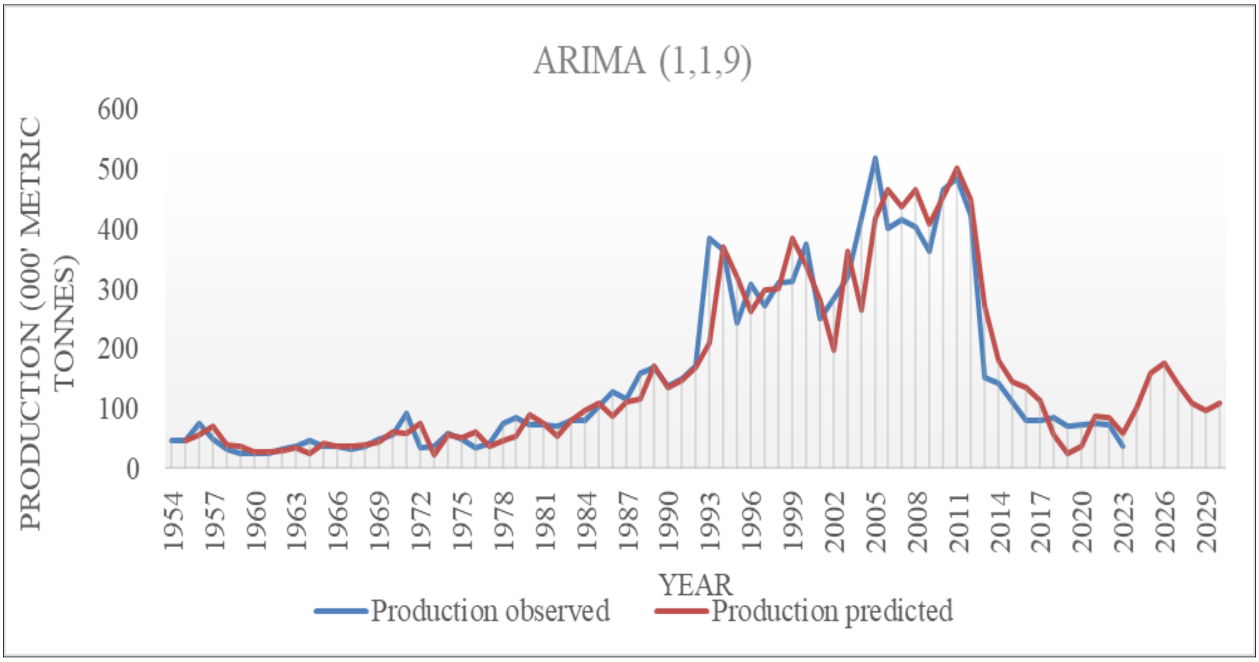

Fig. 4. Observed and forecasted production (000' MT) of turmeric in Andhra Pradesh.

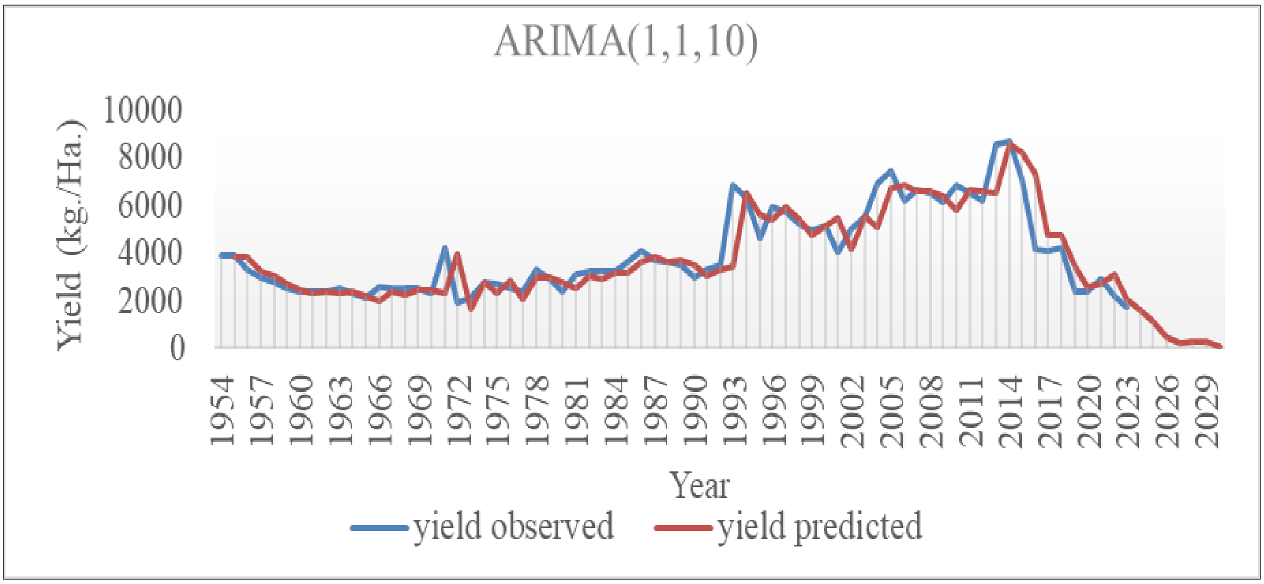

Fig. 5. Observed and forecasted yield under turmeric in Andhra Pradesh.

under turmeric in Andhra Pradesh, is represented in Fig. 6, which suggests that the tentative values of *p* and *q* that would be suitable for area under turmeric are *p*=1 and *q*=10 for Andhra Pradesh. Thus, ARIMA (1, 1, 10) was shown to be the best ARIMA model for the area under turmeric in Andhra Pradesh. The ARIMA (1, 1,1 0) areas under turmeric have low RMSE, MAPE and MAE values in Andhra Pradesh, as shown in Table 2. So, the best-fitting model is ARIMA (1, 1,1 0) in Andhra Pradesh. In 2023-2024, the area of turmeric in Andhra Pradesh was 22.37 thousand ha, respectively, compared to 18.65 thousand ha predicted. Andhra Pradesh will expect to have 9.33 thousand ha, as shown in Table 3 for the years 2030-2031.

The ACF and PACF plot of first difference, the value of production under turmeric in Andhra Pradesh, is represented in Fig. 7, which suggests that the tentative values of *p* and *q* that would be suitable for the area under turmeric are *p*=1 and *q*=9 for Andhra Pradesh. Thus, ARIMA (1, 1, 9) was shown to be the best ARIMA model for production under turmeric in Andhra Pradesh. As shown in Table 4, the ARIMA (1, 1, 9) production under turmeric had low RMSE, AIC values and maximum R^2 Value in Andhra Pradesh. So, the

Table 3. Model validation and forecasting of area (000' ha) under turmeric in Andhra Pradesh

Year	Observed	Predicted
2016	19.18	25.87
2017	19.62	23.24
2018	20.36	10.39
2019	29.72	30.67
2020	30.52	24.94
2021	25.59	26.47
2022	33.42	32.12
2023	22.37	18.65
2024		12.24
2025		11.23
2026		19.9
2027		15.36
2028		14.32
2029		10.32
2030		9.33

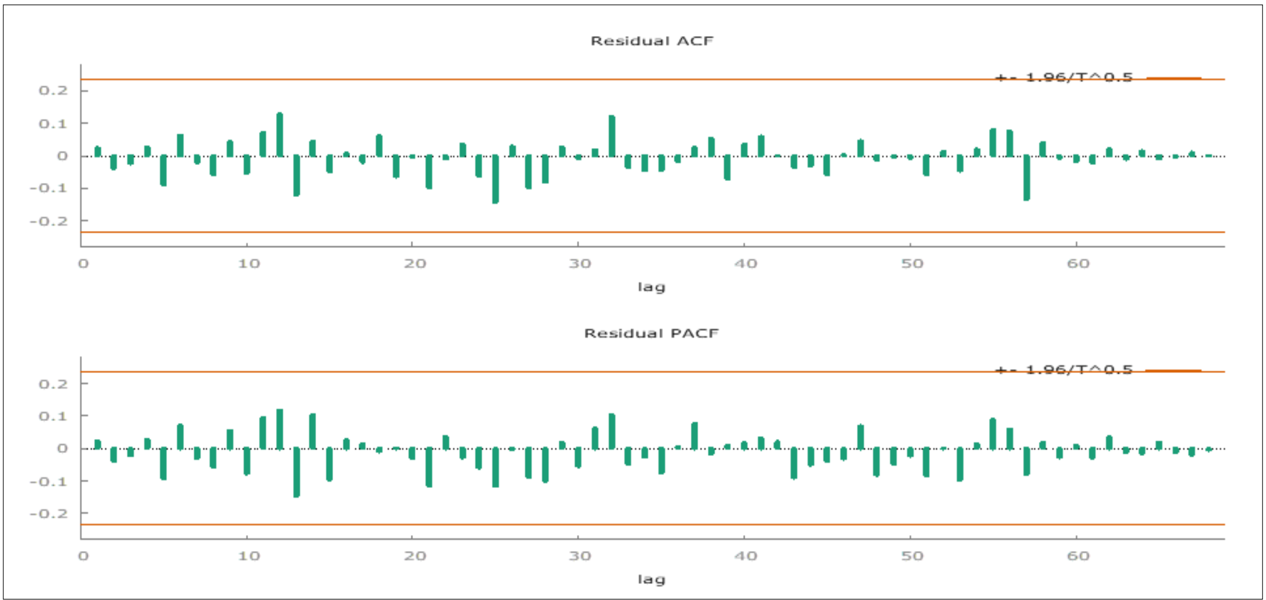

Fig. 6. ACF and PACF graphs of residuals for the best fitted models of the area under turmeric in Andhra Pradesh.

Table 2. Different ARIMA model for the area under turmeric in Andhra Pradesh

AREA ARIMA	R^2	RMSE	MAPE	MAE	AIC
ARIMA (0,1,0)	0.847	7.950	17.313	4.639	**485.903**
ARIMA (0,1,1)	0.850	7.903	17.083	4.555	487.105
ARIMA (0,1,2)	0.849	7.847	17.134	4.516	488.165
ARIMA (0,1,3)	0.855	7.656	17.895	4.686	486.916
ARIMA (0,1,4)	0.855	7.652	17.734	4.631	488.838
ARIMA (0,1,5)	0.858	7.578	18.007	4.579	489.618
ARIMA (0,1,6)	0.858	7.569	18.070	4.596	491.477
ARIMA (0,1,7)	0.859	7.569	18.076	4.608	493.456
ARIMA (0,1,8)	0.860	7.542	17.673	4.489	495.102
ARIMA (0,1,9)	0.862	7.481	17.744	4.384	496.293
ARIMA (0,1,10)	0.864	7.428	17.454	4.353	497.472
ARIMA (1,1,0)	0.849	7.914	17.129	4.577	487.298
ARIMA (1,1,1)	0.850	7.895	17.126	4.553	488.964
ARIMA (1,1,2)	0.851	7.762	17.033	4.500	488.696
ARIMA (1,1,3)	0.855	7.654	17.804	4.657	488.882
ARIMA (1,1,4)	0.856	7.641	17.990	4.710	490.699
ARIMA (1,1,5)	0.859	7.570	18.081	4.601	491.488
ARIMA (1,1,6)	0.858	7.569	18.073	4.569	493.474
ARIMA (1,1,7)	0.861	7.548	17.835	4.565	495.188
ARIMA (1,1,8)	0.878	7.033	16.472	4.343	491.971
ARIMA (1,1,9)	0.878	7.034	16.463	4.344	493.966
ARIMA (1,1,10)	0.886	6.849	17.547	4.386	496.564

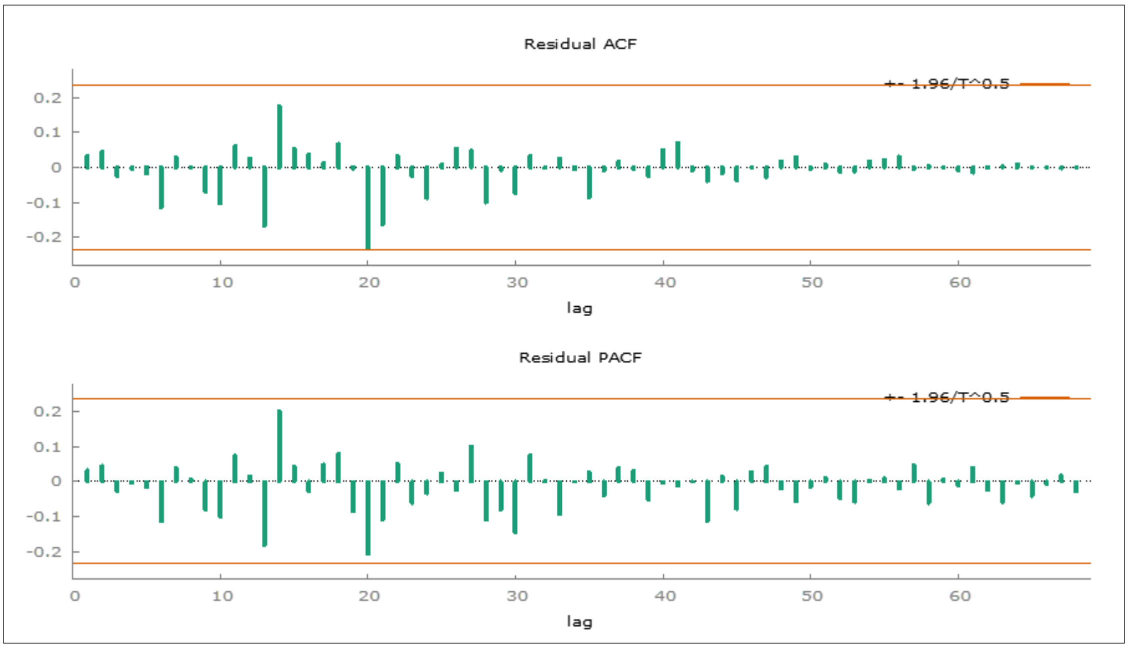

Fig. 7. ACF and PACF graphs of residuals for the best-fitted models of production under turmeric in Andhra Pradesh.

Table 4. Different ARIMA model for production under turmeric in Andhra Pradesh

Production ARIMA	R^2	RMSE	MAPE	MAE	AIC
ARIMA (0,1,0)	0.8424	57.8640	23.5880	32.7690	759.8304
ARIMA (0,1,1)	0.8422	57.8530	23.5680	32.6920	761.8050
ARIMA (0,1,2)	0.8434	57.2990	24.2080	32.9470	762.5164
ARIMA (0,1,3)	0.8437	57.1930	24.7120	33.5170	764.2638
ARIMA (0,1,4)	0.8437	57.1930	24.6940	33.5360	766.2625
ARIMA (0,1,5)	0.8499	56.3640	26.5670	33.9570	766.4311
ARIMA (0,1,6)	0.8499	56.3620	26.2010	33.9880	768.4258
ARIMA (0,1,7)	0.8558	55.6660	25.2850	33.5660	768.8868
ARIMA (0,1,8)	0.8893	48.4590	25.4960	31.6820	761.6305
ARIMA (0,1,9)	0.8900	47.8700	24.8120	30.7250	761.2258
ARIMA (0,1,10)	0.8901	47.8680	24.7510	30.7510	763.2002
ARIMA (1,1,0)	0.8423	57.8560	23.5690	32.7090	761.8115
ARIMA (1,1,1)	0.8432	56.7480	24.6290	33.0870	762.4368
ARIMA (1,1,2)	0.8435	57.2380	24.4970	33.2210	764.3687
ARIMA (1,1,3)	0.8437	57.1930	24.7100	33.5180	766.2637
ARIMA (1,1,4)	0.8468	56.9010	25.0690	33.8260	767.6154
ARIMA (1,1,5)	0.8495	56.3570	26.5460	34.0190	768.4060
ARIMA (1,1,6)	0.8498	56.2960	26.5670	34.0520	770.2545
ARIMA (1,1,7)	0.8586	55.1180	25.6120	33.6470	769.7424
ARIMA (1,1,8)	0.8895	47.8920	25.0270	30.6310	761.4822
ARIMA (1,1,9)	0.9041	44.8520	23.2520	29.0740	758.2617
ARIMA (1,1,10)	0.9038	44.7940	23.3120	29.1190	759.9181

best-fitting model is ARIMA (1, 1, 9) in Andhra Pradesh. In 2023-2024, the production of turmeric in Andhra Pradesh was 38.03 thousand MT compared to 57.67 thousand MT predicted. As shown in Table 5 for the years 2030-2031 andhra Pradesh is expected to have 108.12 thousand MT, respectively.

The ACF and PACF plot of first difference, the value of yield under turmeric in Andhra Pradesh was represented in Fig. 8, which suggests that the tentative values of *p* and *q* that would be suitable for yield under turmeric are *p*=1 and *q*=10 for Andhra Pradesh. Thus, ARIMA (1, 1, 10) were shown to be the best ARIMA model for yield under turmeric in Andhra Pradesh. As shown in Table 6, the ARIMA (1, 1, 10) yield under turmeric has the lowest RMSE, MAPE and MAE values and the maximum R^2 Value in Andhra Pradesh. So the best fitting model is ARIMA (1, 1, 10) in Andhra Pradesh. In 2023-2024, the yield of turmeric in Andhra Pradesh was 1700 kg/ha, respectively, compared to 2032.18 kg/ha predicted. As shown in Table 7 for the years 2030-2031 andhra Pradesh will expect to have 118.23 kg/ha.

Table 5. Model validation and forecasting of production (000 MT) under turmeric in Andhra Pradesh

Year	Observed	Predicted
2016	79.73	136.14
2017	79.73	112.86
2018	85.5	55.12
2019	71.32	24.18
2020	73.24	36.88
2021	74.69	87.74
2022	73.52	83.99
2023	38.03	57.67
2024		101.3
2025		158.1
2026		175.72
2027		139.83
2028		109.89
2029		95.9
2030		108.12

Table 6. Different ARIMA models for yield (kg/ha) under turmeric in Andhra Pradesh.

Yield ARIMA	R^2	RMSE	MAPE	MAE	AIC
ARIMA (0,1,0)	0.7470	910.3400	14.9570	578.8200	1140.1210
ARIMA (0,1,1)	0.7459	904.3400	14.7700	573.2800	1141.2300
ARIMA (0,1,2)	0.7560	879.4700	14.6410	555.7800	1139.4990
ARIMA (0,1,3)	0.7619	872.2400	14.1080	540.0200	1140.4170
ARIMA (0,1,4)	0.7621	869.8500	14.2680	537.3300	1142.0930
ARIMA (0,1,5)	0.7620	869.5200	14.1530	533.3500	1144.0380
ARIMA (0,1,6)	0.7660	860.7000	14.2230	531.8000	1144.7950
ARIMA (0,1,7)	0.7670	859.5600	13.9070	527.0900	1146.5700
ARIMA (0,1,8)	0.7702	856.0800	13.7590	528.8700	1148.1090
ARIMA (0,1,9)	0.7737	852.1900	13.9490	530.7500	1149.7850
ARIMA (0,1,10)	0.7755	849.4700	13.7160	521.2200	1151.3700
ARIMA (1,1,0)	0.7464	907.1000	14.7950	574.9500	1141.6360
ARIMA (1,1,1)	0.7469	896.2200	14.8920	571.5200	1142.0140
ARIMA (1,1,2)	0.7628	868.6400	14.4060	541.3600	1139.9350
ARIMA (1,1,3)	0.7626	868.2300	14.4920	543.6300	1141.8780
ARIMA (1,1,4)	0.7637	867.4700	14.3300	541.4100	1143.7540
ARIMA (1,1,5)	0.7636	867.4500	14.3340	541.0300	1145.7510
ARIMA (1,1,6)	0.7664	860.1400	14.0710	528.8100	1146.6840
ARIMA (1,1,7)	0.7719	854.8000	13.7150	525.5300	1147.9530
ARIMA (1,1,8)	0.7745	851.4000	13.8000	526.5000	1149.6090
ARIMA (1,1,9)	0.7752	850.4600	13.8230	525.4500	1151.5260
ARIMA (1,1,10)	0.7761	848.7400	13.6380	518.3800	1153.2210

Fig. 8. ACF and PACF graphs of residuals for the best-fitted models of yield under turmeric in Andhra Pradesh.

Table 7. Model validation and forecasting of production under turmeric in Andhra Pradesh

Year	Observed	Predicted
2016	4160	7259.64
2017	4063	4727.69
2018	4200	4732.06
2019	2400	3447.71
2020	2400	2578.71
2021	2920	2728.7
2022	2200	3120.15
2023	1700	2032.18
2024		1577.03
2025		1147.4
2026		482.26
2027		244.02
2028		259.02
2029		293.4
2030		118.23

Conclusion

This study demonstrates substantial shifts in turmeric farming trends in Andhra Pradesh over time. While there was significant expansion from 1984 to 1993, the recent years (2014 -2023) have seen a drop in both area and output, primal due to bifurcation of Andhra Pradesh, which led to regional reorganisation and altered resource distribution. This decreasing trend may continue, with acreage and output likely to decrease even more by 2030 -31, as per the records. To address these declining trends, strategic initiatives are required. Efforts such as promoting sustainable farming techniques, improving market access, providing financial assistance and harnessing current agricultural technology can all help to stabilise turmeric production. Addressing these concerns is crucial to protect turmeric farmers' livelihoods and maintain Indias' dominating position in the global turmeric trade.

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Authors' contributions

MPN were involved in conceptualisation and wrote and prepared the original draft. RRK were involved in conceptualisation and was responsible for the supervision. HM, MG, ST and DS took part in reviewing and editing. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare

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