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Analysis of Trends, Decomposition, Growth, and Instability in Maize Production of Uttar Pradesh, India

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ABSTRACT

Maize (*Zea mays* L.) is a globally cultivated cereal crop grown for diverse purposes, including human consumption, livestock feed, and various industrial applications. It thrives in warm regions with proper drainage and adequate rainfall. In India, it primarily thrives in regions like Karnataka, Madhya Pradesh, and Uttar Pradesh. Uttar Pradesh cultivates Maize in the *rabi, kharif,* and Zaid seasons, primarily as a *kharif* crop, even though it is grown throughout the state. The time series data on maize area, production, and yield, spanning the years 1950-51 to 2022-23, were sourced from the Indiastat website. The study examines this dataset using measures such as the coefficient of variation, instability index, and growth rate. Growth rates were calculated using the Compound Annual Growth Rate (CAGR) method, while the coefficient of variation and the Cuddy Della Valle Index were applied to assess instability in the data. The Maize growth rates throughout the study duration are categorized into four sub-periods: Period-I (1950-1973), Period-II (1974-1997), Period-III (1998-2022), and the Overall Period (1950-2022). Trend values were estimated using established statistical linear and nonlinear regression models, including the linear, logarithmic model, quintic model, power model, exponential model, quadratic model, and cubic model. Furthermore, the accuracy of various fitted models was evaluated using statistical measures such as the coefficient of determination (R^2), adjusted R^2, root mean square error (RMSE), and relative mean absolute percentage error (RMAPE). According to these statistical measures, specifically R^2, adjusted R^2, RMSE and RMAPE, the cubic model represents the optimal fit for Maize's area, production, and yield in Uttar Pradesh. Analysis of maize decomposition reveals that the area effect of Maize was the primary factor driving the rise in Maize production in Uttar Pradesh.

Keywords Compound annual growth rates, Decomposition, Instability index, Maize, Statistical modeling, Uttar Pradesh.

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INTRODUCTION

Maize (*Zea mays* L.) belongs to Poaceae family. It is the third most significant cereal crop in India, is grown across 188 million hectares in over 170 nations, yielding 1,423 million metric tons. India is positioned 4th in area, with 9.89 million hectares allocated to Maize farming. State-wise production in India highlights Karnataka as the leading producer, with the largest area of 1,972 thousand hectares, followed by Madhya Pradesh at 1,543 thousand hectares and Maharashtra at 1,326.17 thousand hectares. Bihar leads in overall Maize output, yielding 5,709.43 thousand tonnes, followed by Karnataka with 5,629.24 thousand tonnes and Madhya Pradesh with 4,338.69 thousand tonnes. Although West Bengal and Tamil Nadu have extensive agricultural areas and outputs, their productivity levels are moderate at 6,663 and 6,239 kg per hectare, respectively (IndiaStat, 2022-2023). In Uttar Pradesh, Bahraich led in Maize cultivation area (95,069 ha), Kannauj topped in production (192,187 tonnes), and Etah recorded the highest productivity (9.72) (DES 2022).

Numerous scientists and researchers have conducted multiple studies on time series analysis related to Maize and other agricultural crops. Yadav *et al.* (2016) estimated that by 2025, India would need 50 MMT of Maize, with major demand from the feed and industrial sectors, highlighting the need and opportunity to double Maize production from the current 25 MMT over the next decade. Kumar and Paul (2017) estimated growth patterns, instability, and the effects of explanatory variables on Maize production in Andhra Pradesh from 1990-91 to 2014-15, using compound growth rates, Coppock's Instability index, and decomposition analysis for inter-district data. Anjum and Madhulika (2018) carried out growth and instability of major Indian crops using the Cuddy-Della Valle Index and Coppock's Instability Index across three sub-periods: 1990-91 to 1999-2000, 2000-01 to 2009-10, and 2009-10 to 2016-17. Dhunde *et al.* (2018) examined the area, production, and productivity of pigeon pea in the Marathwada region during 1996-97 to 2015-16, dividing the analysis into two sub-periods. Growth rates were estimated using exponential functions, while instability was assessed through the Coefficient of Variation and the Cuddy-Della Valle Index. Ahmad *et al.* (2018) investigated positive growth trends in area, production, and productivity across all states of India except Uttar Pradesh, where recent years showed negative growth; decomposition analysis revealed a high interaction effect contributing to improved productivity nationwide. Sanjay *et al.* (2018) assessed trends, growth, and instability in cotton area, production, and yield in Haryana from 1966-67 to 2013-14 using semi-log linear functions, compound annual growth rates (CAGRs), and the coefficient of determination for variation in yield CDVI. Prioty *et al.* (2023) assessed 40 years (1981–2020) of black gram data using exponential growth functions and the CDVI to evaluate growth rates and instability in area, production, and yield across four sub-periods. Prakash and Venkataramana (2023) analyzed growth patterns in the area, production, and productivity of maize in both India and Karnataka, along with assessing production risks in Karnataka, using primary data from selected key districts and secondary data from official sources. Tripathi *et al.* (2023) measured instability in sesame production using the CV and CDVI, and assessed the contributions of the area and yield through area, yield, and interaction effects. Pooja *et al.* (2023) defined forecasting of crop production as predicting the future values of cultivated crops before harvest and applied to the area and production of pulses in India over 71 years (1951–2021) using linear, logarithmic, quadratic, cubic, power, and exponential models. Yadav *et al.* (2023) analyzed both the area and production of nutri-cereals in India over 70 years (1951–2020) using several regression models. Supriya *et al.*(2023) used annual data (1970–2019) from the annual report of Agricultural Statistics at a Glance to forecast lentil production up to 2029 and found the area effects were dominant in most states, while the yield effect was key in Uttar Pradesh, highlighting future production-demand gaps. Ramoliya *et al.* (2022) estimated growth and instability of major oilseed production in India from 1990-91 to 2019-20 using compound growth rates and the Cuddy-Della Valle Index, dividing the period into three sub-periods to analyze recent trends. Kumar, Singh *et al.* (2024) analyzed compound growth rates and Cuddy-Della Valle instability for major pulses (chickpea, pigeon pea, urdbean, and mungbean) in India using published data from 2000 to 2021. Kumar *et al.* (2024) assessed long-term trends and growth rates of major millets in India (1966-2021) using regression and growth models on data from milletstats.com. Kumari and Singh (2024) analyzed 30 years (1992–2022) of Maize production in Himachal Pradesh, revealing a slight increase in growth rates for area, production and productivity across three sub-periods. Mhaskey *et al.* (2025) examined growth rates, instability indicators, trend models, and decomposition in groundnut, rapeseed, and mustard production in Rajasthan using 2000-2022 secondary data. Neerugatti *et al.* (2025) investigated the trends, instability, and decomposition analysis of the area, production, and yield of turmeric in Andhra Pradesh over the last 70 years from 1954 to 2023. Using secondary data, collected information from indiastat (www.indiastat.com). Singh and Kumar (2025) analyzed trend patterns of pigeon in India from 2001 to 2023 using time series data and fitted statistical models, including linear, exponential, quadratic, and cubic models. Singh *et al.* (2025) analyzed trend patterns in the of lentil crop in India for the period 2001-2023 using secondary time series data and fitted linear, exponential, quadratic, and cubic models to estimate trend values. The present study aims to assess the growth rates, instability, decomposition, and trend patterns in the area, production, and yield of Maize in Uttar Pradesh, based on secondary time series data from 1950-51 to 2022-23.

MATERIALS AND METHODS

Sources of data

The secondary data on Maize area, production, and yield were collected from the IndiaStat website. The period of data from 1950-51 to 2022-23. The growth rates, instability, and decomposition analysis were assessed based on the specified study period.

Compound annual growth rate (CAGR)g

The study utilized time series data on maize area, production, and yield, along with compound annual growth rate estimates, categorized into four-time frames: Period I (1950-51 to 1973-74), Period II (1974-75 to 1997-98), Period III (1998-99 to 2022-23), and the overall period spanning 1950-51 to 2022-23.

To evaluate the annual compound annual growth rates (CAGRs), the following model is used and first linearized by taking the natural logarithm on both sides:

$$\log Y_t = \log a + t \log (1 + r_t)$$

or,

$$Y^*_t = a^* + bt$$

Where,

$Y^*_t = \log Y_t$, $a^* = \log a$ and $b = \log (1+r_l)$

Compound annual growth rate is then computed as,

$$\text{CAGR} = (\text{antilog of } \hat{b} - 1) \times 100$$

This gives the percentage growth rate per year.

Instability index

The instability in maize area, production, and yield in Uttar Pradesh during the study period 1950-51 to 2022-23 was assessed using the Coefficient of Variation (CV) and the Cuddy-Della Valle Index (CDVI), which were employed to estimate the respective instability indices.

$$\textit{Instability index} = \text{C. V.} \sqrt{1-R^2}$$

$$C.\,V. = \frac{\sigma}{\mu} \times 100$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}$$

Where, n is total sample size, *C.V.* is the coefficient of variation of variables, R^2 is the coefficient of determination from the trend regression, σ is the standard deviation, is the Overall mean, μ is the actual value of the dependent variable (area or production and yield of Maize), $\bar{Y}_i$ is the predicted value of the dependent variable (area or production and yield of Maize) and $\bar{Y}$ is the mean of the actual value of the dependent variable (area or production and yield of Maize).

Decomposition analysis

To evaluate the contribution of area effect and yield effect of Maize and their interaction effect on the change in production of Maize.

$$\Delta P = A_o (Y_n - Y_o) + Y_o (A_n - A_o) + \Delta A \Delta Y$$

$$1 = \left[\frac{(A\Delta Y)}{\Delta P}\right] + \left[\frac{(Y\Delta A)}{\Delta P}\right] + \left[\frac{(\Delta A\Delta Y)}{\Delta P}\right]$$

Where,

ΔP is the change in production, A_o is an area of the base year, A_n is an area of the current year, Y_o represents the output of base year, Y_n is the yield of Maize in the current year, ΔA is the change in the area (A_n–A_o) and ΔY is the change in the yield of Maize (Y_n–Y_o).

This breakdown allows us to assess how much the change in total production is due to variations in yield, variations in area and the combined effect of both.

Well-known linear and non-linear models

To evaluate trend patterns of Maize area, production as well as yield of Uttar Pradesh, we estimated the trend values by fitting various regression models, such as linear, quadratic, quintic, logarithmic, exponential, power, and cubic, for the data of Maize in UP.

Models	Form
Linear	$Y_t = \alpha+\beta t+\varepsilon_t$
Quadratic	$Y_t = \alpha +\beta t+\gamma t^2 + \varepsilon_t$
Cubic	$Y_t =\alpha + \beta t+\gamma t^2 +\theta t^3 +\varepsilon_t$
Quintic	$Y_t= \alpha + \beta t + \gamma t^{2} + \theta t^3 + \delta t^4 +\omega t^5+\varepsilon_t$
Logarithmic	$Y_t = \alpha + \beta \ln (t) + \varepsilon_t$
Exponential	$Y_t = ae^{\beta t}.e^{\varepsilon t}$
Power	$Y_t=at^{\beta}.\ e^{\varepsilon t}$

Where,

'Y_t ' is dependent variable (i.e., area or production or yield of crop) 'α ' is the intercept, 'β' 'γ', ' θ', 'δ' and 'ω' area the regression coefficient, 't ' is an independent variable (i.e., time in years) and 'ε_t ' is error term, $\varepsilon_t \sim N (o, \sigma^2)$.

Statistical measures for evaluation of best fitted models

The precision of the models applied to the data has been assessed using various statistical measures, such as the coefficient of determination R^2, adjusted R^2, root mean square error (RMSE), and relative mean absolute percentage error (RMAPE), shown in the formulas below:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2}{\sum_{i=1}^{n}(Y_i-\bar{Y})^2}$$

$$\text{Adjusted } R^2 = 1 - \frac{(1-R^2)\ (n-1)}{n-p-1}$$

R^2 is the coefficient of determination, n is total sample size and p is a number of independent variables.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t-\hat{y})^2}$$

$$\text{RMAPE} = \frac{I}{n}\sum_{t=1}^{n}\left|\frac{y_t-\hat{y}}{Y_t}\right| \times 100$$

n represents number of years for the time-series data on the variable Y, y_t is the actual value of dependent variable (area, production and yield of Maize) and $\hat{y}_t$ is the predicted trend value of the dependent variable (area, production and yield of Maize).

RESULTS AND DISCUSSION

Compound annual growth rate (CAGR)

This study analyzed time series data on maize area, production, and yield in Uttar Pradesh for the period 1950-51 to 2022-23. The data were segmented into four timeframes: Period I (1950-51 to 1973-74), Period II (1974-75 to 1997-98), Period III (1998-99 to 2022-23), and the overall period (1950-51 to 2022-23). Growth trends were assessed using the Compound Annual Growth Rate (CAGR), while variability was measured through the Coefficient of Variation (CV) and the Cuddy-Della Valle Index (CDVI).

Period-I (1950-51 to 1973-74)

Table 1 and Fig. 1 explains that compound annual growth rates (CAGRs) for area, production and yield were all positive (i.e., 2.63%, 2.97%, 0.33%), indi-

Table 1. Compound growth rate of area, production and yield of Maize in Uttar Pradesh.

Periods	Area	Production	Yield
Period-I (1950-51 to 1973-74)	2.63*	2.97*	0.33
Period-II (1974-75 to 1997-98)	-0.92*	2.86*	3.81*
Period-III (1998-99 to 2022-23)	-1.03*	1.53*	2.59*
Overall Period (1950-51 to 2022-23)	-0.66*	0.95*	1.62*

* Indicate significance at a 5% level.

cating an increasing trend in Maize cultivation during this study period. Area, production has a significant result and yield has a non-significant result at the 5% level for this period. They could be a proper use of agricultural land for cultivation of Maize, advanced technology, high inputs and high-yielding varieties of Maize and the effect of the same policies.

Period-II (1974-75 to 1997-98)

Table 1 and Fig. 1 explain that in period II, Production (2.86%) and yield (3.81%) exhibited positive growth rates, except for the area, which showed a decline of (-0.92%). It could be agricultural land degradation or the urbanization of agricultural fields. Production and yield were positively significant at the 5% level, except area of Maize in Uttar Pradesh.

Period-III (1998-99 to 2022-23)

Table 1 and Fig. 1 explains that, during period III, the growth rates were the same as those in period II. Production (1.53%) and yield (2.59%) demonstrated positive growth rates, except for area (-1.03%). Maize production and yield are statistically significant at a 5% level, excluding the area for Maize in Uttar Pradesh. The area has a significantly negative result reason as low input expenditure in Maize cultivation and low interest from farmers in Maize, as they don't receive proper Minimum Support Price (MSP) on Maize in Uttar Pradesh during this period of study.

Overall period (1950-51 to 2022-23)

Table 1 and Fig. 1 revealed that overall, the CAGR of area (-0.66%) was negative, except for production (0.95%) and yield (1.62%) in Uttar Pradesh. Production and yield were positively significant at the 5% level, except area of Maize in Uttar Pradesh.

Instability index

To evaluate the instability in the area, production and yield of the Maize are measured using measures of variation and mean. The coefficient of variation (CV) tends to include the effect of trends, which can cause it to overstate instability in data with long-term trends. To address this issue, this study uses the Cuddy Della Valle (1978), which adjusts the coefficient of variation

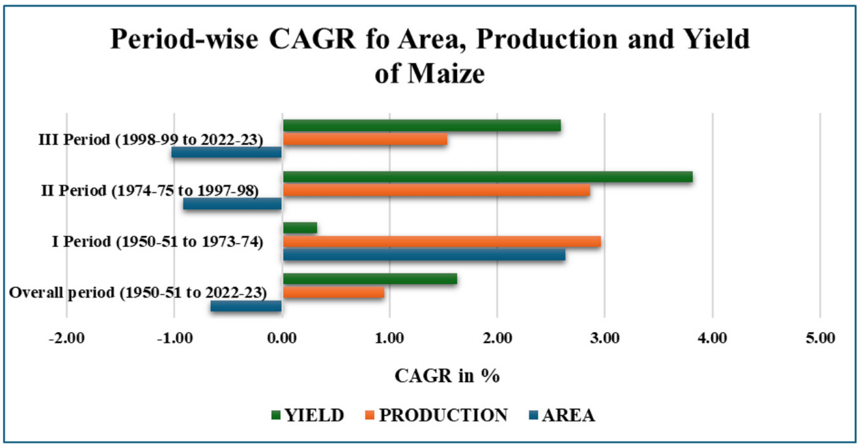

Fig. 1. Period-wise comparison of compound annual growth rate of area, production and yield of Maize.

Table 2. Instability index of area, production and yield of Maize in Uttar Pradesh.

Particulars	Instability index (%)	
Area	CV	22.11
	CDVI	17.70
Production	CV	28.03
	CDVI	21.01
Yield	CV	39.48
	CDVI	18.95

Table 3. Decomposition analysis of Maize in Uttar Pradesh.

Particular	% Contribution
Area effect	90.4
Interaction effect	6.2
Yield effect	3.4

by accounting for the underlying trend.

In Table 2 showing Uttar Pradesh, from 1950 to 2022, the Maize crop expressed the highest Coefficient of Variation (CV) in yield (39.48%), with production (28.03%) and area (22.11%) following, whereas the least Cuddy Della Valle Instability Index (CDVI) values were noted for area (17.70%), yield (18.95%), and production (21.01%), suggesting moderate instability in all parameters.

Decomposition analysis

To evaluate the relative contribution of Maize area, yield effect and their interaction effect to the changes in Maize production in Uttar Pradesh from 1950-51 to 2022-23.

Table 3 indicates that throughout the entire study period, all three factors contributed to Maize production. The growth of production was mainly influenced by the interaction effect (6.2%), next was the yield effect (3.4%), and lastly the area effect (90.4%).

Well-known linear and non-linear models

For the understanding of the trend pattern of Maize area, production and yield in Uttar Pradesh from 1950-51 to 2022-23 were applied to various linear and non-linear regression models were applied.

Tables 4–5 shows that the models applied are suitable for examining trend patterns and predicting the upcoming area for Maize cultivation in Uttar Pradesh. Among the various models assessed, the cubic model demonstrates greater accuracy compared to the others, as shown by its highest R^2 (i.e., 0.8576) and adjusted R^2 (i.e., 0.8514) along with the minimum values for RMSE (i.e., 0.8624) and MAPE (i.e., 0.0601). In light of these, based on statistical coefficients, the cubic model is recognized as the best choice for predicting the future. The region designated for the cultivation of mustard and rapeseed in India.

Table 4. Statistical models for area of Maize in Uttar Pradesh.

	Models						
Parameters	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quintic
α	139.42*	985.70*	5.3×10^{6}*	1.7×10^{44}*	-1.26×10^{4}*	**-1.06×10^{6}***	-1.08×10^{5}*
β`	-0.665*	-128.43*	-0.007*	-13.107*	12.7632*	**1.59×10^{3}***	0
γ					-0.0032*	**-0.7982***	0
θ						**0.00013***	1.37×10^{-4}*
δ							-1.03×10^{-7}*
ώ							2.10×10^{-11}*

Table 5. Measures for evaluation of fitted models of Maize area in Uttar Pradesh.

	Measures for the evaluation of fitted models						
Measures	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quintic
R^2	0.3589	0.3557	0.3969	0.3934	0.6738	**0.8576**	0.8580
Adj.R^2	0.3499	0.3466	0.3884	0.3849	0.6644	**0.8514**	0.8228
RMSE	1.8296	1.8342	1.9016	1.9065	1.3052	**0.8624**	0.8611
MAPE	0.1434	0.1440	0.1464	0.1469	0.0959	**0.0601**	0.0600

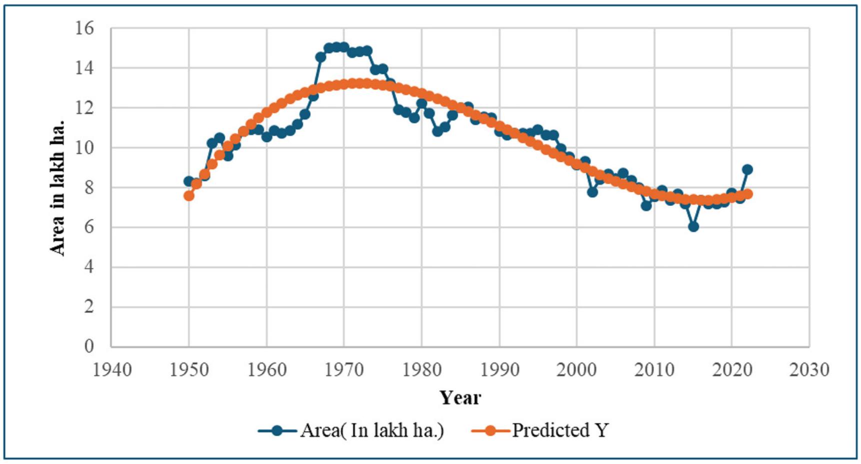

Fig. 2. Actual vs trend values of area of maize data using the best-fitted model.

The connection between actual values compared to the trend values for the region of Maize is presented in Fig. 2.

Tables 6–7 explain that the fitted various models are appropriate for examining trend patterns and projecting future production for Maize in Uttar Pradesh. Among the assessed models, the cubic model demonstrates greater accuracy than the others, as shown by its highest R^2 (i.e., 0.4870) and adjusted

Table 6. Statistical models for production of Maize in Uttar Pradesh.

	Models						
Parameters	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quintic
α	-193.18*	-1546.03*	7.6 $\times 10^{-8*}$	8.0$\times 10^{-62}$*	-4253.2*	**-6.41$\times 10^{5}$***	-6.62$\times 10^{4}$*
β	0.1032*	205.144*	0.0095*	18.846*	4.1922*	**966.8773***	0
γ					-0.0010*	**-0.4858***	0
θ						**0.0001***	8.38 $\times 10^{-5}$*
δ							-6.32$\times 10^{-8}$*
ώ							1.27$\times 10^{-11}$*

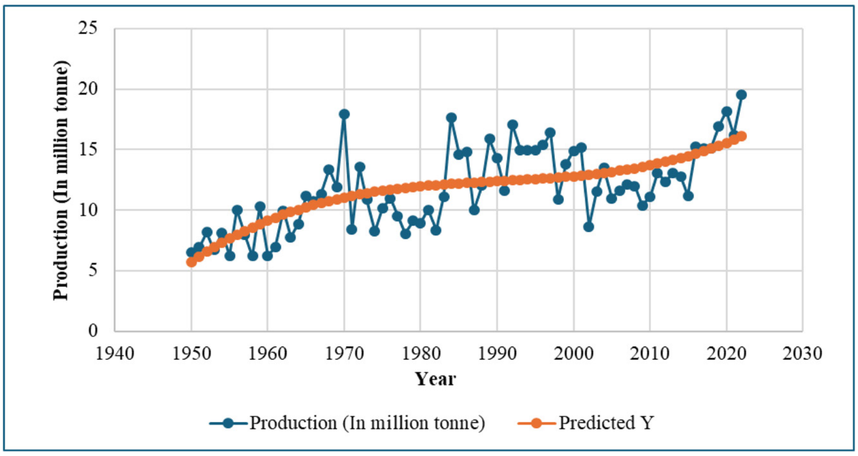

Fig. 3. Actual vs trend values of production of Maize data using the best-fitted model.

Table 7. Measures for evaluation of fitted models of Maize production in Uttar Pradesh.

	Measures for the evaluation of fitted models						
Measures	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quintic
R^2	0.4385	0.4393	0.4741	0.4753	0.4540	**0.4870**	0.4882
Adj. R^2	0.4306	0.4314	0.4667	0.4680	0.4384	**0.4647**	0.4370
RMSE	2.4611	2.4594	2.5144	2.5123	2.4269	**2.3523**	2.3496
MAPE	0.1796	0.1794	0.1754	0.1751	0.1772	**0.1757**	0.1756

Table 8. Statistical models for yield of Maize in Uttar Pradesh.

	Models						
Parameters	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quintic
α	-3776.6*	-29421.8*	$1.4\times10^{-12*}$	$4.7\times10^{-104*}$	131932.8*	**-3.76×10^{5}**	-1.9×10^{4}*
β	1.9621*	3890.27*	0.0161*	31.953*	-134.72*	**632.2304**	0
γ					0.0344*	**-0.3518**	0
θ						**0.000065**	4.3×10^{-5}
δ							-3.4×10^{-8}
ώ							$7.8\times$ 10-[12]

Table 9. Measures for evaluation of fitted models of Maize yield in Uttar Pradesh.

	Measures for the evaluation of fitted models						
Measures	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quintic
R^2	0.7695	0.7671	0.7665	0.7649	0.8536	**0.8537**	0.8537
Adj. R^2	0.7663	0.7638	0.7632	0.7616	0.8494	**0.8473**	0.8184
RMSE	22.625	22.744	19.8618	19.9599	18.0344	**18.0281**	18.0267
MAPE	0.1796	0.1804	0.1564	0.1570	0.1418	**0.1423**	0.1424

R^2 (i.e., 0.4647) and the minimum values for RMSE (i.e., 2.3523) and MAPE (i.e., 0.1757). Grounded in these statistical coefficients, the cubic model is recognized as the best option for predicting future production designated for the cultivation of Maize in Uttar Pradesh. The comparison between actual values

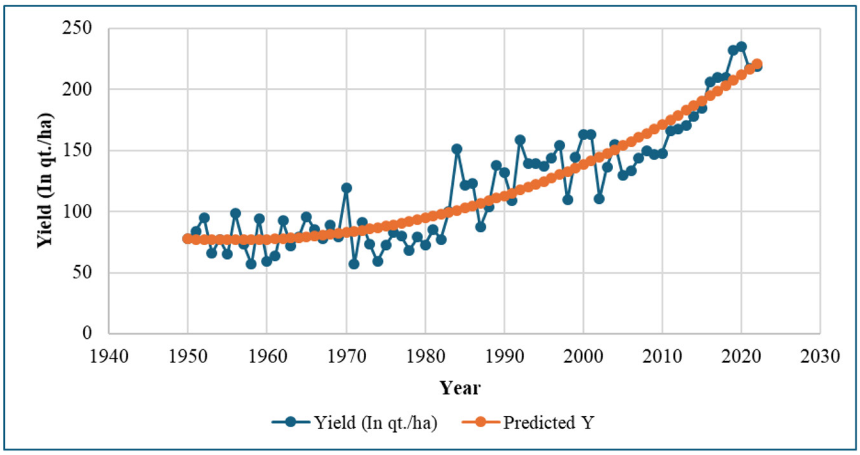

Fig. 4. Actual vs trend values of yield of Maize data using the best-fitted model.

compared to trend values for Maize production is portrayed in Fig. 3.

Tables 8–9 shows that the models fitted are suitable for examining trend patterns and predicting future yields in Maize cultivation in Uttar Pradesh. The models assessed, the cubic model demonstrates greater accuracy than the rest, as shown by its highest R^2 (i.e., 0.8537), adjusted R^2 (i.e., 0.8473), long with the minimum RMSE (i.e., 18.0281) and MAPE (i.e., 0.1423). According to these statistical coefficients, the cubic model is determined to be the best option for predicting future yield designated for Maize cultivation in Uttar Pradesh. Figure 4 shows the comparison between observed values and predicted values for Maize yield.

CONCLUSION

The area, yield, and production for period-I represent a positive trend. For period-II, production and yield improved. In period-III, the production and yield remained positive. Overall growth rates for Maize area, production, and yield across the periods reflected a mixed trend. The yield of Maize had the highest coefficient of variation, followed by the production of Maize, while the area of Maize exhibited the lowest Coefficient of variation. Cuddy Della Valle Index (CDVI) instability for Maize production was the highest, with the Maize yield following, while the lowest instability index was noted in the area of Maize. The contribution of the area effect and the yield effect was substantial, while their interaction effect also contributed to Maize production. The cubic model is the best-fitted model for area, production, and yield, based on measures for the evaluation of fitted models. To stabilize Maize production in Uttar Pradesh, focus on securing the cultivated area and enhancing yield through improved varieties and timely inputs. Use the cubic model for accurate forecasting and data-driven policy planning.

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