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Projecting growth in Indian horticulture: A time series analysis of area, production, and productivity using ARIMA models

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ABSTRACT

The horticulture sector plays a crucial role in India's agricultural economy, emerging as a dynamic and rapidly expanding component of agriculture. It contributes significantly to farmers' income, food security, and nutritional well-being. The present study analyzed trends and patterns in the area, production, and productivity of the Indian horticulture sector over 33 years (1991–92 to 2023–24). The time-series data for this period were collected from Horticulture Statistics at a Glance, published by the Department of Agriculture and Farmers Welfare, Government of India. ARIMA models were employed to generate forecasts for the period 2025–26 to 2050–51. The results indicated a continuous upward trend in all three parameters over the study period. The area under horticulture is projected to reach about 42.77 mha by 2050–51, while production and productivity were expected to rise to 567.25 mt and 16.30 t/ha, respectively. These projections were validated through residual analysis with low Mean Absolute Percentage Error (MAPE) values (2.17% for area, 2.65% for production, and 3.05% for productivity), confirming the robustness of the predictions. The study suggested that, to maintain this positive trajectory, targeted investments in research, modern infrastructure, efficient resource management, post-harvest management strategies, sustainable farming practices, and supportive policy measures are needed to sustain the horticulture sector's growth.

Keywords: ARIMA, Forecasting, Horticulture, Residual analysis, Trend analysis

India's horticulture sector has grown into one of the most dynamic and promising segments of agriculture, offering immense opportunities to diversify income sources and boost the country's economic growth. This sector includes a diverse range of crops such as fruits, vegetables, ornamental plants, medicinal and aromatic plants, spices, and plantation crops. The country's vast climatic diversity and soil variations create highly favourable conditions for the cultivation of a wide array of horticultural crops, making India a global leader in this domain. This sector plays a pivotal role in enhancing farmers' incomes, particularly benefiting small and marginal farmers, who often struggle to earn returns from traditional cereal crops. Unlike conventional agriculture, horticultural crop production is more labour-intensive, providing substantial employment opportunities, particularly in rural areas. The sector supports not only on-farm employment but also off-farm activities such as processing, packaging, and marketing, contributing to overall economic growth (Agarwal *et al.* 2016). Beyond economic benefits, horticultural crops also play a crucial role in ensuring food and nutritional security. Fruits and vegetables are rich source of essential nutrients, including vitamins, minerals, proteins, and carbohydrates, which are vital for human health. Their high nutritional value has earned them the title of "protective foods," making them essential in combating malnutrition and improving dietary diversity in India. Over the past few decades, India's horticulture sector has witnessed remarkable growth. The country is now the world's second-largest producer of fruits and vegetables, following China (Mitra and Panda 2020, Chauhan *et al.* 2022). India contributes 11.3% of global fruit production and 17.4% of global vegetable production. Additionally, the horticulture sector accounts for 33% of India's agricultural Gross Value Added (GVA), underscoring its critical role in the nation's agricultural economy (GoI 2025).

Historically, Indian horticulture received little attention, as Indian agriculture was primarily focused on staple food crops such as rice and wheat to meet the country's food security needs. However, things began to change in the 1980s, when institutional support and policy reforms paved the way for growth in this sector (Doddamani *et al.* 2014). The real turning point came in 1991 with India's economic reforms, which introduced market liberalization,

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spurred urbanization, and led to shifts in dietary habits. As income rose and lifestyles changed, people began to demand a wider range of agricultural products, including fruits, vegetables, and other high-value crops, moving beyond traditional food grains (Hassan *et al.* 2021). This shift created a fertile ground for horticulture to flourish. Since 2010, horticulture production has consistently surpassed food grain production (Jaiswal *et al.* 2023). For instance, in 2023–24, horticulture production reached 352.23 mt, surpassing food grain production, which stood at 328.55 mt (GoI 2025). States like Uttar Pradesh, Madhya Pradesh, and West Bengal have been at the forefront of this growth, with Uttar Pradesh leading the country in horticultural production during 2023–24, followed by Madhya Pradesh and West Bengal (National Accounts Statistics 2024). Several factors have fueled this remarkable growth. Changing consumer preferences, driven by rising incomes and urbanization, have increased demand for high-value horticultural products such as fruits, vegetables, and spices. At the same time, expanding export markets have opened up new opportunities for Indian farmers. Government initiatives have also played a crucial role in boosting productivity and supporting the sector's growth. Programmes like the National Horticulture Mission (NHM) and the Mission for Integrated Development of Horticulture (MIDH) have introduced advanced technologies, improved infrastructure, and provided financial support to farmers (Narmadha and Karunakaran 2022, Meena *et al.* 2023). Additionally, the growing population and evolving consumption patterns have made horticulture an indispensable part of India's agricultural landscape (Nabi and Bagalkoti 2017).

Despite these achievements, the sector faces challenges such as climate change, resource limitations, and the need for better storage and processing facilities. Addressing these issues through sustainable practices, policy support, and increased investment in research and development will be essential to ensure the sector's continued growth and resilience. Given the sector's economic significance and its contribution to India's agricultural GVA, it is crucial to analyze trends in horticultural area, production, and productivity. Understanding these trends will not only help forecast future production but also enable efficient resource management and provide valuable insights for policymakers and stakeholders. By leveraging these insights, India can further strengthen its horticulture sector, ensuring it remains a cornerstone of the country's agricultural and economic development. Although several studies have examined growth trends in horticultural production in India, the systematic forecasting using ARIMA models based on recent datasets remains limited. Therefore, the present study attempts to analyze historical trends and generate long-term forecasts for the horticulture sector in India using ARIMA time-series modelling.

MATERIALS AND METHODS

The present study used time-series data on the area (mha), production (mt), and productivity (t/ha) of India's horticulture sector from 1991–92 to 2023–24. The data were taken from the Horticulture Statistics published by the Department of Agriculture and Farmers Welfare, Government of India. The collected data were analyzed using R software, with a focus on identifying trends, patterns, and seasonality. The initial step involved exploratory data analysis to detect irregularities, assess stationarity, and visualize each variable's movement over time using time-series plots. Thereafter, the Univariate Box-Jenkins Autoregressive Integrated Moving Average (ARIMA) model was used to forecast each variable's future values. The ARIMA model is widely used for time-series forecasting because it can handle various patterns of trend and seasonality in the data. The general form of the ARIMA model, denoted as ARIMA (p, d, q), is as:

$$Y_t = c + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots\ldots.. + \phi_p Y_{t-p} + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \ldots\ldots + \theta_q \epsilon_{t-q} + \epsilon_t$$

Where Y_t, Observed value at time t; c, Constant; ϕ_1, ϕ_2, ..., ϕ_p, Autoregressive coefficients; θ_1, θ_2, ..., θ_q, Moving average coefficients; and ϵ_t, Error term at time t.

Model selection: The appropriate ARIMA model was selected using auto.arima() function in the R software. This function automatically identifies the best-fitting ARIMA model by minimizing the Akaike Information Criterion (AIC). Although auto.arima() provides an automated approach for model identification; the final model selection was further verified through residual diagnostic analysis and examination of parameter significance. The ARIMA model is generally expressed as ARIMA (p, d, q), where, p represents the number of autoregressive terms; d represents the number of non-seasonal differences needed for stationarity; and q represents the number of lagged forecast errors in the prediction equation. Stationarity of the series was assessed during the model identification process using the auto. arima() function in R, which automatically evaluates unit roots and determines the required order of differencing for ARIMA model estimation.

Model diagnostics and forecasting validation: Once the ARIMA model was fitted to each series, its adequacy was evaluated by examining the residuals for autocorrelation. The Box-Pierce test was used to assess whether the residuals from the fitted ARIMA models were independently distributed and behaved as white noise. Although the Ljung-Box test provides a small-sample correction, the Box–Pierce test is widely used in ARIMA diagnostic checking and produces similar results when the sample size is moderate (Box *et al.* 2015). The null hypothesis for the test was that there is no autocorrelation in the residuals, indicating that the model is adequately capturing the data patterns. The test statistic for the Box-Pierce test is:

$$Q = n\sum_{k=1}^{m} r_k^2$$

Where n, Sample size; r_k, Autocorrelation at lag k; and m, Number of lags considered.

Further, the validation of the forecasting performance of the ARIMA models in the accuracy of predicted values was carried out by the measures of Mean Absolute Error (MAE) which measured the average magnitude of the errors in the forecasted values, without considering their direction; Root Mean Squared Error (RMSE) which indicated the square root of the average squared differences between the forecasted and actual values; Mean Absolute Percentage Error (MAPE) which expressed the forecast error as a percentage of actual values; and Standard Error (SE) which represented the standard deviation of forecast errors, providing insight into the variability of the forecast accuracy. These metrics provided a comprehensive evaluation of the model's forecasting accuracy by quantifying the average error, the error relative to the size of the observations, and the overall performance of the model. Mathematically, these matrices are expressed as:

$$MAE = \frac{1}{n}\sum_{i=1}^{n} | F_i - A_i |$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (F_i - A_i)^2}$$

$$MAPE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \left| \frac{F_i - A_i}{A_i} \right|} \times 100$$

$$SE = \sqrt{\frac{\frac{1}{n}\sum_{i=1}^{n} (F_i - A_i)^2}{n}}$$

$$MASE = \frac{MAE}{\frac{1}{n-1}\sum_{i=2}^{n} (A_i - A_{i-1})}$$

Where, F_i is the forecasted value; A_i is the actual value; and n is the number of observations.

RESULTS AND DISCUSSION

Trends in area, production, and productivity of horticulture in India: The horticulture sector in India has witnessed remarkable growth over the past three decades, emerging as a critical component of the country's agricultural economy. The trends in area, production, and productivity of horticulture from 1991–92 to 2023–24 (Fig. 1), revealed a consistent upward trajectory. The area under horticulture expanded from 12.77 mha in 1991-92 to 28.63 mha in 2023–24, reflecting a more than two-fold increase. This expansion may be associated with several factors, including government initiatives to promote horticultural practices, enhancing agricultural diversification, and improving farmer incomes. Programmes such as the National Horticulture Mission (NHM) and the Mission for Integrated Development of Horticulture (MIDH) have played a pivotal role in encouraging farmers to shift from traditional crops to high-value horticultural crops like fruits, vegetables, spices, and flowers (Singh *et al.* 2022, Jaiswal *et al.* 2023 and Yadav *et al.* 2024). Similarly, horticultural production in India surged from 96.56 mt in 1991-92 to 352.23 mt in 2023–24, marking a 3.65-fold increase. Advancements in crop varieties, improved irrigation facilities, and the adoption of modern agricultural practices have driven this growth (Janbandhu *et al.* 2024). The introduction of high-yielding and disease-resistant varieties, production methods, better access to fertilizers and pesticides and marketing facilities has significantly boosted crop productivity (Kumar *et al.* 2023). Moreover, micro-irrigation systems and protected cultivation techniques have further enhanced production efficiency (Singh and Singh 2021 and Kachwaya *et al.* 2024). Similarly, productivity, measured in t/ha, also showed a steady rise from 7.56 t/ha in 1991–92 to 12.30 t/ha in 2023–24. This increase in productivity highlighted the significant impact of technological advancements, improved cultivation practices, and better resource management in the horticulture sector (Agarwal *et al.* 2016). It also underscored the importance of sustainable intensification, which focuses

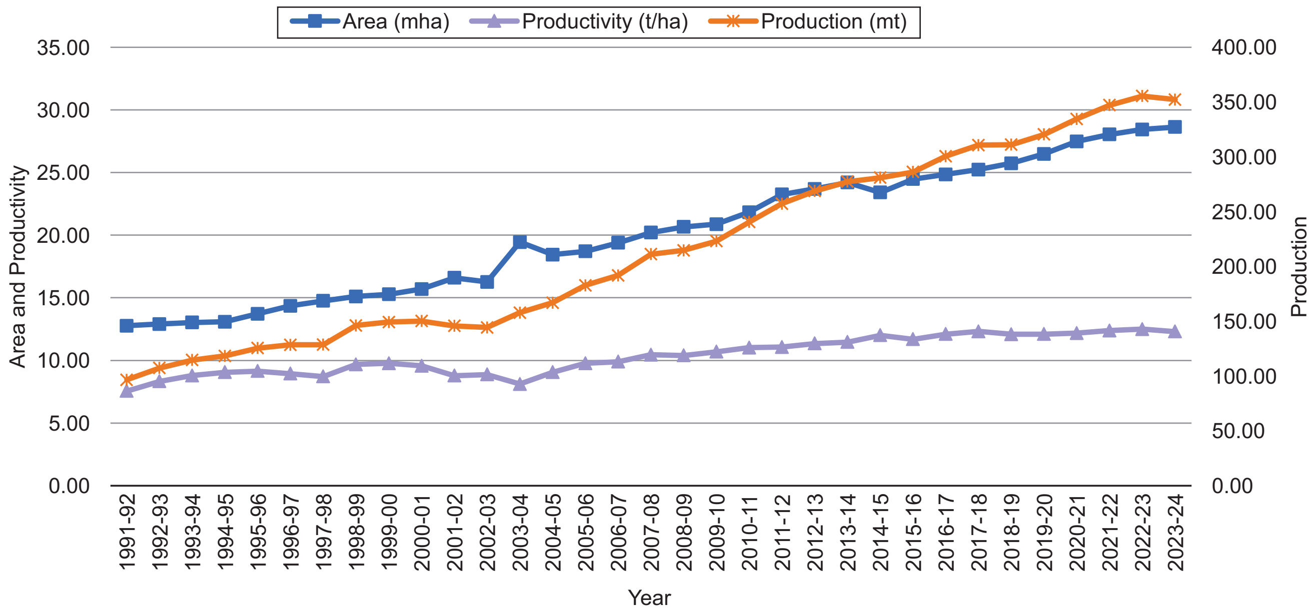

Fig. 1 Trends in area, production and productivity of horticulture in India.
Source: Horticulture Statistics at a Glance (various issues from 1991 to 2024), Department of Agriculture and Farmers Welfare, Government of India

on obtaining higher outputs from the same or smaller land areas without over-exploiting natural resources. Meena *et al.* (2023) suggested that the growth strategy for horticulture should focus on increasing productivity through large-scale cultivation, advanced farming techniques, and better post-harvest management, while also addressing market access and reducing intermediaries through programmes.

Model estimation: The analysis of Indian horticulture trends using ARIMA models revealed insightful patterns in area, production, and productivity, offering a robust basis for future planning and policy interventions. The ARIMA (0,1,1) model for area demonstrated a strong fit, supported by its low Akaike Information Criterion (AIC) value of 62.89 and a high *p*-value (0.960) in the Box-Pierce test, indicating no significant autocorrelation in the residuals (Table 1). This suggested that the model effectively captures the underlying trends in horticultural land use, which is relatively stable with minor fluctuations, as reflected in the low sigma square value of 0.363. Such stability implies that the area under horticulture is less susceptible to abrupt changes, making it a reliable factor for long-term planning. Similarly, for production, the ARIMA (0,1,0) model also performed well, with an AIC value of 212.45 and a *p*-value of 0.799 in the Box-Pierce test, confirming the model's adequacy. However, the high sigma square value of 40.77 highlighted significant variability in production. This variability is likely driven by external factors such as unpredictable weather patterns, fluctuations in input availability, and market dynamics (Gora *et al.* 2019; Ningi *et al.* 2019 and Tiwari *et al.* 2021). These findings underscore the need for targeted interventions, such as improved irrigation infrastructure, better pest management, and climate-resilient farming practices, to mitigate risks and stabilize production levels. Further, productivity modeled using ARIMA (0,1,0), showed a similar strong fit, with an AIC value of 36.70 and a *p*-value of 0.687, indicating well-specified residuals. The low sigma square value of 0.168 suggested that productivity is relatively stable, with minor fluctuations over time. This stability reflected the consistent adoption of improved agricultural practices and technologies. These findings underscore the importance of continued investment in research and development to further enhance productivity while addressing challenges like climate change and resource constraints.

Forecasting using ARIMA models: Over the past three decades, the area under horticulture increased by 2.24 times, rising from 12.77 mha in 1991–92 to 28.63 mha in 2023–24 (Fig. 1). Similarly, production witnessed an even more remarkable growth, surging by 3.65 times from 96.56 mt to 352.23 mt during the same period. This substantial growth underscored the increasing importance of horticulture in India's agricultural landscape and its contribution to food security and economic development. The forecasts generated using ARIMA models (Table 2) indicated that this upward trajectory is expected to continue over the next few decades. The area under horticulture is projected to increase by 1.49 times, reaching 29.82 mha by 2025–26, 32.41 mha by 2030–31, 37.49 mha by 2040–41, and 42.77 mha by 2050–51. Correspondingly, production is forecasted to grow by 1.61 times, rising to 368.21 mt by 2025-26, 408.16 mt by 2030–31, 488.05 mt by 2040-41, and 567.25 mt by 2050–51. These projections highlighted not only the expansion of horticultural land but also the sector's increasing efficiency and output. Similarly, productivity, a critical measure of resource efficiency, is expected to improve, although at a slower pace. From 2023–24 to 2051–52, productivity is forecasted to increase by 1.05 times, reaching 16.30 t/ha by 2050–51. This rise in productivity reflected the potential for further intensification and optimization of horticultural practices through technological advancements, better resource management, and innovative farming techniques. The forecasts suggested that while the area under horticulture would continue to expand, the increase in production would outpace it, indicating improved efficiency and sustainability in the sector. It should be noted that long-term forecasts extending up to 2050–51 are subject to uncertainty due to potential structural changes in technology, climate conditions, policy frameworks, and market dynamics which may influence future trends beyond the patterns captured in historical data. Overall, the forecasts painted an optimistic future for India's horticulture sector, positioning it as a key player in global agricultural markets while contributing to the nation's food and nutritional security and economic growth.

Diagnostic checking: The accuracy of the forecasts generated by the ARIMA models for area, production, and productivity in Indian horticulture was thoroughly evaluated through residual analysis. The results presented in Table 3, demonstrated that the models performed exceptionally well in capturing the underlying trends and producing reliable forecasts. The Mean Error (ME) values for area (-0.033), production (0.003), and productivity (0.0002) were found to be very close to zero, indicating that the models exhibited minimal bias in their predictions. This suggested that the forecasts were not systematically overestimating

Table 1 ARIMA model estimates for area, production and productivity of horticulture in India

Series	Model	Parameter		Sigma square	Log likelihood	aic value	Box-Pierce Test	
		AR(1)	MR(1)				Test statistic	*p*-value
Area	ARIMA (0,1,1)	-	-0.676 (0.2194)	0.363	-28.44	62.89	0.625	0.960
Production	ARIMA (0,1,0)	-	-	40.770	-104.23	212.45	1.651	0.799
Productivity	ARIMA (0,1,0)	-	-	0.168	-16.35	36.70	2.267	0.687

The figure in parenthesis of parameter is the value of the standard error.

Table 2 Forecast for area, production and productivity of horticulture in India

Year	Area (mha)	Production (mt)	Productivity (t/ha)
2025–26	29.82	368.21	12.35 (12.60)
2030–31	32.41	408.16	12.59 (13.34)
2040–41	37.59	488.05	12.98 (14.82)
2050–51	42.77	567.95	13.28 (16.30)

The values in parentheses represent productivity calculated from projected area and production, whereas the values inside parentheses represent productivity forecasts obtained directly from the ARIMA model.

or underestimating the actual values, which is a critical indicator of model reliability. The Root Mean Square Error (RMSE) values further supported the models' accuracy. For area, the RMSE was 0.574, while for production and productivity, the values were 6.189 and 0.397, respectively. These relatively low RMSE values indicated that the forecast errors were small, meaning the models were able to capture the variability in the data effectively without significant deviations from the actual observed values. This was particularly important for production, which exhibited higher variability due to external factors such as weather conditions and market fluctuations. Despite this, the ARIMA model managed to produce forecasts with reasonable precision. Similarly, the Mean Absolute Error (MAE) values reinforced the models' reliability. The MAE for the area was 0.410, for production, it was 5.031, and for productivity, it was 0.295. These low MAE values indicated that the forecasts were consistently close to the actual values, with minimal errors in predicting future trends. This was a strong indication that the models were well-suited for forecasting horticultural trends, as they consistently provided accurate predictions. The Mean Absolute Percentage Error (MAPE) values further highlighted the models' effectiveness. The MAPE for area was 2.169%, for production it was 2.648%, and for productivity, it was 3.046%. These low percentages indicated that the deviations between the forecasted and actual values were minimal, with the models capturing the trends with high accuracy. This was particularly impressive given the inherent variability in horticultural data, especially

Table 3 Forecast evaluation using ARIMA residuals

Year	Area	Production	Productivity
ME	-0.033	0.003	0.0002
RMSE	0.574	6.189	0.397
MAE	0.410	5.031	0.295
MPE	-0.470	-0.273	-0.027
MAPE	2.169	2.648	3.046
MASE	0.653	0.588	0.885

ME, Mean error; RMSE, Root mean square error; MAE, Mean absolute error; MAPE, Mean absolute percentage error; MASE, Mean absolute scaled error.

in production, which is often influenced by unpredictable factors. Additionally, the Mean Absolute Scaled Error (MASE) values provided further evidence of the models' superiority over simpler baseline models. The MASE values for area (0.653), production (0.588), and productivity (0.885) were all below 1, indicating that the ARIMA models outperformed naive forecasting methods. This strengthened the reliability of the forecasts and underscored the models' ability to provide accurate and actionable insights for future planning in the horticulture sector.

The study highlights a substantial expansion in the horticulture sector from 1991–92 to 2023–24, with area increasing from 12.77 mha to 28.63 mha and production from 96.56 mt to 352.23 mt. This growth reflected the concerted efforts of farmers, policymakers, and supportive government interventions. The ARIMA (Auto Regressive Integrated Moving Average) model effectively captured trends and projected continued growth, with area, production, and productivity expected to reach 42.77 mha, 567.25 mt, and 16.30 t/ha, respectively, by 2050–51. These projections underscored the immense potential of the horticulture sector to contribute to India's economic development, food security, and rural livelihoods. However, realizing this potential will require sustained investment in innovation, infrastructure, and capacity-building. For instance, expanding cold storage facilities, improving supply chain logistics, and promoting value addition through food processing can help reduce post-harvest losses and increase farmers' incomes. Similarly, adopting climate-resilient practices and leveraging digital technologies can enhance the sector's adaptability to changing environmental conditions. Moreover, diversifying agriculture toward high-value horticultural crops can improve nutritional outcomes by increasing the availability of fruits, vegetables, and other nutrient-dense produce. Overall, the study highlighted the transformative impact of horticulture on India's agricultural landscape. The sector is poised to play a pivotal role in ensuring food security, enhancing rural prosperity, and driving sustainable development with continued support and strategic interventions.

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