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A Multi-Decadal Review Of Sugarcane Sector Dynamics In India: Growth Trends, Influencing Factors, And Policy Implications

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Abstract
This study offers an extensive examination of the Indian sugarcane industry spanning six decades, from 1964–65 to 2023–24. It fills a significant void in the current research by measuring historical growth tendencies and integrating them with modern technological, environmental, and socio-economic aspects. Using Compound Annual Growth Rate (CAGR) and correlation analysis on official time-series data, the research demonstrates a fundamental shift in the sector's growth trajectory: an initial period of area-led expansion gave way to a modern, productivity-driven model. The results indicate an almost perfect positive connection between area and production (r=0.993) and a robust positive link between productivity and production (r=0.911). The data reveals notable regional inequalities, with northern governments prioritizing area development, whilst southern states attain greater production through enhanced water-use efficiency and mechanization.
Keywords: *Sugarcane, India, CAGR, Productivity, Correlation Analysis, Regional Disparities*

1. INTRODUCTION

Sugarcane (*Saccharum officinarum L.),* indigenous to New Guinea (Daniels & Daniels, 1993), is a crop of global importance, farmed over approximately 27 million hectares in over 120 countries (Birthal et al., 2015; South African Sugar Association, 2022). Its significance beyond sugar production, encompassing a diverse range of high-value by-products, including ethanol, paper, and electricity, which are essential for economic development and diversification (Dotaniya et al., 2016; Santos et al., 2020). India, as a significant agricultural powerhouse, occupies a dominant position in the global sugarcane market, affecting international supply and pricing dynamics. The nation is the world's second-largest producer, trailing only Brazil, and the largest consumer of sugar (FAO, 2023). India constitutes 23% of world sugarcane production (FAO, 2022), and the strategic importance of its industry is heightened by its profound socio-economic foundations. The sector directly engages almost 7.5% of the rural population in cultivation and related activities, comprising around 45 million sugarcane farmers and their dependents, along with a substantial agricultural workforce (Gupta et al., 2020).

Despite achieving remarkable output levels, the sugarcane sector in India confronts a significant challenge: stagnant productivity (Wageningen University & Research, 2022). This problem is especially severe due to the restricted potential for increasing the cultivated land area (Raju & Kiran Kumar, 2019). To satisfy the anticipated domestic demand for sugar and ethanol, estimated to necessitate approximately 520 million tonnes of sugarcane by 2030, a significant enhancement in per-hectare productivity is essential—from the current average of roughly 70 tonnes per hectare to about 100-110 tonnes per hectare (Wageningen University & Research, 2022). This is not solely an economic objective but a national necessity for food and energy security. The difficulty is exacerbated by other intricate elements, such as escalating water scarcity, unpredictable monsoons, extreme weather events induced by climate change, and the surge of pests and illnesses (Mercer, 2020; Upadhyay, 2021). The future growth of the sector is further complicated by socio-economic hurdles, such as market volatility, price regulations (Sharma & Thakur, 2005), and labor shortages, which can destabilize production and farmer livelihoods. In India, sugarcane is a "politically sensitive" crop, indicating that policy decisions affecting farmers might result in substantial changes in cropping patterns and rural economic stability

(Gupta et al., 2020). Consequently, tackling the productivity challenge is crucial for guaranteeing the long-term profitability and sustainability of the entire sector.

Research Objectives

1. To examine the long-term growth patterns of sugarcane acreage, production, and productivity in India over a span of six decades (1964-65 to 2023-24).
2. To analyze the statistical correlations among essential cultivation indicators to identify the principal determinants of output growth.
3. To contextualize these trends and correlations by incorporating current discoveries on technological, environmental, and socio-economic issues.
4. To furnish evidence-based policy, managerial, and academic implications to promote sustainable growth in the sector.

2. LITERATURE REVIEW

2.1. A Multi-Decadal Analysis of Sugarcane Trends in India

The historical development of sugarcane industry demonstrates a clear change in its growth factors. During the initial stages of agricultural growth, increases in productivity were mostly driven by the extension of cultivated land (Raju & Kiran Kumar, 2019). This trend is a prevalent feature of developing economies where land resources are plentiful and readily available for cultivation.Existing studies confirm that this model of area-driven growth, while effective for a time, eventually reached its limits as land availability plateaued (Birthal et al., 2015; Chand & Raju, 2009). The sector then transitioned toward a productivity-led growth model, evidenced by continued output increases despite a relatively unchanged or slightly increasing area under cultivation (Raju & Kiran Kumar, 2019). This alteration in growth dynamics is essential and is reflected in the varied performance of several regions around the country. A national-level approach, although beneficial for identifying macro patterns, may mask the inherent variability. The northern states, especially Uttar Pradesh, excel in cultivated area yet have consistently exhibited lower average production (MoA & FW, 2024). Conversely, southern states like as Maharashtra and Tamil Nadu, although possessing smaller farmed lands, have attained markedly greater yields per hectare, frequently exceeding national averages (Kamble et al., 2019; MoA & FW, 2024). This geographical variance underscores that the national average is not a homogeneous metric butrather a composite of varied regional results, each influenced by different factors and facing unique challenges.

2.2. Factors Influencing and Limiting Sugarcane Cultivation

The development of India's sugarcane sector is a direct consequence of a complex interaction among technical adoption, environmental concerns, and policy frameworks.

Technological Advancements

Contemporary agricultural methods have proved crucial in improving productivity. The use of sophisticated irrigation systems, including drip and sprinkler methods, has proven especially beneficial in water-scarce areas such as Maharashtra and Tamil Nadu, significantly enhancing water-use efficiency and increasing yields (Kamble et al., 2019; Wageningen University & Research, 2022). Likewise, the growing mechanization of farming and harvesting in regions such as Karnataka and Maharashtra has diminished reliance on manpower and decreased crop losses (Kamble et al., 2019). The advancement of enhanced seed types has greatly influenced the favorable yield trends noted in recent decades (Gupta et al., 2020). In addition to conventional techniques, precision agriculture technologies, including remote sensing and drones, are currently employed for the early identification of pests and diseases, facilitating timely interventions (Li, 2024; Waters et al., 2024).

Climatic and Environmental Challenges

The sector's vulnerability to climate change is a major concern. Sugarcane, as a water-intensive crop, is especially vulnerable to water scarcity and unpredictable monsoons (Wageningen University & Research, 2022). Severe weather phenomena, such as droughts, floods, and heatwaves, can significantly impair crops at essential growth stages, resulting in diminished yields and erratic production (Msomba et al., 2021; Sorvali et al., 2021). The increase of pests and diseases, including red rot disease and shoot borers, presents a considerable challenge, often intensified by shifting climatic circumstances (Bordonal et al., 2018; January et al., 2020).

Policy and Socioeconomic Factors

Government policies significantly influence the sector's performance. Pricing strategies, such as the Fair and Remunerative Price (FRP) system, are crucial for securing farmer income and maintaining agricultural production (Sharma & Thakur, 2005). However, market instability and price regulations can make the sector vulnerable, as seen in past periods of production contraction (Raju & Kiran Kumar, 2019). Furthermore, the industry faces unexpected socio-economic issues. For instance, research indicates that the physically demanding work of sugarcane harvesting, particularly under hot conditions, can lead to chronic health issues for agricultural laborers, such as kidney injury (Hossain et al., 2019; Parajuli et al., 2020). This raises a critical point: the long-term sustainability of the sector must encompass not only economic and environmental viability but also the health and social well-being of its workforce. This perspective broadens the scope of "sustainability" beyond traditional metrics, making it a truly holistic concept.

2.3. Methodological Approaches and Research Gap

The analysis of agricultural growth rates commonly employs Compound Annual Growth Rate (CAGR) and correlation analysis (Birthal et al., 2015; UNCTAD, 2022). While these methods provide a straightforward way to quantify long-term trends and relationships, they possess certain limitations. A significant deficiency of the traditional CAGR model is its reliance on a linear, exponential growth assumption, which is often unrealistic for agricultural data that is constrained by finite resources (A New Methodology for Computing Compound Growth Rate, n.d.). This can lead to flawed interpretations and an inaccurate representation of the underlying growth dynamics (A New Methodology for Computing Compound Growth Rate, n.d.). A key research gap exists in integrating a robust quantitative analysis with a comprehensive qualitative synthesis of the complex drivers affecting the sector. This study addresses this gap by applying these standard methodologies while acknowledging their limitations and contextualizing the findings with recent scientific and socio-economic literature. This approach provides a more nuanced and accurate portrayal of the sector's evolution and offers a more solid foundation for future research.

3. METHODOLOGY

3.1. Data Collection and Sources

This study is based on a comprehensive analysis of secondary time-series data covering the period from 1964–65 to 2023–24. Data on sugarcane area, production, and productivity were meticulously collected from various official government publications and records, including the Ministry of Agriculture and Farmers Welfare (MoA & FW), the Ministry of Commerce and Industry, and the official publication *Agricultural Statistics at a Glance* (Gupta et al., 2020). To provide a rich contextual background and validate trends, this primary dataset was supplemented with insights and data points from recent Scopus-indexed literature, including reports from the USDA and the OECD, as well as academic journals specializing in agricultural economics and agronomy (OECD & FAO, 2021; Wageningen University & Research, 2022).

3.2. Analytical Methods

The study employed two primary statistical methods to achieve its objectives:

3.2.1. Compound Annual Growth Rate (CAGR): The CAGR method was used to assess the long-term growth trends of sugarcane area, production, and productivity across six distinct decades (Raju & Kiran Kumar, 2019). This metric provides a smoothed average annual growth rate, assuming compounding over the period, which is useful for observing macro-level changes in the sector's trajectory.

$CAGR = ((EY/BY)^{(1/N)}) - 1$

Where,

EY: Ending Year

BY: Beginning Year

N: No. of years CAGR to be calculated

3.2.2. Correlation matrix: The correlation matrix is a statistical tool used to assess the strength and direction of linear relationships between multiple variables. In this research, it is employed to analyze key sugarcane performance indicators—namely, area under cultivation, total production, and productivity. By examining the correlation matrix, the study provides a clear and concise understanding of how these variables are interrelated, revealing the extent to which changes in one metric are associated with changes in the others.

Each cell in the matrix displays the correlation coefficient (ranging from -1 to +1), where:

- +1 indicates a perfect positive linear relationship,
- 0 indicates no linear relationship, and

- -1 indicates a perfect negative linear relationship.

The methodology is designed to be fully transparent and replicable. All analyses were performed using standard statistical software, ensuring that the results can be verified and reproduced by other researchers. While the study employs these foundational methods, it is recognized that for future research, more advanced time-series modeling techniques, such as the logistic or Gompertz models, which account for finite resource constraints, or machine learning models like Long Short-Term Memory (LSTM), could be used for more accurate long-term forecasting (A New Methodology for Computing Compound Growth Rate, n.d.; Time Series and Artificial Intelligence Models, 2020).

4. RESULTS AND DISCUSSION

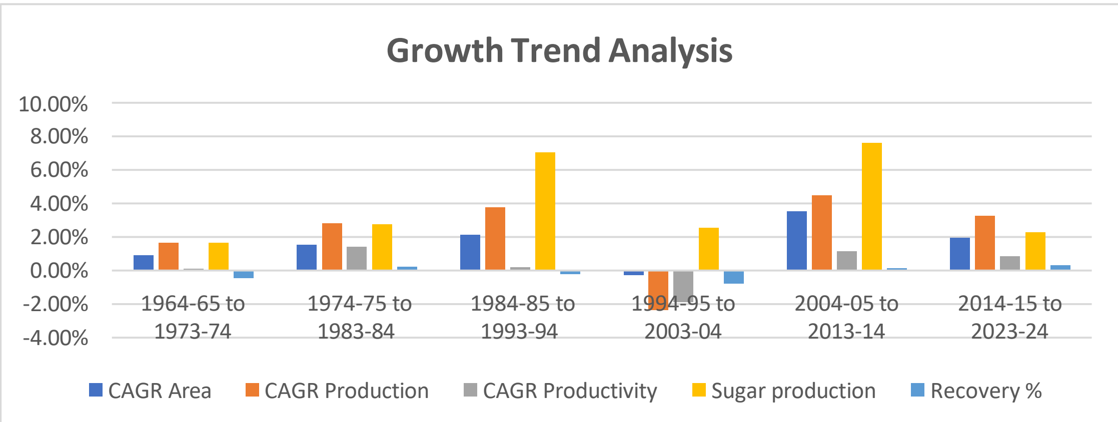
4.1. Long-Term Growth Trends Analysis

Over the past six decades, India's sugarcane sector has undergone significant structural transformations, as reflected in the decadal CAGRs presented in Table 1.

Table 1. Decadal Compound Annual Growth Rates of Sugarcane Area, Production, and Productivity in India (1964–65 to 2023–24)

Year	Area (M ha)	CAGR Area	Production (MMT)	CAGR Production	Productivity (Tons /ha)	CAGR Productivity
1964-65 to 1973-74	2.22	0.92%	108	1.66%	57.00	0.11%
1974-75 to 1983-84	2.68	1.53%	149	2.81%	62.60	1.42%
1984-85 to 1993-94	3.18	2.15%	205	3.76%	70.10	0.20%
1994-95 to 2003-04	4.02	-0.25%	273	-2.36%	67.60	-1.85%
2004-05 to 2013-14	4.40	3.54%	305	4.49%	68.70	1.14%
2014-15 to 2023-24	4.90	1.94%	388	3.26%	77.40	0.87%

Figure:1. Decadal CAGR of Sugarcane Area, Production, and Productivity in India (1964–65 to 2023–24)



The data from the initial two decades (1964–65 to 1983–84) clearly show that growth in production was primarily fueled by area expansion, with productivity gains remaining modest (Reddy & Bantilan, 2001). This trend is consistent with historical observations that early agricultural growth in India was input-driven rather than efficiency-driven. A significant shift occurred in the subsequent decade (1974–75 to 1983–84), with the advent of the Green Revolution's influence, leading to more substantial gains in productivity (Raju & Kiran Kumar, 2019). This period reflects the early impacts of improved seed varieties, better irrigation, and increased fertilizer use.

The period from 1994–95 to 2003–04 was marked by a notable contraction, with all three indicators recording negative CAGRs. This decline has been linked in the literature to a combination of adverse policy conditions, unremunerative market prices, and a possible combination of drought and pest outbreaks (Sharma & Thakur, 2005; Raju & Kiran Kumar, 2019). The sector rebounded sharply in the decade from 2004–05 to 2013–14, demonstrating robust growth in all three metrics, likely due to institutional support, favorable market conditions, and improved ratoon management practices (ICAR-Sugarcane Breeding Institute, 2012; SBI, 2014). The most recent decade (2014–15 to 2023–24) shows a more stable and balanced growth pattern, with both area and productivity contributing to production increases (Kamble et al., 2019). This suggests that modern interventions, such as precision farming techniques and better pest control, are having a cumulative effect on the sector's performance (Singh & Pujan, 2014).

4.2. Statistical Relationships and Driving Factors

The analysis of the correlation matrix reveals the strong interdependencies among the key cultivation variables, as presented in Table 2.

Table 2. Correlation Matrix of Key Sugarcane Cultivation Indicators

Particulars	Area (Mha)	Production (MMT)	Productivity (tons /ha)
Area (Mha)	1		
Production (MMT)	0.99344242	1	
Productivity (tons /ha)	0.878241993	0.911130917	1

The correlation coefficient between area and production is extremely high (r=0.993), indicating a near-perfect positive linear relationship. This confirms that, historically, the expansion of cultivated area has been the dominant driver of increased production (Chand & Raju, 2009). The correlation between productivity and production is also very strong (r=0.911), which suggests that as the sector matures, improvements in per-hectare yield are playing an increasingly vital role in boosting overall output (Birthal et al., 2015). The strong relationship between productivity and production is not a coincidence but rather a direct consequence of strategic interventions. The literature indicates that the increased adoption of modern technologies like drip irrigation and the implementation of effective extension services have been crucial in driving these yield gains (Kamble et al., 2019; Wageningen University & Research, 2022). The moderate-to-strong correlation between area and productivity (r=0.878) is also notable. It indicates that while larger areas are being cultivated, productivity gains do not always increase proportionally, which can be attributed to regional disparities in input access and the uneven adoption of advanced agronomic practices across the country (Singh & Pujan, 2014).

4.3. Regional Disparities and the Productivity Imperative

A crucial finding is that the national growth trends are an aggregation of highly disparate regional performances. As demonstrated in Table 3, a comparison of key states highlights this regional heterogeneity.

Table 3. Comparative Sugarcane Productivity Metrics: India vs. Key States (Last 5 years)

Region/State	Cultivated Area (M ha)	Production (MMT)	Productivity (tons/ha)
India (National Avg.)	5.74	453.16	77.84
Uttar Pradesh	2.30	188.26	81.5
Maharashtra	1.12	46.509	88.01
Tamil Nadu	0.15	15.461	104.5

Source: MoA & FW (2024)

In the above table, based on the five-year average, Uttar Pradesh remains the dominant sugarcane-growing state, accounting for about 40 percent of the total cultivated area (2.30 M ha) and nearly 41 percent of national production (188.26 MMT). Its productivity level of 81.5 tons/ha is only slightly above the national average of 77.84 tons/ha, reflecting that its leadership is largely area-driven. Maharashtra, on the other hand, contributes around 19.5 percent of the area (1.12 M ha) but only 10.3 percent of production (46.51 MMT), despite achieving a relatively higher productivity of 88.01 tons/ha. This imbalance indicates that limited area under cultivation, coupled with climatic fluctuations, restricts its overall output. Tamil Nadu, with the smallest share of area (2.6 percent; 0.15 M ha) and production (3.4 percent; 15.46 MMT), distinguishes itself with the highest productivity (104.5 tons/ha), well above the national average.

These stark differences are rooted in region-specific factors. States with lower productivity often face issues of water stress, limited access to modern technologies, and a higher reliance on traditional farming methods (Wageningen University & Research, 2022). Conversely, states with high productivity have successfully implemented scientific and institutional innovations, such as drip irrigation, which significantly enhances water-use efficiency (Kamble et al., 2019). This analysis confirms that addressing these regional disparities is the most critical lever for achieving the national productivity targets and securing the sector's future.

5. Conclusion, Implications, and Future Research

5.1. Summary

This comprehensive analysis confirms a significant evolution in India's sugarcane sector. The study's primary findings are threefold: first, the sector has transitioned from a growth model driven by area expansion to one increasingly dependent on per-hectare productivity gains. Second, this shift is statistically validated by the strong correlations between area, production, and productivity. Finally, the analysis reveals a critical disconnect between high-area northern states and high-productivity southern states, underscoring the importance of regional factors in shaping the sector's overall performance. Ultimately, the future of the Indian sugarcane sector lies squarely in a productivity-led growth model.

5.2. Policy and Managerial Implications

The findings carry significant implications for policymakers and industry leaders seeking to foster sustainable growth.

Policy Recommendations

Targeted Interventions: The presence of regional disparities necessitates a move away from uniform national policies toward location-specific interventions that address the unique challenges of each region. Policymakers should focus on incentivizing yield improvements rather than mere area expansion.

Sustainable Resource Management: Given the increasing water scarcity and the sector's high water consumption, policies must prioritize the widespread adoption of water-conserving technologies like drip and sprinkler irrigation, citing the proven success in states like Maharashtra and Tamil Nadu (Kamble et al., 2019; Wageningen University & Research, 2022).

Climate Resilience: To mitigate the threats of climate change, the government should invest in the development of climate-resilient sugarcane varieties and promote integrated pest and disease management (IPDM) strategies (Mercer, 2020).

Market and Farmer Support: To maintain farmer interest and reduce market volatility, policies should ensure timely cane payments and a more efficient and effective Fair and Remunerative Price (FRP) system (Sharma & Thakur, 2005).

Managerial Implications

Technological Investment: Sugar mills and other industry stakeholders should invest in modern technologies, including mechanization and precision agriculture tools like remote sensing and drones for early pest and disease detection (Li, 2024; Waters et al., 2024).

Value-Chain Diversification: To build resilience against market fluctuations and enhance profitability, companies should actively diversify their value chains by expanding into ethanol production and other high-value by-products (Dotaniya et al., 2016).

Worker Welfare: The industry must address the under-explored issue of worker health and safety, particularly the risk of kidney injury from physically demanding harvesting work (Hossain et al., 2019; Parajuli et al., 2020).

5.3. Academic Implications and Future Research

This study contributes to the academic literature by providing a multi-decadal, data-driven analysis that integrates quantitative trends with a holistic view of the underlying drivers. For future research, it is recommended to move beyond traditional linear models to employ more sophisticated time-series models, such as the logistic or Gompertz models, which are better suited for analyzing agricultural data with finite resource constraints (A New Methodology for Computing Compound Growth Rate, n.d.). Additionally, machine learning algorithms like Long Short-Term Memory (LSTM) could be utilized for more accurate long-term production and yield forecasting (Time Series and Artificial Intelligence Models, 2020). A deeper understanding of the sector would also benefit from granular, micro-level studies that investigate the socio-economic and policy factors at the district or village level. Finally, primary research is needed to address the under-explored issue of the health and safety of sugarcane workers, a critical aspect of the sector's long-term sustainability that extends beyond traditional economic metrics (Hossain et al., 2019; Parajuli et al., 2020).

5.4. Limitations of the Study

The study acknowledges its primary limitation in relying on secondary data, which may not fully capture the complexity and nuanced realities at the farm level. While the analysis provides a comprehensive macro-level perspective, more detailed, primary data would be needed to establish definitive causal links between specific interventions and their on-the-ground outcomes.

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