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Comprehensive Analysis of Sugarcane Production and Productivity: Historical Trends, Growth Dynamics, and Statistical Modeling

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***Abstract*— This study provides a comprehensive examination of sugarcane production and productivity in India from 2000-01 to 2022-23, utilizing advanced statistical methods, including regression analysis, rank correlation, and productivity modeling. The findings reveal that Uttar Pradesh, Maharashtra, and Karnataka are the leading contributors to India's sugarcane output, with Tamil Nadu achieving the highest yield per hectare despite its smaller cultivation area. Globally, Brazil and India dominate production, with Brazil exhibiting superior efficiency. The study identifies significant fluctuations in growth rates and productivity, highlighting the necessity for region-specific strategies to enhance yields. Additionally, the correlation between inflation rates and sugarcane prices is analyzed, indicating the impact of macroeconomic variables on agricultural commodities. Insights from this study are vital for policymakers and industry stakeholders aiming to optimize sugarcane production and ensure sustainability within the sector.**

***Keywords*— sugarcane; growth rate; productivity; yield; production; regression coefficient; rank correlation**

I. INTRODUCTION

A. Overview

Sugarcane (Saccharum officinarum L.) is a vital tropical crop that holds substantial economic importance, particularly in global agriculture. It plays a crucial role in ensuring food security and renewable energy production through ethanol. Understanding the dynamics of sugarcane production is essential for addressing sustainable agricultural practices and meeting the increasing demand for sugar and its by-products.

B. Historical Background

The cultivation of sugarcane dates back over 2,000 years, originating in Southeast Asia. Its global spread was facilitated by trade routes and colonial expansion, leading to significant advancements in agricultural techniques. Over the centuries, sugarcane agriculture has evolved from manual harvesting to modern mechanized irrigation practices, profoundly shaping the global sugarcane industry in major producing regions [3].

C. Key Contributions

Recent research has provided critical insights into various aspects of sugarcane production. For instance, Greeshma et al. (2007) advanced growth modeling by applying mathematical techniques to examine trends in sugarcane cultivation and productivity within coastal Andhra Pradesh. Kumar et al. (2022) developed mathematical models that specifically analyze sugarcane production trends across India. Gupta et al. (2020) established a robust foundation in mathematical statistics, facilitating regression and correlation analyses that identify significant relationships between cultivation area and production levels at both regional and global scales [6].

D. Methodology

This study employs a rigorous quantitative research design to analyze historical data on sugarcane production and productivity in India from 2000-01 to 2022-23. Data were collected from reliable sources, including the Ministry of Agriculture and Farmers' Welfare, and relevant scholarly articles, encompassing historical production records and economic data such as inflation rates.

A simple linear regression model is utilized to explore the relationship between sugarcane production and cultivation area. Additionally, Spearman's rank correlation coefficient is calculated to assess the strength and direction of the relationship between sugarcane cultivation area and production across various Indian states and union territories. The methodology also investigates the correlation between inflation rates and sugarcane prices to emphasize the impact of macroeconomic factors on

agricultural commodities. Results from the analyses are presented through comprehensive tables and charts to facilitate understanding and support decision-making processes among policymakers and stakeholders in the sugarcane industry.

E. Research Objectives

The primary objective of this study is to assess the relationship between sugarcane cultivation area and production through the use of Spearman's rank correlation coefficient, which will illustrate the strength and direction of this association across Indian states and union territories. Furthermore, the study aims to investigate the influence of cultivation area on sugarcane production using a simple linear regression model. Another key objective is to analyze how inflation rates impact sugarcane prices, thereby highlighting the role of macroeconomic factors in shaping agricultural commodity markets. This mathematical framework serves as a vital tool for predicting production trends, optimizing resource management, and providing actionable insights to enhance productivity in underperforming regions, ultimately supporting sustainable growth in the global sugarcane sector.

This study aims to contribute valuable insights into optimizing sugarcane production and promoting sustainable agricultural practices, addressing both global and regional challenges.

II. MATHEMATICAL ASPECTS OF STATISTICAL ANALYSIS FOR SUGARCANE PRODUCTION AND PRODUCTIVITY

The percentage share of a country in sugarcane production or area can be calculated using the formula:

$$\text{Percentage share by the country} = \frac{\psi_i}{\psi_T} \times 100$$

Where,

ψ_i = Production or area of the i^{th} (country or state)

ψ_T = Total sugarcane production of the whole world or state

Productivity: Productivity measures the efficiency of converting inputs into outputs and is calculated as:

$$\text{Productivity} = \frac{\text{Total Production (in Kg)}}{\text{Total Area (in hectare)}}$$

[3,10].

TABLE I
OVERVIEW OF SUGARCANE AREA, PRODUCTION, AND YIELD IN INDIAN STATES AND UNION TERRITORIES (2022-23):

S.No.	States/ UT	Area M Hect	%age of Total Area	Production M Tones	%age of Total Production	Yield Tonnes/ ha.
1	Uttar Pradesh	2.74	46.52%	225.22	45.57%	82.31
2	Maharashtra	1.36	23.09%	123.97	25.08%	91.2
3	Karnataka	0.69	11.71%	62.46	12.64%	90
4	Bihar	0.21	3.57%	12.06	2.44%	57.46
5	Gujarat	0.19	3.23%	14.69	2.97%	76.5
6	Tamil Nadu	0.16	2.72%	16.92	3.42%	104.78
7	Madhya Pradesh	0.09	1.53%	6.45	1.31%	70.05
8	Haryana	0.11	1.87%	8.86	1.79%	82.23
9	Punjab	0.09	1.53%	7.64	1.55%	84.69
10	Uttrakhand	0.05	0.85%	3.76	0.76%	80
11	Andhra Pradesh	0.04	0.68%	3.12	0.63%	78.04
12	Telangana	0.03	0.51%	2.64	0.53%	79.85
13	West Bengal	0.02	0.34%	1.48	0.30%	80
14	Others	0.11	1.87%	4.96	1.00%	47.78
	All India	5.89	100.00%	494.23	100.00%	84.01

Source-E&S, DAC, New Delhi, 3rd Adv. Est.-2022-23, [10, 11].

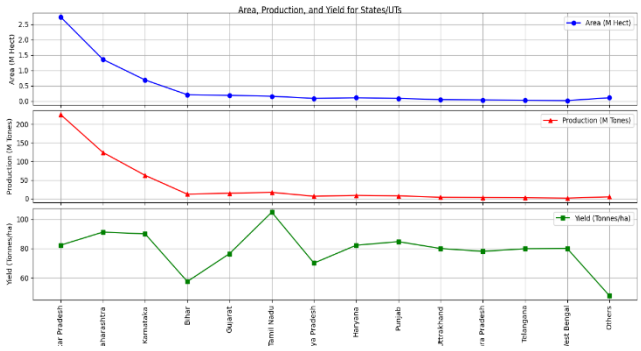

Figure 1. 2D graph of table1

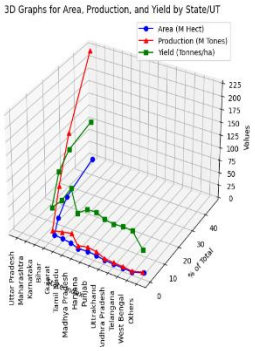

Figure 1. This 3D graph shows Uttar Pradesh has major production and Tamil Nadu has a high yield in 2022-23.

These graphs show the highest production and area for Uttar Pradesh and the highest yield for Tamil Nadu which has a smaller area.

A. Insight from Table I

1) State-wise Analysis of Sugarcane Cultivation in India: The data in Table 1 offers an in-depth state-wise analysis of sugarcane cultivation, with a focus on the area harvested, total production, and yield per hectare. Uttar Pradesh, the largest contributor to India's sugarcane sector, dominates both the area under cultivation and total production. This prominence is largely due to favorable climatic conditions and the state's established agricultural practices. However, productivity data highlights higher efficiency in Maharashtra and Karnataka, where advanced irrigation infrastructure and modern farming techniques allow for greater yield per hectare, despite smaller cultivation areas.

A critical observation is the variability in productivity across states, with regions like Tamil Nadu and Andhra Pradesh experiencing fluctuations due to adverse weather conditions and water scarcity. These findings suggest that while northern states, particularly Uttar Pradesh, lead in total production, western and southern regions are more efficient in productivity. This indicates a potential for targeted agricultural interventions, especially in underperforming states, to boost productivity across India.

TABLE II

COMPARATIVE ANALYSIS OF GLOBAL SUGARCANE PRODUCTION AND CULTIVATION:

S.No.	Country	Production M Tonnes	%age Share of the country	Area M Hect	%age Share of the country
1	Brazil	613	29.52%	9.2	35.38%
2	India	494.23	23.80%	5.1	19.62%
3	Thailand	131	6.31%	1.8	6.92%
4	China	110	5.30%	1.4	5.38%
5	Pakistan	66.9	3.22%	1	3.85%
6	Mexico	59.3	2.86%	0.79	3.04%
7	Colombia	32.7	1.57%	0.48	1.85%
8	Australia	32.4	1.56%	0.46	1.77%
9	Indonesia	29.1	1.40%	0.44	1.69%
10	Guatemala	29.1	1.40%	0.43	1.65%
11	United States	29	1.40%	0.37	1.42%
12	Philippines	20.7	1.00%	0.36	1.38%
13	South Africa	19.5	0.94%	0.29	1.12%
14	Argentina	17.7	0.85%	0.27	1.04%
15	Egypt	16.3	0.78%	0.23	0.88%
16	Vietnam	15.3	0.74%	0.2	0.77%
17	Myanmar	11.8	0.57%	0.18	0.69%
18	Peru	10.9	0.52%	0.17	0.65%
19	Bolivia	9.6	0.46%	0.14	0.54%
20	Iran	9.3	0.45%	0.13	0.50%
21	Rest of the world	319	15.36%	2.56	9.85%
	Total	2076.83	100.00%	26.9	100.00%

Source- USDA [13],[17]

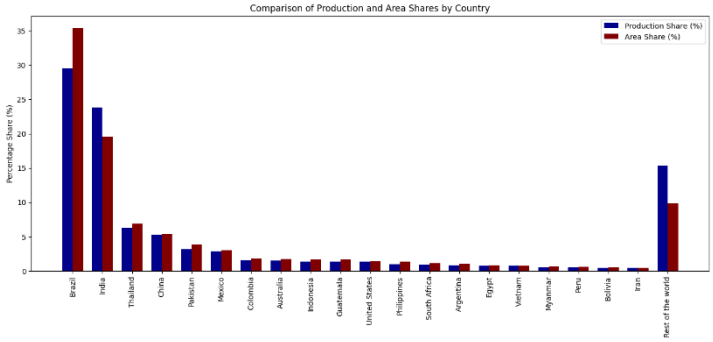

Figure 2. This figure shows Brazil has the highest percentage share of Production and area and India is in second position in 2022-23, (10).

B. Insight from Table II

1) Global Analysis of Sugarcane Production and Productivity: Table 2 offers a global perspective, comparing the performance of major sugarcane-producing countries. Brazil stands out as the world's leading producer, with extensive

cultivation areas and high production volumes. However, countries like Mexico and Indonesia, despite smaller cultivation areas, demonstrate higher productivity due to the adoption of advanced agricultural practices and sustainable farming methods.

India, though the second-largest producer globally, faces challenges in terms of yield per hectare, lagging behind countries like Thailand and China. This productivity gap highlights the need for improvements in irrigation, crop management, and soil fertility to enhance India's efficiency and align it with global leaders. The role of emerging markets like Thailand, with significant productivity growth, underscores the potential for agricultural innovations to further optimize yields.

Table III

State-Wise Distribution of Sugarcane Cultivation in India – Detailed Analysis:

S.No.	States/ UT	Area M Hect	Production M Tones	Productivity(Kg./hectare)
1	Uttar Pradesh	2.74	225.22	82197.08029
2	Maharashtra	1.36	123.97	91154.41176
3	Karnataka	0.69	62.46	90521.73913
4	Bihar	0.21	12.06	57428.57143
5	Gujarat	0.19	14.69	77315.78947
6	Tamil Nadu	0.16	16.92	105750
7	Madhya Pradesh	0.09	6.45	71666.66667
8	Haryana	0.11	8.86	80545.45455
9	Punjab	0.09	7.64	84888.88889
10	Uttrakhand	0.05	3.76	75200
11	Andhra Pradesh	0.04	3.12	78000
12	Telangana	0.03	2.64	88000
13	West Bengal	0.02	1.48	74000
14	Others	0.11	4.96	45090.90909
	All India	5.89	494.23	

Source-E&S, DAC, New Delhi, 3rd Adv. Est.-2022-23

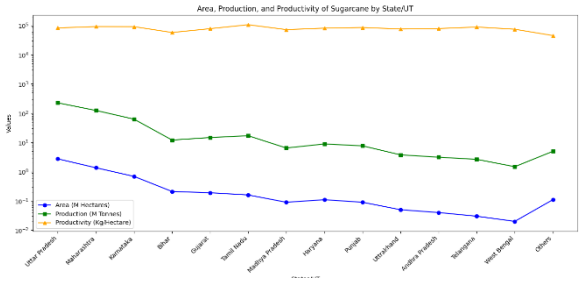

Figure 3. These graphs compare the Areas, production, and productivity of Indian states.

C. Insights from Table III

1) State-wise distribution of Sugarcane Cultivation in India: Table 3 highlights substantial regional variations in sugarcane cultivation across India. Uttar Pradesh dominates the sector with 2.74 million hectares under cultivation, producing 225.22 million tonnes of sugarcane. In contrast, states like West Bengal and Telangana have much smaller cultivation areas and production volumes, indicating notable disparities between regions.

Tamil Nadu stands out for its remarkable productivity of 105,750 kg/hectare, far surpassing other states, despite having a relatively smaller area under cultivation. On the other hand, states like Bihar report lower productivity (57,428 kg/hectare), potentially due to underdeveloped farming techniques and less favorable agricultural conditions. These differences underline the importance of region-specific agricultural policies aimed at addressing productivity disparities and improving overall efficiency in sugarcane cultivation across India.

Table IV

Global Analysis of Sugarcane Cultivation: Production, Area, and Productivity:

S.No.	Country	Production M Tonnes	Area M Hect	Productivity (Kg./hectare)
1	Brazil	613	9.2	66630.43478
2	India	494.23	5.1	96907.84314
3	Thailand	131	1.8	72777.77778
4	China	110	1.4	78571.42857
5	Pakistan	66.9	1	66900
6	Mexico	59.3	0.79	75063.29114
7	Colombia	32.7	0.48	68125
8	Australia	32.4	0.46	70434.78261
9	Indonesia	29.1	0.44	66136.36364
10	Guatemala	29.1	0.43	67674.4186
11	United States	29	0.37	78378.37838
12	Philippines	20.7	0.36	57500
13	South Africa	19.5	0.29	67241.37931
14	Argentina	17.7	0.27	65555.55556
15	Egypt	16.3	0.23	70869.56522
16	Vietnam	15.3	0.2	76500
17	Myanmar	11.8	0.18	65555.55556
18	Peru	10.9	0.17	64117.64706

19	Bolivia	9.6	0.14	68571.42857
20	Iran	9.3	0.13	71538.46154
21	Rest of the world	319	2.56	124609.375
	Total	2076.83	26.9	

Source- USDA [13],[17]

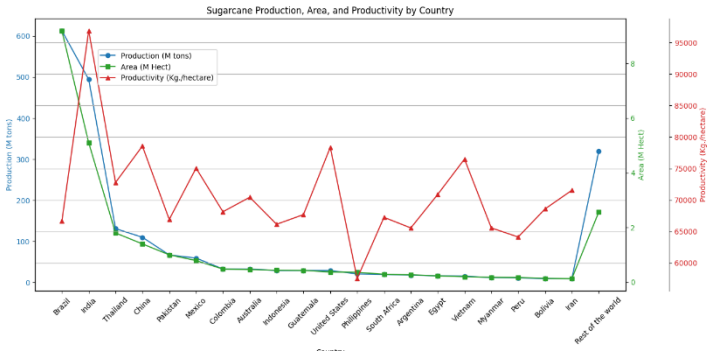

Figure 4. This figure compares area, production, and productivity.

D. Insights from Table IV

1) Global Analysis of Sugarcane Cultivation: Table 4 provides a global overview of sugarcane production, demonstrating the significant variance in cultivated areas, production volumes, and productivity among key producing nations. Brazil, the largest producer, cultivates 613 million tonnes of sugarcane over 9.2 million hectares. However, its productivity (66,630 kg/hectare) remains moderate compared to other countries due to its extensive land use.

India, the second-largest producer, demonstrates higher efficiency, with a productivity of 96,908 kg/hectare over 5.1 million hectares, reflecting advances in agricultural practices. Other countries, such as Thailand (72,778 kg/hectare) and China (78,571 kg/hectare), also show high productivity. In contrast, the "Rest of the World" category, representing smaller sugarcane-producing nations, achieves an impressive average productivity of 124,609 kg/hectare. These findings underscore the critical role of technological advancements in boosting global productivity and suggest further research into optimizing yields worldwide [14, 15].

III. STATISTICAL ANALYSIS OF SUGARCANE CULTIVATION: TRENDS AND GROWTH RATES: NATIONAL TRENDS IN SUGARCANE CULTIVATION

Table V

Trends in Sugarcane Cultivation in India (2000-01 to 2022-23):

S. No.	Year	Area (in M ha)	Production (in M tons)	Productivity (tons /ha)
1	2000-01	4.316	295.956	68.6
2	2001-02	4.411	297.208	67.4
3	2002-03	4.520	287.383	63.6
4	2003-04	3.938	233.862	59.4
5	2004-05	3.662	237.088	64.8
6	2005-06	4.201	281.172	66.9
7	2006-07	5.151	355.520	69
8	2007-08	5.055	348.188	68.9
9	2008-09	4.415	285.029	64.6
10	2009-10	4.175	292.302	70
11	2010-11	4.886	342.382	70.1
12	2011-12	5.038	361.037	71.7
13	2012-13	4.998	341.198	68.3
14	2013-14	4.993	352.142	70.5
15	2014-15	5.067	362.333	71.5
16	2015-16	4.927	348.448	70.7
17	2016-17	4.436	306.070	69

18	2017-18	4.732	376.905	79.66
19	2018-19	5.114	405.427	78.25
20	2019-20	4.603	370.500	80.5
21	2020-21	4.857	399.263	82.2
22	2021-22	5.175	439.432	84.91
23	2022-23*	5.883	494.228	84.48

*3rd advanced estimates

Source: Directorate of Economics and Statistics, Ministry of Agriculture & Farmers' Welfare, New Delhi [16]

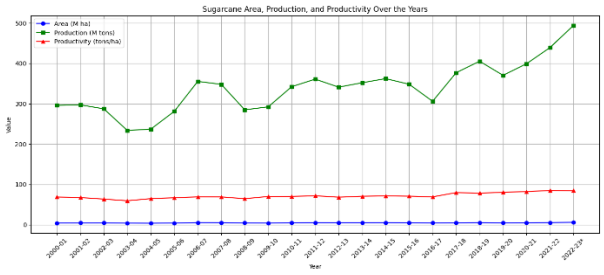

Figure 5. This graph shows the year-wise comparison in Sugarcane Area, Production, and Productivity (2000-01 to 2022-23).

A. Discussion and interpretation

The data demonstrates significant variability in sugarcane cultivation metrics over the period studied. The area under cultivation generally shows an upward trend, with notable increases in recent years, especially in 2022-23. Production figures also exhibit considerable fluctuations, with significant increases towards the end of the period. Productivity has improved overall, reflecting possible advancements in agricultural practices or favorable environmental conditions.

National trends indicate a positive trajectory in sugarcane cultivation, with increasing area and production. Productivity improvements suggest ongoing enhancements in cultivation practices. However, the variability in production underscores the need for continuous monitoring and adaptation to ensure sustained growth and optimization.

The compound growth rate is calculated using the following formula:

$$\text{Compound Growth Rate} = \frac{\chi_{t+1} - \chi_t}{\chi_t} \times 100$$

Where χ_t and χ_{t+1} are the production values at yearst and $t+1$, respectively. This formula provides the annual growth rate for each year, which can then be averaged or further analyzed [2],[3].

B. Regional Trends in Uttar Pradesh

Table VI

Growth Rate of Area, Production, and Productivity of Uttar Pradesh (2000-01 to 2022-23)

S.No.	Year	Area (in M ha)	Area Growth rate per annum	Production (in M tons)	Production Growth rate per annum	Productivity (tons /ha)	Productivity Growth rate per annum
1	2000-01	1.938		106.068		54.7	
2	2001-02	2.035	5.005159959	117.982	11.23241694	58	6.032906764
3	2002-03	2.149	5.601965602	120.948	2.513942805	56.3	-2.931034483
4	2003-04	2.030	-5.537459283	112.754	-6.774812316	55.5	-1.420959147
5	2004-05	1.955	-3.694581281	118.715	5.286730404	60.7	9.369369369
6	2005-06	2.156	10.28132992	125.470	5.690098134	58.2	-4.118616145
7	2006-07	2.247	4.220779221	133.949	6.757790707	59.6	2.405498282
8	2007-08	2.179	-3.026257232	124.665	-6.930996125	57.2	-4.026845638
9	2008-09	2.084	-4.359798073	109.048	-12.52717282	52.3	-8.566433566
10	2009-10	1.977	-5.134357006	117.140	7.42058543	59.3	13.38432122
11	2010-11	2.125	7.486090035	120.545	2.906778214	56.7	-4.384485666
12	2011-12	2.162	1.741176471	128.819	6.863826787	59.6	5.114638448
13	2012-13	2.212	2.312673451	132.427	2.80082907	59.9	0.503355705
14	2013-14	2.228	0.723327306	134.689	1.708110884	60.5	1.001669449
15	2014-15	2.141	-3.904847397	133.061	-1.208710437	62.1	2.644628099
16	2015-16	2.169	1.307800093	145.385	9.261917466	67	7.890499195
17	2016-17	2.160	-0.414937759	140.169	-3.587715376	64.9	-3.134328358
18	2017-18	2.234	3.425925926	177.056	26.31608986	79.3	22.18798151
19	2018-19	2.224	-0.447627574	179.715	1.501784746	80.8	1.891551072
20	2019-20	2.208	-0.71942446	179.539	-0.097932838	81.3	0.618811881
21	2020-21	2.180	-1.268115942	177.672	-1.039885484	81.5	0.24600246
22	2021-22	2.177	-0.137614679	179.175	0.845940835	82.3	0.981595092
23	2022-23*	2.736	25.6775379	225.224	25.70057207	82.31	0.012150668

*3rd advanced estimates

Source: Directorate of Economics and Statistics, Ministry of Agriculture & Farmers' Welfare, New Delhi [16].

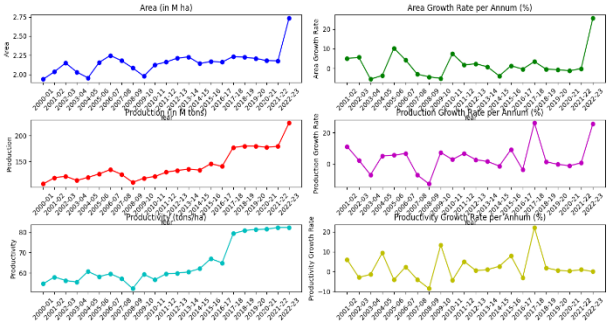

Figure 6. Analysis of growth rate of Sugarcane Area, Production, and Productivity of Uttar Pradesh (2000-01 to 2022-23).

C. Discussion and Interpretation

In Uttar Pradesh, the growth rates exhibit notable fluctuations. The areas under cultivation show periods of significant growth, particularly in recent years. Production growth rates vary widely, reflecting changes in agricultural practices or climatic conditions. Productivity growth rates indicate overall improvement, although there are periods of decline that warrant further investigation [5].

Regional trends in Uttar Pradesh align with national patterns but with more pronounced fluctuations. The data suggest that while the area and production are growing, productivity improvements are inconsistent. Addressing these variations through targeted regional policies and practices could enhance overall efficiency and stability [6].

D. Comparative Analysis of National and Regional Trends

Table VII

Annual Growth Rate of Area, Production, and Productivity of India (2000-01 to 2022-23):

S. No.	Year	Area (in M ha)	Area Growth rate	Production (in M tons)	Production Growth rate	Productivity (tons /ha)	Productivity Growth rate
1	2000-01	4.316		295.956		68.6	
2	2001-02	4.411	2.201112141	297.208	0.423035857	67.4	-1.749271137
3	2002-03	4.520	2.47109499	287.383	-3.305765659	63.6	-5.637982196
4	2003-04	3.938	-12.87610619	233.862	-18.62357899	59.4	-6.603773585
5	2004-05	3.662	-7.008633824	237.088	1.379445998	64.8	9.090909091
6	2005-06	4.201	14.71873293	281.172	18.5939398	66.9	3.240740741
7	2006-07	5.151	22.61366341	355.520	26.44217774	69	3.139013453
8	2007-08	5.055	-1.863715783	348.188	-2.062331233	68.9	-0.144927536
9	2008-09	4.415	-12.66073195	285.029	-18.13933852	64.6	-6.240928882
10	2009-10	4.175	-5.43601359	292.302	2.551670181	70	8.359133127
11	2010-11	4.886	17.02994012	342.382	17.13296522	70.1	0.142857143
12	2011-12	5.038	3.110929185	361.037	5.448592508	71.7	2.282453638
13	2012-13	4.998	-0.793965859	341.198	-5.495004667	68.3	-4.741980474
14	2013-14	4.993	-0.100040016	352.142	3.207521732	70.5	3.221083455
15	2014-15	5.067	1.482074905	362.333	2.894002987	71.5	1.418439716
16	2015-16	4.927	-2.76297612	348.448	-3.832110241	70.7	-1.118881119
17	2016-17	4.436	-9.965496245	306.070	-12.16192947	69	-2.404526167
18	2017-18	4.732	6.672678088	376.905	23.14339857	79.66	15.44927536
19	2018-19	5.114	8.072696534	405.427	7.567424152	78.25	-1.770022596
20	2019-20	4.603	-9.992178334	370.500	-8.614867781	80.5	2.875399361
21	2020-21	4.857	5.518140343	399.263	7.763292848	82.2	2.111801242
22	2021-22	5.175	6.54725139	439.432	10.060787	84.91	3.296836983
23	2022-23*	5.883	13.68115942	494.228	12.46973366	84.48	-0.506418561

*3rd advanced estimates

Source: Directorate of Economics and Statistics, Ministry of Agriculture & Farmers' Welfare, New Delhi [16].

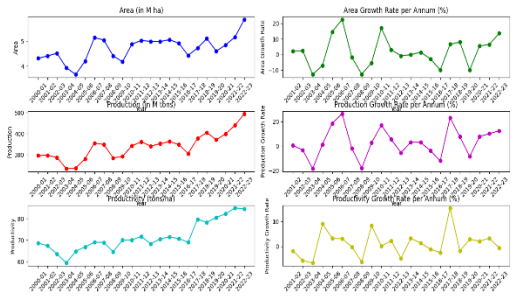

Figure 7. Analysis of the growth rate of Sugarcane Area, Production, and Productivity of India (2000-01 to 2022-23)

E. Discussion and interpretation

National trends reveal significant improvements in both area and production, especially in recent years. Productivity growth rates show variability but generally reflect positive changes. Comparing national and regional data, Uttar Pradesh's growth

patterns align with broader national trends but with more pronounced fluctuations, highlighting the need for targeted regional policies.

The comparative analysis underscores the overall positive growth in sugarcane cultivation nationally and regionally. While Uttar Pradesh reflects the broader trends, its more pronounced fluctuations suggest that tailored regional strategies could better address specific challenges and opportunities [4].

IV. RANK CORRELATION ANALYSIS OF SUGARCANE CULTIVATION AREA AND PRODUCTION IN INDIAN STATES/UTS

This analysis employs Spearman's rank correlation coefficient to evaluate the strength and direction of the relationship between sugarcane cultivation area and production across Indian states and union territories (UTs). Spearman's coefficient measures how well the rankings of these two variables correspond.

A. Spearman's rank correlation coefficient r is calculated using the formula

Spearman's rank correlation coefficient r measures the strength and direction of the association between two ranked variables.

$$r = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}$$

Where d_i is the difference between the ranks of corresponding variables and n is the number of observations [8].

1) Calculation for Indian States/UTs

Table VIII

Rank Correlation between Sugarcane Cultivation Area and Production for Indian States/UTs

S.No.	States/UT	Area (M Hect)	Rank	Production (M Tones)	Rank	d_i	d_i^2
1	Uttar Pradesh	2.74	1	225.22	1	0	0
2	Maharashtra	1.36	2	123.97	2	0	0
3	Karnataka	0.69	3	62.46	3	0	0
4	Bihar	0.21	4	12.06	6	-2	4
5	Gujarat	0.19	5	14.69	5	0	0
6	Tamil Nadu	0.16	6	16.92	4	2	4
7	Madhya Pradesh	0.09	9	6.45	9	0	0
8	Haryana	0.11	7	8.86	7	0	0
9	Punjab	0.09	9	7.64	8	1	1
10	Uttarakhand	0.05	11	3.76	11	0	0
11	Andhra Pradesh	0.04	12	3.12	12	0	0
12	Telangana	0.03	13	2.64	13	0	0
13	West Bengal	0.02	14	1.48	14	0	0
14	Others	0.11	7	4.96	10	-3	9
	All India	5.89		494.23			$\sum d_i^2 = 18$

Source-E&S, DAC, New Delhi, 3rd Adv. Est.-2022-23 [6].

Since we have the rank correlation coefficient $r \in [-1, 1]$, we have:

The sum of d_i^2: 18

Number of observations(n): 14

Using the formula:

$r = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}$

Substitute

$\sum d_i^2 = 18$ and $n = 14$

$r \approx 0.960$

The Spearman's correlation coefficient is approx 0.960.

B. Interpretation

1) Exceptionally Strong Positive Association: Spearman's rank correlation coefficient of 0.960 indicates an exceptionally strong positive correlation between sugarcane cultivation area and production. This suggests that states and UTs with larger cultivation areas generally achieve higher production levels, reflecting highly efficient agricultural practices.

2) High Consistency: The near-perfect correlation underscores a high degree of consistency between the relative rankings of cultivation area and production. This highlights that agricultural output is closely aligned with the area under cultivation, emphasizing the importance of cultivation area in determining production levels [8].

C. Rank Correlation Analysis for Global Data

Table IX

Rank Correlation between the data of Production and Area for the top 20 Sugarcane Producing Countries:

S.No.	Country	Production M Tonnes	Rank	Area M Hect	Rank	d_i	d_i^2
1	Brazil	613	1	9.2	1	0	0
2	India	494.23	2	5.1	2	0	0
3	Thailand	131	4	1.8	4	0	0

4	China	110	5	1.4	5	0	0
5	Pakistan	66.9	6	1	6	0	0
6	Mexico	59.3	7	0.79	7	0	0
7	Colombia	32.7	8	0.48	8	0	0
8	Australia	32.4	9	0.46	9	0	0
9	Indonesia	29.1	10	0.44	10	0	0
10	Guatemala	29.1	10	0.43	11	-1	1
11	United States	29	12	0.37	12	0	0
12	Philippines	20.7	13	0.36	13	0	0
13	South Africa	19.5	14	0.29	14	0	0
14	Argentina	17.7	15	0.27	15	0	0
15	Egypt	16.3	16	0.23	16	0	0
16	Vietnam	15.3	17	0.2	17	0	0
17	Myanmar	11.8	18	0.18	18	0	0
18	Peru	10.9	19	0.17	19	0	0
19	Bolivia	9.6	20	0.14	20	0	0
20	Iran	9.3	21	0.13	21	0	0
21	Rest of the world	**319**	3	**2.56**	3	0	0
	Total	**2076.83**		**26.9**			$\sum d_i^2 = 1$

Source- USDA [13],[17]

We have,
The sum of d_i^2: 1
Number of observations (n): 21
Substitute, $\sum d_i^2 = 1 \; and \; n = 21.$
$r \approx 0.999$

The Spearman's rank correlation coefficient is approximately 0.999.

D. Interpretation

1) Exceptionally Strong Positive Correlation: Spearman's rank correlation coefficient of approximately 0.999 signifies an exceptionally strong positive relationship between sugarcane production and cultivation area among the top 20 sugarcane-producing countries. This near-perfect correlation indicates that the ranking of countries by production is almost identical to their ranking by area under cultivation. This suggests that increases in cultivation areas closely correspond to increases in production levels.

2) Highly Consistent Association: The near-perfect correlation demonstrates that the relative rankings of countries by cultivation area and production are highly consistent. This indicates that the area under cultivation is a decisive factor influencing production outcomes on a global scale.

This analysis underscores the importance of cultivation areas in determining sugarcane production levels and provides valuable insights into global agricultural efficiency and planning.

This concludes the detailed rank correlation analysis for both Indian states/UTs and top sugarcane-producing countries.

V. SIMPLE LINEAR REGRESSION ANALYSIS

A simple linear regression model was employed to investigate further the relationship between sugarcane production (dependent variable Y) and cultivation area (independent variable X). The regression equation is given by:

The regression equation is given by:

$$Y = \zeta_o + \zeta_1 X + \epsilon$$

Where:

- Y denotes the production of Sugarcane.
- X represents the area under cultivation.
- ζ_0 is the intercept of the regression line.
- ζ_1 is the Slope of the regression line, and
- ε is the error term.

The coefficients ζ_0 and ζ_1 are estimated using the least squares method, with the following formulas:

$$\zeta_1 = \frac{[`n(\sum_{i=1}^{n} X_i Y_i) - (\sum_{i=1}^{n} X_i)(\sum_{i=1}^{n} Y_i)]}{n(\sum_{i=1}^{n} {X_i}^2) - (\sum_{i=1}^{n} X_i)^2}$$

$$\zeta_o = \frac{\sum_{i=1}^{n} Y_i - \zeta_1(\sum_{i=1}^{n} X_i))}{n}$$

Where n is the number of observations, and $\sum$ denotes the summation of observations (8).

A. Regression Analysis for Indian States

Table X

Regression Analysis for Sugarcane Production and Area under Cultivation in Various States of India:

S.No.	States	Area M Hect(X)	x	x^2	Production M Tones (Y)	y	y^2	xy
1	Uttar Pradesh	2.74	2.32	5.3824	225.22	189.92	36069.6064	440.6144
2	Maharashtra	1.36	0.94	0.8836	123.97	88.67	7862.3689	83.3498
3	Karnataka	0.69	0.27	0.0729	62.46	27.16	737.6656	7.3332
4	Bihar	0.21	-0.21	0.0441	12.06	-23.24	540.0976	4.8804
5	Gujarat	0.19	-0.23	0.0529	14.69	-20.61	424.7721	4.7403
6	Tamil Nadu	0.16	-0.26	0.0676	16.92	-18.38	337.8244	4.7788
7	Madhya Pradesh	0.09	-0.33	0.1089	6.45	-28.85	832.3225	9.5205
8	Haryana	0.11	-0.31	0.0961	8.86	-26.44	699.0736	8.1964
9	Punjab	0.09	-0.33	0.1089	7.64	-27.66	765.0756	9.1278
10	Uttrakhand	0.05	-0.37	0.1369	3.76	-31.54	994.7716	11.6698
11	Andhra Pradesh	0.04	-0.38	0.1444	3.12	-32.18	1035.5524	12.2284
12	Telangana	0.03	-0.39	0.1521	2.64	-32.66	1066.6756	12.7374
13	West Bengal	0.02	-0.4	0.16	1.48	-33.82	1143.7924	13.528
14	Others	0.11	-0.31	0.0961	4.96	-30.34	920.5156	9.4054
	All India	ΣX=5.89	**Σx=0.01**	**Σx^2=7.5069**	ΣY=494.23	**Σy=0.03**	**Σy^2=53430.11**	**Σxy=632.1106**

Source-E&S, DAC, New Delhi, 3rd Adv. Est.-2022-23 [6].

1) The regression equation for predicting area based on production (X on Y) is:

$$X - \overline{X} = b_{XY} \cdot (Y - \overline{Y})$$

Where:

$$\overline{X} = 0.42, \overline{Y} = 35.30$$

$$b_{XY} = \frac{\sum XY}{\sum Y^2} = 0.012$$

Hence, the regression equation becomes:

$$X = 0.012Y - 0.0036$$

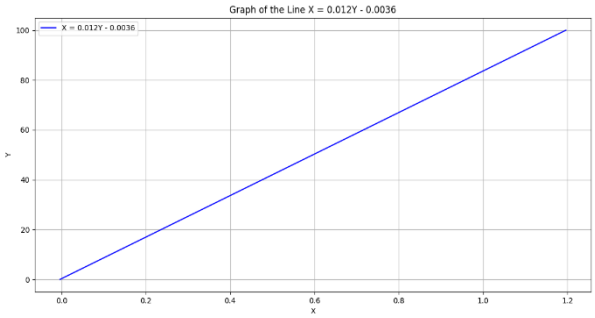

Figure 8. This is the graph of the regression equation of Y on X.

2) Interpretation: The coefficient 0.012 indicates that for each additional million tonnes of sugarcane produced, the area under cultivation is expected to increase by 0.012 million hectares. This suggests a modest positive relationship between production and cultivation area.

3) The regression equation for predicting production based on area (Y on X) is:

$$Y - \bar{Y} = b_{XY} \cdot (X - \bar{X})$$

Where:

$$b_{YX} = \frac{\sum XY}{\sum X^2} = 84.2$$

Thus, the regression coefficient $b_{YX} = 84.2$

Simplifying:

$$Y = 84.2X - 0.062$$

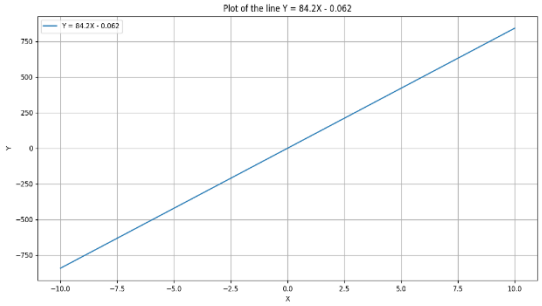

Figure 9. This is the graph of the regression equation of Y on X

4) Interpretation: The coefficient 84.2 indicates that for each additional million hectares of cultivated area, sugarcane production increases by 84.2 million tonnes. The intercept of -0.062 adjusts the regression line for better fit, though it is not practically meaningful [8].

B. Regression Analysis for Global Data

Table XI

Regression Analysis for Sugarcane Production and Area under Cultivation in Various Countries

S.No	Country	Production M Tonnes(X)	x=(X-98.9)	x^2	Area M Hect(Y)	y=(Y-1.3)	y^2	xy
1	Brazil	613	514.1	264298.81	9.2	7.9	62.41	4061.39
2	India	494.23	395.33	156285.8089	5.1	3.8	14.44	1502.254
3	Thailand	131	32.1	1030.41	1.8	0.5	0.25	16.05
4	China	110	11.1	123.21	1.4	0.1	0.01	1.11
5	Pakistan	66.9	-32	1024	1	-0.3	0.09	9.6
6	Mexico	59.3	-39.6	1568.16	0.79	-0.51	0.2601	20.196
7	Colombia	32.7	-66.2	4382.44	0.48	-0.82	0.6724	54.284
8	Australia	32.4	-66.5	4422.25	0.46	-0.84	0.7056	55.86
9	Indonesia	29.1	-69.8	4872.04	0.44	-0.86	0.7396	60.028
10	Guatemala	29.1	-69.8	4872.04	0.43	-0.87	0.7569	60.726
11	United States	29	-69.9	4886.01	0.37	-0.93	0.8649	65.007
12	Philippines	20.7	-78.2	6115.24	0.36	-0.94	0.8836	73.508
13	South Africa	19.5	-79.4	6304.36	0.29	-1.01	1.0201	80.194
14	Argentina	17.7	-81.2	6593.44	0.27	-1.03	1.0609	83.636
15	Egypt	16.3	-82.6	6822.76	0.23	-1.07	1.1449	88.382
16	Vietnam	15.3	-83.6	6988.96	0.2	-1.1	1.21	91.96
17	Myanmar	11.8	-87.1	7586.41	0.18	-1.12	1.2544	97.552
18	Peru	10.9	-88	7744	0.17	-1.13	1.2769	99.44
19	Bolivia	9.6	-89.3	7974.49	0.14	-1.16	1.3456	103.588
20	Iran	9.3	-89.6	8028.16	0.13	-1.17	1.3689	104.832
	Rest of the world	**319**	220.1	48444.01	**2.56**	1.26	1.5876	277.326
	Total	**ΣX=2076.83**	**Σx=-0.07**	**Σx^2=560367**	**ΣY=26.9**	**Σy=-1.3**	**Σy^2=93.3524**	**Σxy=7006.923**

Source- USDA [13],[17]

1) The regression equation for predicting production based on (X on Y) is:

$$X - \bar{X} = b_{XY} \cdot (Y - \bar{Y})$$

Where:

$$\bar{X} = 98.9, \qquad \bar{Y} = 1.3$$

$$b_{XY} = \frac{\sum XY}{\sum Y^2} = 75.06$$

$$X = 75.06Y + 1.32$$

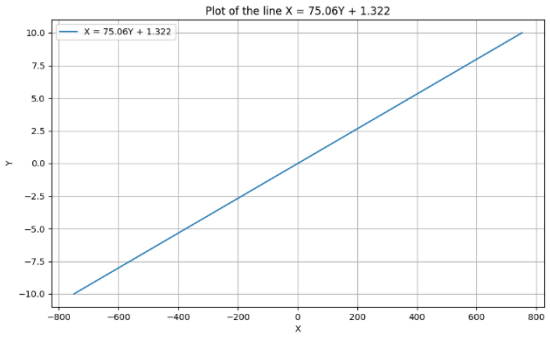

Figure 10. This is the graph of the regression equation of X on Y.

2) Interpretation: The coefficient of 75.06 suggests that for each additional million hectares of cultivated area, sugarcane production is expected to increase by 75.06 million tonnes. The positive relationship indicates that larger cultivation areas are associated with higher production levels.

3) The regression equation for predicting area based on production (Y on X) is:

$$Y - \overline{Y} = b_{YX} \cdot (X - \overline{X})$$

Where:

$$b_{XY} = \frac{\sum XY}{\sum X^2} = 0.013$$

Simplifying:

$$Y = 0.013X - 0.0143$$

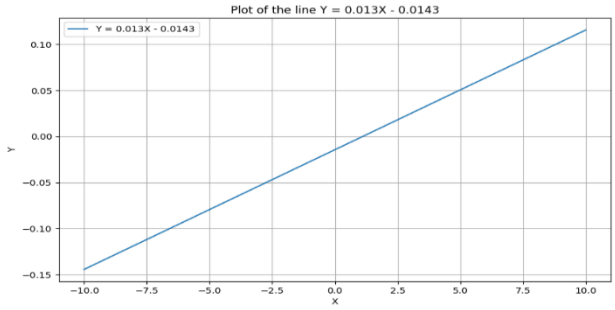

Figure 10. Regression equation of Y on X

4) Interpretation: The coefficient 0.013 indicates that for each additional million tonnes of sugarcane produced, the area under cultivation is expected to increase by 0.013 million hectares. The intercept of -0.0143 adjusts the regression line, though it is not practically meaningful [8, 12].

VI. INFLATION RATE

Table XII

Sugarcane Price and Inflation Rate (2014-2024)

S.N.	Financial Year	Sugarcane Price (Rupees per quintal)	Inflation Rate (%)
1	2014	210	-
2	2015	220	4.76
3	2016	230	4.55
4	2017	230	0
5	2018	255	10.87
6	2019	275	7.84
7	2020	275	0
8	2021	285	3.64
9	2022	290	1.75
10	2023	305	5.17
11	2024	315	3.28

Source: ISMA.

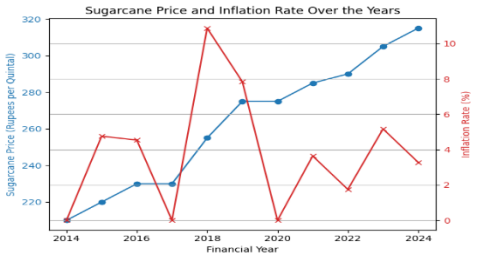

Figure 11. 2D representation of Inflation.

A. Discussion and Interpretation

Table 12 presents the trends in sugarcane prices from 2014 to 2024, illustrating notable increases, particularly in 2018 and 2019. These increases correlate with rising inflation, as shown in Figure 11. The stagnation of prices during 2016 and 2017 contrasts sharply with the subsequent price hikes, suggesting a delayed market response to economic conditions.

The analysis highlights the sensitivity of sugarcane prices to macroeconomic factors. Gradual price increases appear to be driven by cost-push inflation and potential government interventions, such as Minimum Support Prices (MSP). The stability of prices in certain periods may indicate effective market regulation or production surpluses.

This study underscores the significant impact of inflation on agricultural commodities and provides vital insights for policymakers. Understanding these dynamics is crucial for formulating strategies to maintain price stability and promote sustainable market practices.

VII. CONCLUSION

Our analysis reveals distinct regional and global patterns in sugarcane production and productivity.

A. Regional Insights

In India, Uttar Pradesh, Maharashtra, and Karnataka are major producers, while Tamil Nadu stands out for its high yield per hectare despite a smaller cultivation area. This indicates a need for focused strategies to enhance yields in less productive states.

B. Global Overview

Brazil and India lead global sugarcane production, with Brazil excelling in efficiency. The disparity in productivity between countries highlights opportunities for adopting best practices to improve performance in less productive regions.

C. Trends and Growth Rates

Data from 2000-01 to 2022-23 shows a general upward trend in sugarcane area, production, and productivity, though fluctuations indicate the need for stable growth strategies.

D. Correlation Analysis

The high-rank correlation coefficients between cultivation area and production in India (0.960) and globally (0.999) suggest strong relationships, indicating that increased cultivation area generally leads to higher production. Additionally, the correlation between inflation rates and sugarcane prices reveals that rising inflation can exert upward pressure on sugarcane prices, impacting farmers' income and overall market stability.

E. Predictive Modeling

Regression models demonstrate a strong connection between sugarcane area and production, providing valuable tools for predicting production based on cultivation area. This aids in effective planning and resource management to optimize sugarcane yields.

F. Future Directions

Our findings suggest that implementing region-specific strategies and adopting efficient practices could enhance productivity and support sustainable growth in the sugarcane sector globally.

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