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RESEARCH ARTICLE

Five decades of crop production in Odisha (1970-2020): Disentangling growth drivers of major field crops through decomposition analysis

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Abstract

Despite numerous studies on agricultural growth in India, there remains a critical gap in understanding long-term, crop-specific growth dynamics and their underlying drivers in climatically vulnerable states like Odisha. Paddy, green gram, and groundnut are the major field crops of Odisha, occupying the majority of the cultivated area. This study aims to analyse the long-term growth trends and production dynamics from 1970 to 2020, using secondary data to estimate compound annual growth rates (CAGR) at both overall and decadal periods. It employs an additive decomposition method to quantify the contributions of area, yield and interaction effects on change in production for revealing complex, non-linear crop-specific patterns. In the case of paddy, production grew with CAGR of 1.76 %; it was predominantly driven by yield improvements despite slight decline in area. Green gram displayed volatile trends with periods of stagnation and recovery. Notably, a production surge in the period from 1990 to 2000, which was due to combined area expansion and yield gains, followed by yield led growth in 2010-2020. Groundnut experienced growth phases, shifting from area led expansion in early decades to yield driven resurgence post 2000, aided by high-yielding, resilient varieties and enhanced extension services, though area contraction in the last decade tempered overall gains. The findings emphasize the importance of balanced strategies to stabilize the area under cultivation and promote yield enhancement through technological interventions and policy support, essential for sustainable agricultural resilience amid climatic variability and socio-economic challenges in Odisha.

Keywords: agricultural growth; compound annual growth rate; decomposition analysis; green gram; groundnut; Odisha agriculture; paddy

Introduction

Agriculture serves as the cornerstone of Odisha, one of the most resource rich state of India renowned for its diverse agro climatic zones, coastal plains, plateaus and hilly terrains (1). Agriculture lies at the heart of Odisha; its economy supports over 80 % of its rural population and serves as a vital contributor to both gross domestic product (GDP) and food security. However, crop productivity continues to be fragile, primarily due to the sector's reliance on monsoonal rainfall, persistent soil degradation and insufficient infrastructural development. Cropping of major field crops such as paddy, green gram and groundnut support the income of agrarian economy of Odisha. Paddy, as the predominant staple crop, occupies the largest share of cultivated land in Odisha, underpinning both subsistence and commercial production systems while playing a vital role in ensuring food security and sustaining rural livelihoods. An assessment of rice production trends 1960 to 2019 indicated a marginal decline in the area devoted to rice cultivation (-0.18 %), in contrast to notable positive growth in yield (1.95 %) and total production (1.76 %) (2, 3). Green gram, improves soil fertility via nitrogen fixation and provides essential dietary protein, while groundnut contributes to edible oil production and livestock feed. Table 1 represents the current area, production and productivity of major crops in Odisha, along with their percentage share in India's total area and production (4).

The agriculture in Odisha has exhibited fluctuating growth patterns over recent decades, influenced by technological advancements, policy reforms, irrigation expansions and environmental stressors such as recurrent floods and droughts (5). The period from 1970 to 2020 encapsulates a transformative phase in Indian agriculture, including the post effects of the Green Revolution,

Table 1. Odisha's share of area, production and productivity of major Kharif crops (2023-24)

Crop	Odisha - Area	Odisha production	Odisha productivity	Share of India's area	share of India's production
Rice	40.87 lakh ha	115.39 lakh t (rice)	2823 kg/ha	≈10.03 % of India Kharif rice area (407.34 lakh ha, 2023-24)	≈8.37 % of India rice production (1378.25 LMT, 2023-24)
Green gram (Moong)	1.66 lakh ha	0.89 lakh t	536 kg/ha	≈5.23 % of India Kharif moong area (31.74 lakh ha, 2023-24)	≈2.87 % of India moong production (31.03 LMT, 2023-24)
Groundnut	2.21 lakh ha	2.03 lakh t	921 kg/ha	≈5.46 % of India Kharif groundnut area (40.44 lakh ha, 2023-24)	≈2.00 % of India groundnut production (101.80 LMT, 2023-24)

economic liberalization in the 1990s and a growing emphasis on sustainable and climate resilient practices (6). In Odisha, this era witnessed shifts in cropping patterns, with varying trends in land allocation, yield enhancements and overall output. For example, paddy production has demonstrated resilience through yield improvements in select decades, whereas pulses and oilseeds like green gram and groundnut have faced more erratic trajectories, often due to low productivity and area reductions (7).

Prior research on Odisha agriculture has typically emphasized aggregate trends or region- specific issues, yet there is a notable gap in crop specific, long-term analyses that decompose production changes using quantitative methods (8, 9). Chronic climatic event like the 1999 Super Cyclone, which devastated vast agricultural lands and led to saline intrusion, accent the need for such granular examinations to understand climate induced disruptions. It was observed that agricultural growth rates in Odisha from 1991 to 2008 remained below the national average, reflecting stagnation (10).

This study bridges the gap by investigating the long-term growth trends and production decomposition for paddy, green gram and groundnut in Odisha over the 50-year period from 1970 to 2020. The study has two main objectives. First, to calculate the compound annual growth rates (CAGR) of area, yield and production, both overall and by decade, to capture growth patterns and instability. Second, to apply an additive decomposition model to quantify the contributions of area, yield and interaction effects to changes in production. Decadal analysis (1970-80, 1980-90, 1990-2000, 2000-10 and 2010-20) highlights nonlinear dynamics, including yield driven recoveries in green gram and groundnut during the 2000s and the persistent dominance of yield effects in paddy despite area contractions.

Reports from various sources, including the State Agriculture Statistics Databook of 2020, governmental websites and the State Economic Survey of 2021 (11, 12), were collected and analysed using semi-logarithmic trend models for CAGR estimation because the model explains exponential growth patterns effectively and uses an additive decomposition framework. The study illuminates historical performance but also informs recommendations for enhancing productivity, such as adopting high yielding varieties, expanding irrigation and mitigating area fluctuations in vulnerable crops (13). This research contributes to a deeper understanding of agricultural resilience in climate vulnerable regions like Odisha, aligning with broader calls for climate smart strategies to ensure equity and food security (14, 15). The agricultural sector in Odisha has witnessed substantial changes over the past five decades. Studies highlight improvements in crop area, yield and production, particularly driven by technological adoption and policy interventions (16).

In this context, the present study pursues two specific objectives: (i) to examine the long-term trends in area, yield, and production of major field crops in Odisha during the period 1970-2020, and (ii) to decompose the sources of production growth to quantify the relative contributions of area expansion, yield improvement, and their interaction across successive decades. This study was an attempt to study the drivers and sources of growth in the production of major field crops of Odisha.

Materials and Methods

Data and its sources

This study was undertaken for the state of Odisha using secondary data for area, production and productivity of major field crops of Odisha (11, 12).

Trend analysis

Trends in area production and productivity CAGR provides a robust measure of average annual change over long periods (1970–2020) and within distinct decades. In a state like Odisha, where agricultural progression is nonlinear due to periodic policy shifts, natural disaster, climatic shocks and technological interventions. CAGR allows for quantification of underlying patterns (growth, stagnation or decline) for area, yield and production.

Compounded annual growth rate (CAGR) of key parameters area and production and productivity was estimated for five distinct decades starting with 1970-80, 1980-90, 1990-2000, 2000-10 and 2010-19. The formula for CAGR estimation is an exponential growth function and given as:

$$y_t = ab^t U \qquad \text{(Eqn. 1)}$$

Where,

y_t: value of the variable of area, production and productivity at time t

a: intercept

b: growth factor, (where b = 1 + g and g is the annual compound growth rate)

U: random disturbance term

t: time period (1, 2, ..., n)

After logarithmic transformation of equation (1) the linear form is as follows:

$$\log y_t = \log a + t \log b + \log U_t \qquad \text{(Eqn. 2)}$$

The compound growth rate can be written as follows:

$$g = (\text{antilog } b - 1)\, 100 \qquad \text{(Eqn. 3)}$$

Decomposition of growth in production

The additive decomposition approach quantifies how much of the change in crop production is due to an increase or decrease in cultivated area, improvements in yield (productivity) and the interaction effect (simultaneous changes in both area and yield).

This technique enables identification of whether growth is driven primarily by land expansion, technological improvements or their combinations.

Decomposition of growth isolates the individual contributions of area, yield and their interaction to changes in crop production over time. This method helps understand whether increases in output are primarily due to expanding cultivated area, improvements in productivity (yield) or simultaneous changes in both.

Additive decomposition approach

The additive decomposition approach was employed to quantify the relative contributions of key factors driving changes in crop production over time (17). Specifically, the total change in crop output (ΔQ_t) between two periods was decomposed into three distinct effects: the area effect, representing the influence of changes in the extent of cultivation; the yield effect, reflecting variations in productivity per unit area; and the interaction effect, capturing the combined influence of simultaneous changes in both area and yield.

This framework enables a systematic evaluation of whether production growth is primarily driven by land expansion (extensification), technological or management improvements (intensification), or the synergistic interaction between the two. The decomposition thus provides an analytical basis for understanding the structural dynamics of crop growth and identifying the predominant sources of production change across decades in Odisha's agricultural landscape:

$\Delta Q_t = Q_1 - Q_0$ (Eqn. 4)

Where, $Q_0 = A_0 \times Y_0$: initial period production, $Q_1 = A_1 \times Y_1$: final period production, A: area under cultivation, Y: crop yield per unit area

The change in total output (ΔQ_t) can be decomposed as follows:

$\Delta Q_t = (A_1 - A_0) \times Y_0$(area effect) + $(Y_1 - Y_0) \times A_0$(yield effect) + $(A_1 - A_0) \times (Y_1 - Y_0)$ (interaction effect) (Eqn. 5)

Where ,

ΔQt = change in total output (production) between two time periods, t_0 and t_1

A_0 = area (e.g., land cultivated, hectares planted, etc.) in the base or initial period

A_1 = area in the current or later period

Y_0 = yield (output per unit area, e.g., tons per hectare) in the base or initial period

Y_1 = yield in the current or later period

Area effect: measures the effect on production due solely to change in area, keeping yield constant at the base period's level.

Yield effect: captures the change attributable to yield improvements, with area kept constant at the base period's value.

Interaction effect: reflects the combined effect when both area and yield change simultaneously.

Results

Paddy

This section presents the empirical findings from a comprehensive analysis of time series data on the area, yield and production of paddy (total rice) in the state of Odisha for the 50-year period (1970-71 to 2019-20). The analysis is structured to find the growth trends of each of the five decades in our study period along with drivers of changes in production.

Overall growth trajectory of paddy production (1970-2020)

The overall 50-year period was characterized by a significant and positive growth in paddy production, driven almost exclusively by improvements in land productivity. To quantify these long-term trends, a semi logarithmic model, was fitted to the time series data for area, yield and production. The slope coefficient (b) from this model allows for the calculation of the CAGR.

The analysis reveals that total paddy production in Odisha grew at a CAGR of 1.76 % over the five decades. This growth trend is statistically highly significant, confirming a consistent increase in output over the long term. The primary engine of this growth was a robust and statistically significant increase in yield (kg/ha), which registered a CAGR of 1.95 %. In stark contrast, the area under paddy cultivation experienced a slight but statistically significant decline, with a CAGR of -0.18 %.

The coefficient of determination (R^2) provides insight into the stability of these trends. The regression model for yield explains a substantial portion of the temporal variation (R^2=0.71) and similarly for production (R^2=0.64). This indicates that the growth in yield and production, while subject to fluctuations, followed a relatively strong and persistent upward path. The model for area, however, has a very low explanatory power (R^2=0.25), signifying that the area under cultivation was highly volatile and did not follow a smooth, predictable trend over the 50-year period. These aggregate results are summarized in Table 2.

Decadal patterns of paddy production

While the long-term trends provide a clear overall picture, they mask significant volatility and distinct periods of growth, stagnation and crisis. To capture this dynamic behaviour, the 50-year timeline was disaggregated into five 10-year periods. The CAGR and the corresponding R^2 value were calculated for each decade to assess both the magnitude and stability of growth within each period. The results, presented in Table 3, reveal a tumultuous history. The trendlines of area, yield and production of paddy from 1970-2020 were depicted in Fig. 1-3.

The first decade, 1970-80, was a period of agricultural decline. The area under paddy contracted at a rate of -0.86 % per year, while yield also saw a negative growth of -0.26 %. Consequently, total production fell at a CAGR of -1.13 %. The extremely low R^2 values for yield (0.003) and production (0.046) indicate that this was a decade of extreme instability with no discernible positive trend.

Table 2. Overall growth and trend analysis of paddy in Odisha (1970-2020)

Variable	CAGR (%)	Regression coefficient (b)	Standard error	*t*-statistic	*p*-value	R-squared (R^2)
Area ('000 ha)	-0.18	-0.00180	0.045875	-4.014	<0.001	0.251
Yield (kg/ha)	1.95	0.01930	0.181369	10.858	<0.001	0.711
Production ('000 tonnes)	1.76	0.01749	0.193814	9.209	<0.001	0.639

The 1980-90 decade marked a dramatic reversal, exhibiting the fastest growth of any period for yield and production. Yield grew at an impressive CAGR of 3.56 %, driving production growth to nearly 4.0 % per annum. The area under cultivation also saw a modest expansion (0.40 %). However, the relatively low R^2 values suggest that while the overall trend was strongly positive, the growth was erratic and subject to considerable year on year fluctuation.

This was followed by the decade of 1990-2000, which represents a period of severe crisis and regression. Yield growth turned sharply negative (-1.45 %), pulling down production growth to -1.29 %, despite a marginal increase in area (0.16 %). The very low R^2 values across all three parameters highlight a decade characterized by high volatility and a breakdown of the previous growth momentum.

The decade of 2000-10 witnessed the most remarkable performance in terms of productivity enhancement. Yield grew at an unprecedented CAGR of 4.99 %, the highest recorded in the entire 50-year span. This surge in yield translated directly into a production growth of 4.96 %, even as the area under cultivation remained virtually stagnant (-0.03 %). This was a period of pure, yield driven growth.

Finally, the most recent decade, 2010-20, saw a continuation of yield led growth, though at a more moderate pace. Yield increased at a CAGR of 2.90 %, leading to a production increase of 1.99 %. A notable feature of this decade is the accelerated and more consistent decline in the area under paddy, which contracted at a rate of -0.88 % per year. The comparatively higher R^2 value for area (0.531) in this period suggests a more systematic trend of land being diverted away from paddy cultivation.

Table 3. Decadal compound annual growth rates (%) and trend stability (R^2) of paddy in Odisha

Period	CAGR area (%)	CAGR yield (%)	CAGR production (%)	R^2 area	R^2 yield	R^2 production
1970-80	-0.86	-0.26	-1.13	0.413	0.003	0.046
1980-90	0.40	3.56	3.98	0.145	0.295	0.281
1990-2000	0.16	-1.45	-1.29	0.117	0.119	0.089
2000-10	-0.03	4.99	4.96	0.003	0.338	0.305
2010-20	-0.88	2.90	1.99	0.531	0.176	0.081

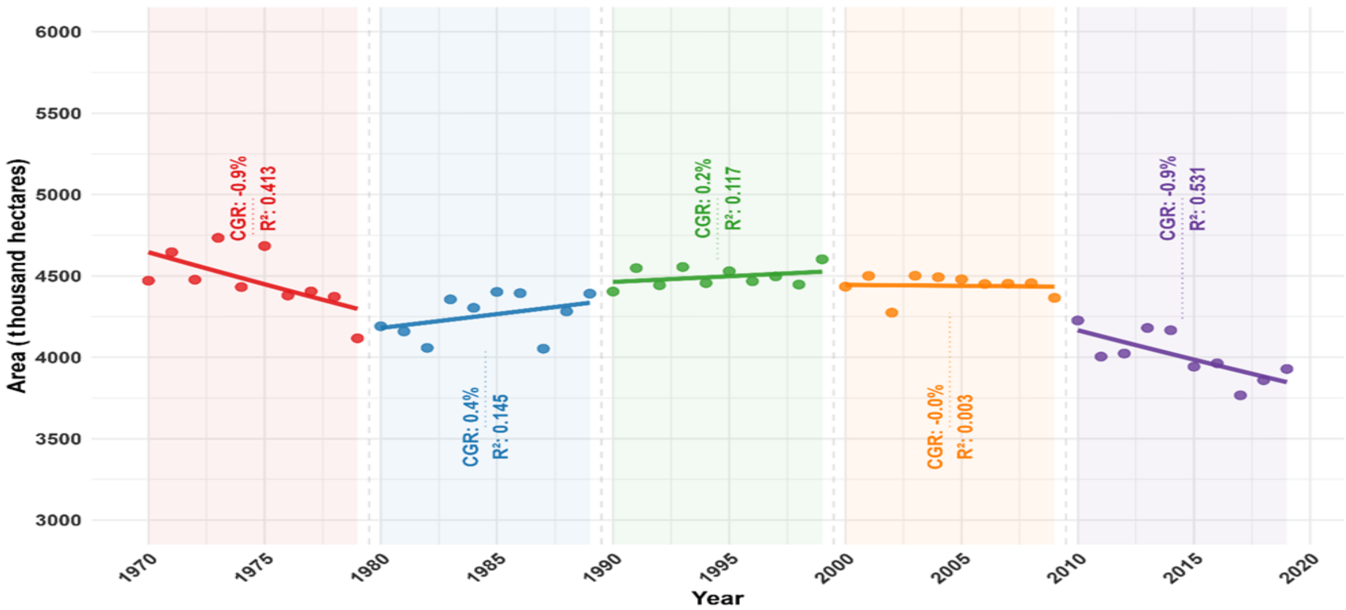

Fig. 1. Paddy area trend in Odisha 1970-2020.

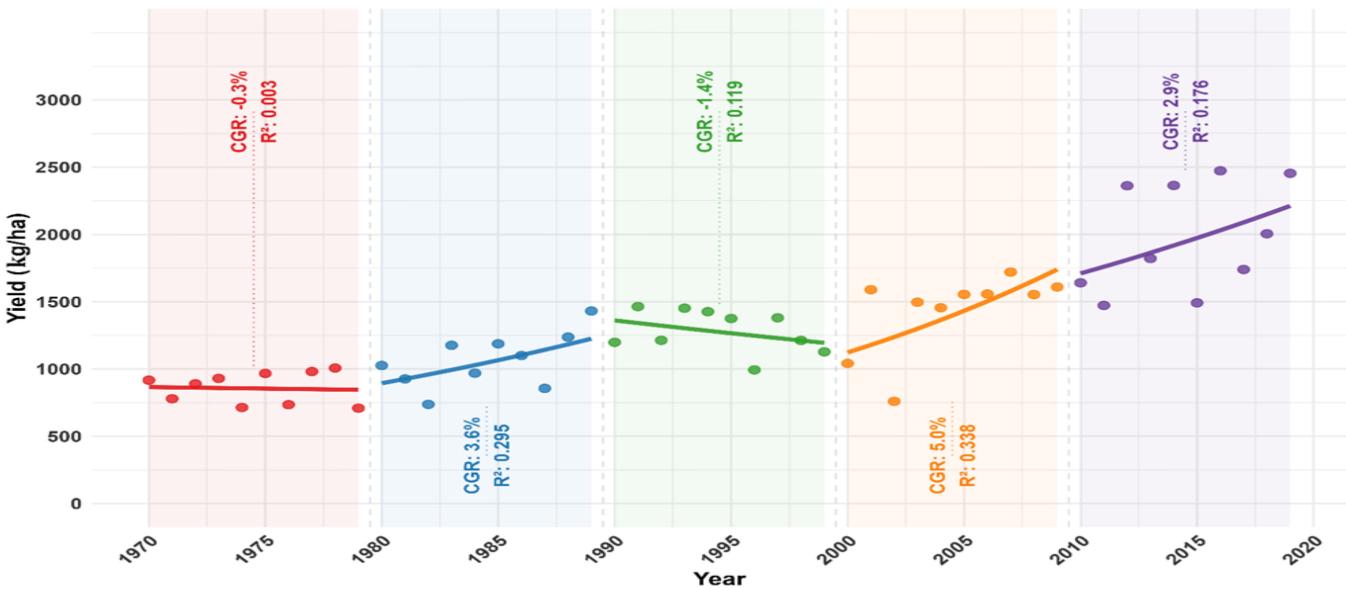

Fig. 2. Paddy yield trend in Odisha 1970-2020.

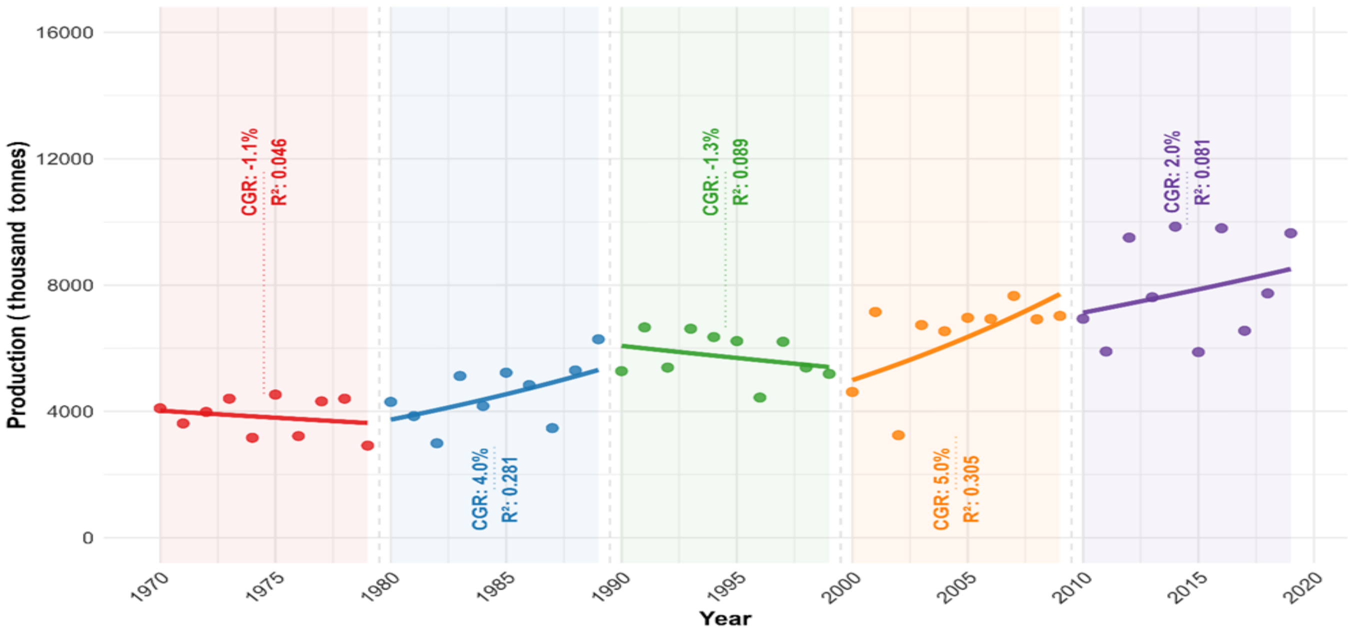

Fig. 3. Paddy production trend in Odisha 1970-2020.

Decomposition of paddy production growth

A decomposition analysis was conducted to quantify the relative contributions of area expansion and yield improvement to changes in paddy production. This method isolates the change in production into three distinct components: the "Area effect" (change due to expansion or contraction of cultivated land), the "Yield effect" (change due to improvements in land productivity) and the "Interaction effect" (the synergistic effect of simultaneous changes in both area and yield).

The results for the 1970-2020 period are clear and decisive. As shown in Table 4, the yield effect was the overwhelming source of production growth, accounting for 91.93 % of the total increase in paddy output. The area effect made a marginal positive contribution of 8.26 %, while the interaction effect, which captures the combined impact, was negligible and slightly negative at -0.19 %. This finding provides definitive quantitative evidence that the story of paddy sector in Odisha over the last half century is fundamentally a story of agricultural intensification.

Table 4. Average decadal contribution of area, yield and interaction effects to production change (%) in paddy

Component	Percentage contribution (%)
Yield effect	91.93
Area effect	8.26
Interaction effect	-0.19

Green gram

This section presents evidence of the trends in area, yield and production of green gram in the state of Odisha, India, over a 50-year period from 1970-71 to 2019-20. The analysis is based on time series data and employs growth rate calculations and decomposition analysis to identify long term trajectories and the sources of change.

Overall growth trajectory of green gram production (1970-2020)

Analysis of the 50-year period reveals divergent trends for the key indicators of green gram cultivation. The area under cultivation experienced a statistically significant positive growth, while yield demonstrated a significant, albeit slight, decline. Consequently, the overall growth in production was modest. A semi logarithmic trend model was fitted to the time series data to estimate the CAGR.

The results, summarized in Table 5, indicate that the area under green gram in Odisha expanded at a CAGR of 1.39 % per annum. This trend is highly significant (p<0.001), with the time variable explaining approximately 54 % of the variation in area (R^2=0.542). In stark contrast, the yield, or productivity, of green gram exhibited a negative CAGR of -0.41 % per annum. While the magnitude of this decline is small, the trend is statistically significant (p=0.011), though the model's explanatory power is low (R^2=0.128). The interplay of these two opposing forces resulted in an overall production growth rate of 0.97 % per annum. This growth in production is also statistically significant (p=0.002), but the low R^2 value (0.187) suggests considerable year to year volatility around this long-term trend.

These aggregate figures establish a central paradox for the study period: a consistent, long-term expansion in the land allocated to green gram cultivation did not translate into proportional production gains due to a simultaneous, persistent challenge in enhancing crop productivity.

Decadal dynamics and structural breaks of green gram production

The 50-year aggregate trends mask significant shifts and periods of acute volatility in green gram cultivation. To capture this nonlinear evolution, the study period was disaggregated into five distinct decades. The analysis of decadal CAGRs, presented in Table 6, reveals a dynamic history characterized by structural

Table 5. Overall growth and trend analysis of green gram in Odisha (1970-2020)

Variable	CAGR %	Regression coefficient (b)	Standard error	*t*-statistic	*p*-value	*R*-square (R^2)
Area ('000 ha)	1.39	0.013764	0.001825	7.543507	1.09E-09	0.542
Yield (kg/ha)	-0.41	-0.00409	0.001541	-2.65467	0.0107	0.128
Production ('000 tonnes)	0.97	0.009667	0.002909	3.322535	0.0017	0.187

breaks rather than smooth progression. The trendlines of area, yield and production of green gram from 1970 to 2020 were depicted in Fig. 4-6.

The 1970s (1970-80) were a period of explosive growth, driven mainly by area expansion. The area under green gram grew at a remarkable rate of 7.83 % per year, a trend with a very strong fit (R^2=0.83). However, this was accompanied by a significant decline in yield, which declined at 2.61 % per year. The net effect was a robust production growth of 5.02 % per annum.

The 1980s (1980-90) marked a period of stagnation and decline in area and yield. Area growth came to a halt, with a statistically insignificant CAGR of 0.41 % (R^2=0.01). The decline in yield continued at -1.89 % per annum, a statistically significant trend (R^2=0.47). This combination of stagnant area and falling yield led to a negative production growth rate of -1.49 % annually.

The 1990s (1990-2000) represented a decade of profound crisis for the green gram sector in Odisha. All three indicators registered sharp and statistically significant negative growth. Area contracted at a rate of -3.54 % per year, yield fell by -3.45 % and consequently, production plummeted by an alarming -6.86 % annually. The R^2 for all three trends are moderately high (around 0.50), indicating a consistent downward spiral during this period.

The 2000s (2000-2010) witnessed a dramatic and comprehensive turnaround. This decade was characterized by strong, positive growth across all metrics. Area expanded at 5.48 % per year, and for the first time in the study period, yield showed an increase of 3.56 % annually. This synergistic growth in both area and yield propelled production to increase at an exceptional rate of 9.23 % per year. The high R^2 values for all three variables (all > 0.71) emphasize the strength and consistency of this recovery.

The final decade, the 2010s (2010-20), can be characterized as a period of consolidation, where growth was sustained primarily through productivity gains. Area growth was minimal at 0.22 % and statistically insignificant (R^2=0.03). However, yield continued to improve at a moderate rate of 1.40 % per annum, which was statistically significant (R^2=0.52). This productivity improvement was sufficient to drive a modest but positive production growth of 1.61 % per year.

Decomposition of green gram production

To further understand the drivers of production changes, a decomposition analysis was conducted. This method disaggregates the year-on-year change in total production into three components: the area effect (change in production due to change in area, holding yield constant), the yield effect (change in production due to change in yield, holding area constant) and the interaction effect (the simultaneous change in both area and yield). The average percentage contribution of each effect to the total change in production was calculated for each decade (Table 7).

The results of the decomposition analysis align perfectly with the decadal growth trends. In the 1970s, the change in production was overwhelmingly dominated by the area effect, which contributed an average of 105.7 % to the change, while the yield effect had a strong negative contribution (-10.4 %). This confirms that the growth in this decade was purely extensification.

During the 1980s, the area effect's contribution diminished significantly to 28.5 %, while the yield effect's negative impact became more pronounced at -27.3 %, explaining the overall production decline. The 1990s crisis saw both area and yield effects contributing negatively, at -39.9 % and -52.2 % respectively, compounding the decline in production.

Table 6. Decadal compound annual growth rates (%) and trend stability (R^2) of green gram in Odisha

Period	Area CAGR (%)	Yield CAGR (%)	Production CAGR (%)	R^2 area	R^2 yield	R^2 production
1970-80	7.83	-2.61	5.02	0.83	0.27	0.39
1980-90	0.41	-1.89	-1.49	0.01	0.47	0.12
1990-2000	-3.54	-3.45	-6.86	0.47	0.51	0.49
2000-10	5.48	3.56	9.23	0.72	0.74	0.78
2010-20	0.22	1.40	1.61	0.03	0.52	0.34

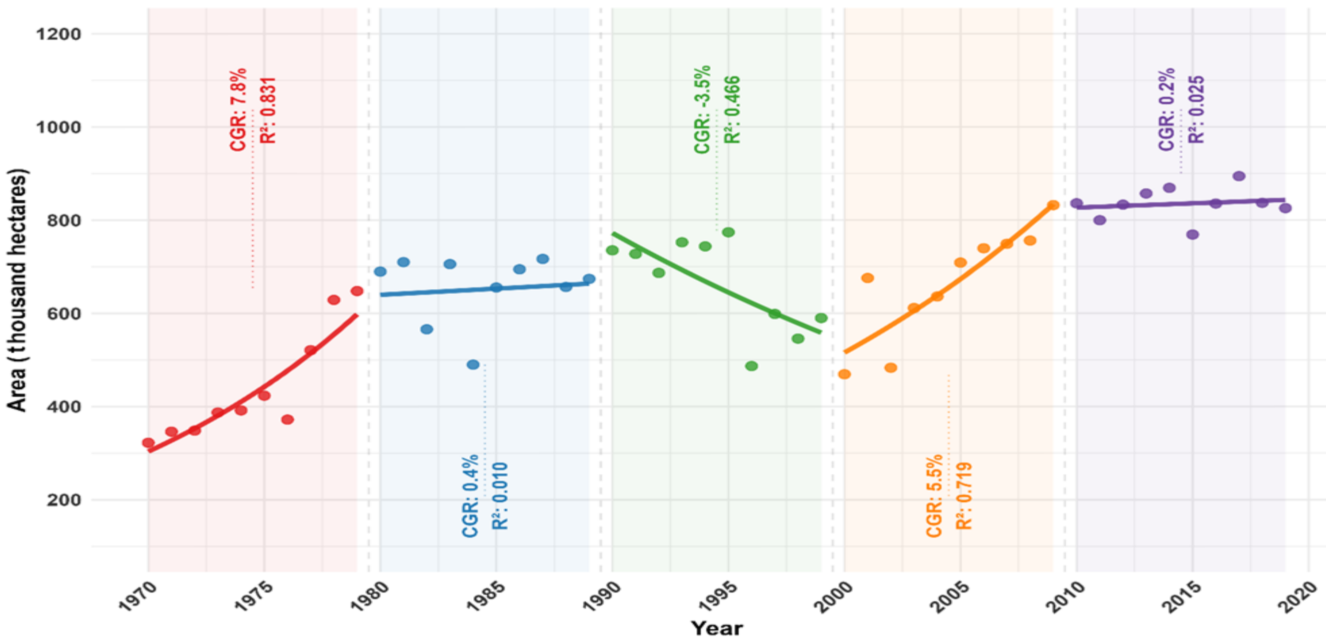

Fig. 4. Green gram area trend in Odisha 1970-2020.

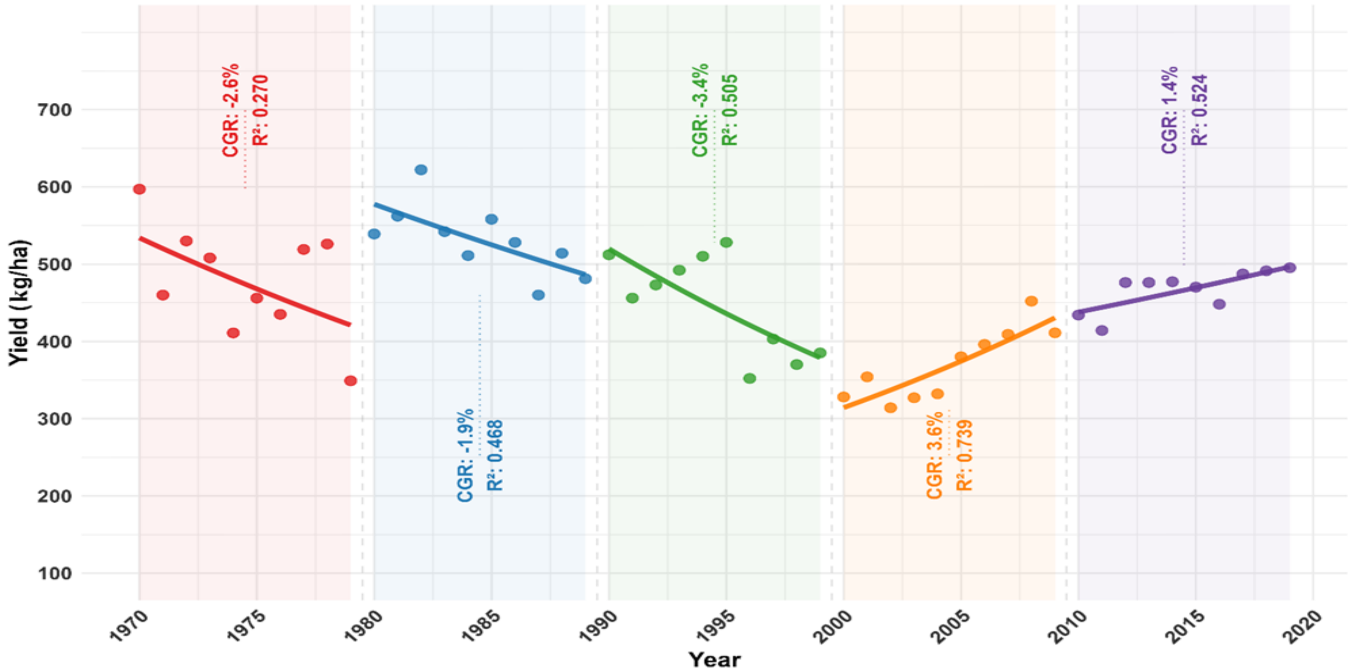

Fig. 5. Green gram yield trend in Odisha 1970-2020.

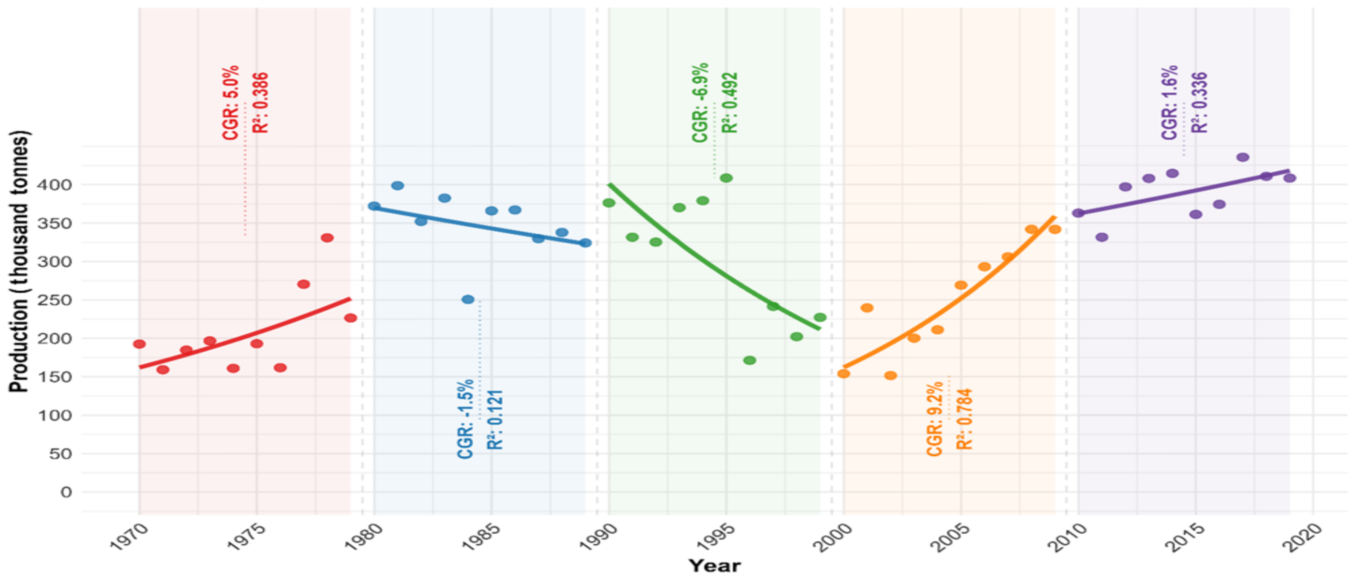

Fig. 6. Green gram production trend in Odisha 1970-2020.

The turn around in the 2000s is clearly reflected in the decomposition results. The yield effect emerged as the primary positive driver, contributing 65.5 % to the production change. The area effect also contributed positively (33.5 %), highlighting the dual engine growth of this decade. Finally, in the 2010s, the yield effect became the sole engine of growth, contributing 129.5 % to the change in production, while the area effect had a negative contribution of -30.5 %, reflecting the volatile but overall stagnant area during this period.The interaction effect remained a minor contributor across all decades

Table 7. Average decadal contribution of area, yield and interaction effects to production change (%) in green gram

Component	Percentage contribution (%)
Yield effect	129.5012
Area effect	-30.512
Interaction effect	1.010776

Groundnut

This section presents the quantitative findings from the analysis of time-series data on the area, yield and production of groundnut in the state of Odisha for the 50-year period from 1970-71 to 2019-20. The analysis employs log-linear regression to determine long-term and decadal growth rates and a decomposition model to ascertain the sources of change in production.

Overall growth trajectory of groundnut cultivation (1970-2020)

To assess the long-term performance of groundnut cultivation, a semi-logarithmic trend equation was fitted to the time-series data for area, yield and production. Here, Y_t represents the variable in year t and b is the regression coefficient used to calculate the CAGR.

The results for the entire 50-year period are summarized in Table 8. Over the long term, the area under groundnut cultivation in Odisha exhibited a marginal but statistically significant positive growth, with a CAGR of 1.37 % per annum (p<0.001). Similarly, groundnut yield demonstrated a modest but highly significant positive trend, growing at a CAGR of 0.81 % (*p*<0.00001). The combined effect of these trends resulted in an overall production growth rate of 2.19 % per annum, which was also highly significant (*p*<0.000001).

A critical finding from the long-term analysis is the low explanatory power of the trend models, as indicated by the R-Square (R^2) values. The R^2 value for area was only 0.207, indicating that a simple time trend explains less than 21 % of the annual variation in cultivated area. For yield and production, the R^2 values were 0.383 and 0.407 respectively. These low values suggest a high degree of volatility and significant year to year fluctuations around the long-term growth path, pointing to the influence of factors not captured by a linear time variable.

Decadal shifts in growth dynamics of groundnut production

To capture nonlinear dynamics and structural shifts over 50 years, the analysis was divided into five decades. This periodized approach reveals a volatile history marked by phases of rapid expansion, severe contraction and technology driven recovery. Decadal growth rates and model fits are presented in Table 9. The trendlines of area, yield and production of groundnut during 1970–2020 are shown in Fig. 7-9.

The first two decades, from 1970 to 1990, were a period of remarkable area led expansion. In the 1970s, area grew at an exceptional rate of 9.15 % per annum, a trend that was highly consistent as shown by the R^2 value of 0.939. This expansion, however, was accompanied by a significant decline in yield at a rate of -4.20 % per annum. In the 1980s, area expansion continued at a robust 8.51 % CAGR, while the decline in yield was arrested, showing near stagnation (-0.58 %). Consequently, production growth accelerated from 4.56 % in the 1970s to 7.87 % in the 1980s, driven almost exclusively by the expansion of cultivated land.

The decade from 1990 to 2000 marked a dramatic and severe reversal. The groundnut sector experienced a systemic shock, with area contracting at a rate of -5.07 % annually. This was not a random fluctuation but a consistent trend, as indicated by a high R^2 of 0.957. Yield also declined at a rate of -1.93 %, leading to a sharp fall in total production with a CAGR of -6.89 %.

The period from 2000 to 2010 represented a significant turnaround, characterized by yield led recovery. While area growth was weak (2.06 %), yield grew at a strong and consistent CAGR of 4.72 % (R^2=0.744). This was the first decade to exhibit sustained productivity gains, which drove a healthy production growth of 6.88 %.

However, this recovery was not sustained into the final decade. From 2010 to 2020, the sector entered another phase of decline. Area under cultivation contracted significantly at a rate of -3.58 % per annum. While yield continued to grow at a modest 0.93 %, this was insufficient to offset the reduction in area, resulting in an overall decline in production at a CAGR of -2.68 %.

Table 8. Overall growth and trend analysis of groundnut in Odisha (1970-2020)

Variable	CAGR %	Regression coefficient (b)	Standard error	*t*-statistic	*p*-value	R-square (R^2)
Area	1.37	0.0136	0.0038	3.53	0.00092	0.207
Yield	0.81	0.0080	0.0015	5.46	1.67e-06	0.383
Production	2.19	0.0216	0.0038	5.74	6.21e-07	0.407

Table 9. Decadal growth performance (CAGR %) and trend stability (R^2) of groundnut in Odisha

Period	Area CAGR (%)	Yield CAGR (%)	Production CAGR (%)	R^2 area	R^2 yield	R^2 production
1970-80	9.15	0.939	-4.2	0.375	4.56	0.435
1980-90	8.51	0.876	-0.58	0.054	7.87	0.82
1990-2000	-5.07	0.957	-1.93	0.156	-6.89	0.693
2000-10	2.06	0.408	4.72	0.744	6.88	0.675
2010-20	-3.58	0.729	0.93	0.728	-2.68	0.503

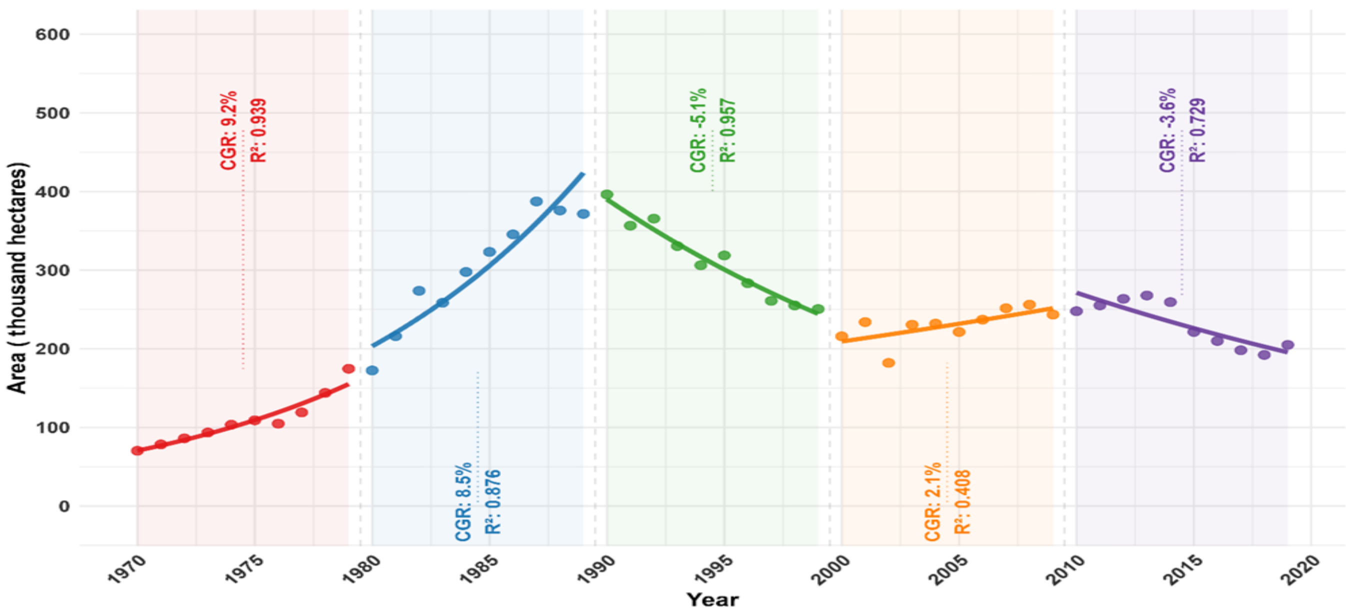

Fig. 7. Groundnut area trend in Odisha 1970-2020.

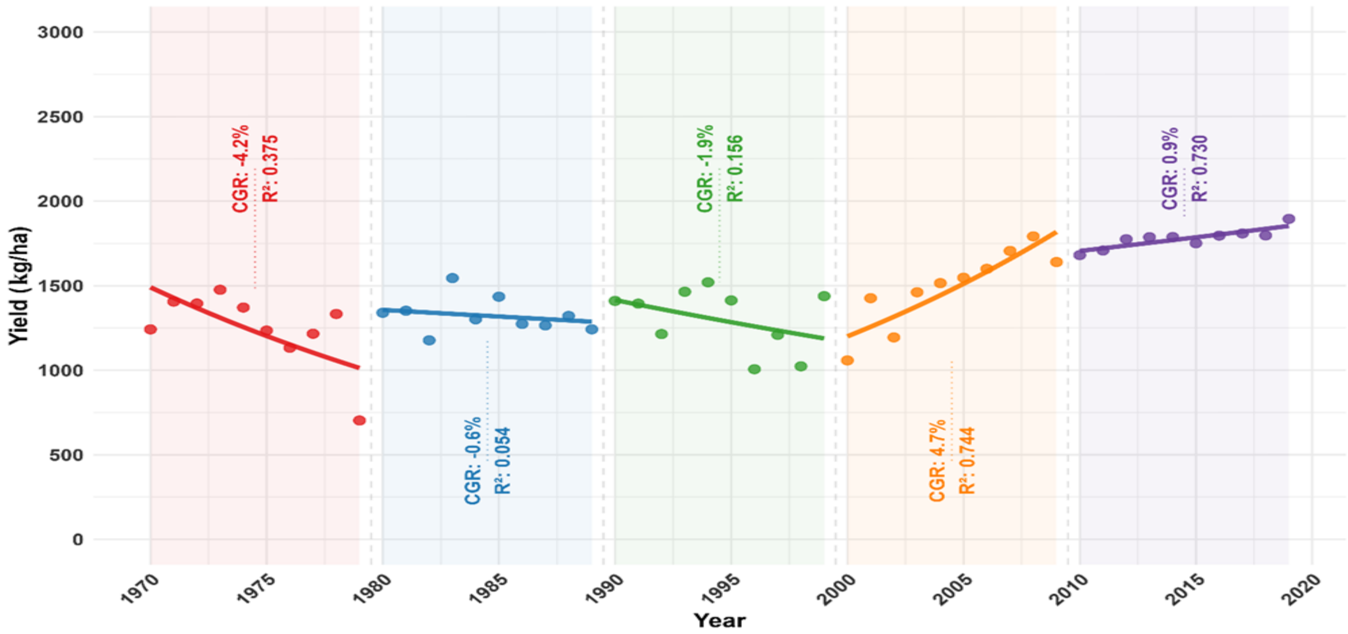

Fig. 8. Groundnut yield trend in Odisha 1970-2020.

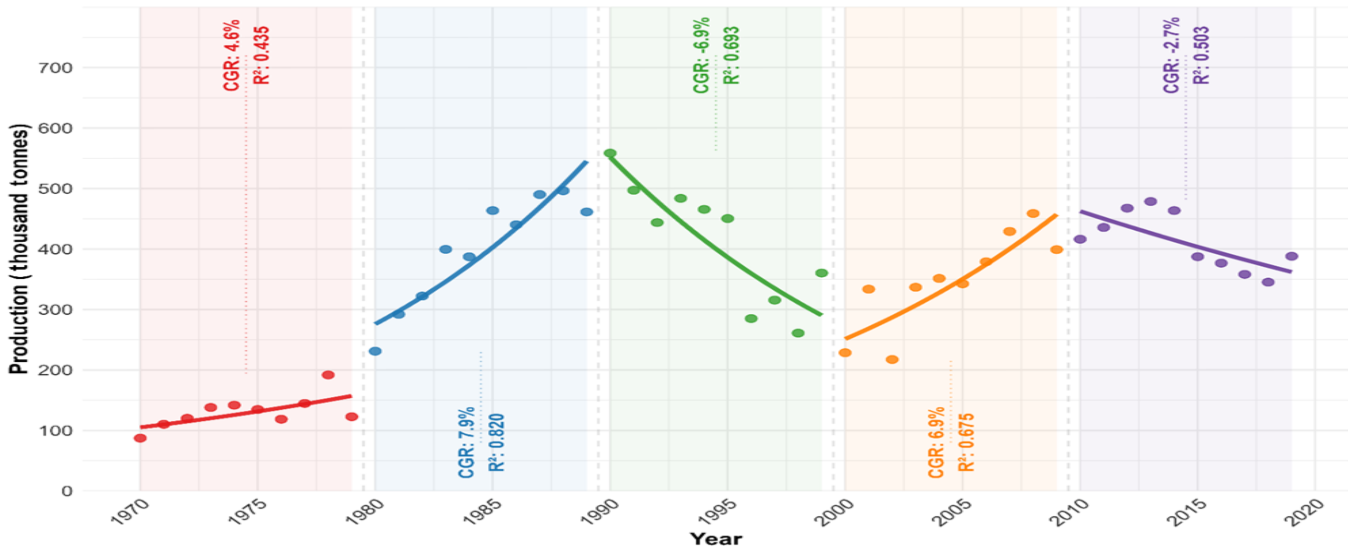

Fig. 9. Groundnut production trend in Odisha 1970-2020.

Decomposition of change in groundnut production

To quantify the relative contributions of area and yield to the change in total groundnut production over the entire 50-year period, a decomposition analysis was performed. The change in production (ΔQ) was separated into three distinct components: the yield effect (change in yield on base year area), the area effect (change in area at base year yield) and the interaction effect (the combined effect of simultaneous changes in both area and yield).

The results, presented in Table 10, reveal a counter intuitive structure of growth. The pure effect of changes in yield contributed a modest 4.20 % to the overall change in production. In stark contrast, the pure effect of changes in cultivated area had a large negative contribution of -57.10 %, indicating that the net withdrawal of land from groundnut cultivation over the 50 years acted as a major drag on total output. Most remarkably, the interaction effect, which captures the synergistic impact of simultaneous changes in area and yield, had a massive positive contribution of 152.90 %. This suggests that the relationship between area and yield changes was a dominant force, more than compensating for the negative influence of area reduction.

Table 10. Average decadal contribution of area, yield and interaction effects to production change (%) in groundnut

Component	Percentage contribution (%)
Yield effect	4.20
Area effect	-57.10
Interaction effect	152.90

Discussion

Both the methodologies have been chosen carefully because all the previous studies have either taken aggregate or region-specific approaches. The rigorous, crop specific, decadal trend and decomposition analysis fills an important gap, supporting targeted and evidence-based recommendations for the state's agricultural planners and policymakers.

Paddy

The empirical trends in paddy cultivation in Odisha over the past five decades reflect a trajectory of intensification shaped by region specific ecological and institutional challenges. This evolution, marked by periods of impressive gains followed by sharp setbacks, is consistent with broader scholarly assessments of eastern India's uneven agricultural transformation. The experience in Odisha exemplifies how agricultural growth in disaster prone and resource constrained environments is not linear, but subject to profound external and policy induced fluctuations.

The growth surge in the 1980s with yield increasing at +3.56 % per annum can be interpreted as the state's belated integration into the green revolution transformations that had revitalized agriculture in northwestern India decades earlier. As documented in empirical and review studies (2, 5), this late phase growth in Odisha coincided with broader diffusion of high yielding varieties (HYVs), increased access to institutional finance and limited but growing fertilizer and irrigation infrastructure in eastern India. Scholars note that this second phase of the revolution was catalysed by both market pull and policy push factors that helped offset initial geographical and infrastructural disadvantages (18).

However, the growth achieved in this phase was ultimately fragile, as it rested upon limited systemic resilience to climatic disruption. This became starkly evident in the 1990s, a period when climatic volatility reversed previous gains. The 1999 super cyclone which destroyed close to 2 million tonnes of rice and inundated 1.7 million hectares represents a textbook case of a climate induced agricultural collapse. Multiple studies confirm that this event not only damaged standing crops but also rendered a wide area infertile due to saline intrusion. As highlighted by IPCC linked regional assessments (14), such extreme weather events in eastern India have increased in frequency and intensity, making Odisha one of the most climate vulnerable agricultural landscapes in the country.

The moderate yet sustained growth during the 2010s reflects a shift in state led intervention, specifically through the Bringing Green Revolution to Eastern India (BGREI) program launched in 2010–11. In contrast to the broader and often inequitable diffusion-based model of the 1980s, BGREI represented a targeted, area specific initiative focusing on yield gaps, resource constraints, and climate vulnerability in eastern India (19, 20). Peer reviewed evaluations of the program demonstrate significant gains in productivity following the adoption of interventions such as line transplanting, stress tolerant varieties and site-specific nutrient management.

Importantly, BGREI served as a corrective policy mechanism explicitly responding to the deficiencies of the first green revolution and the devastation of the 1990s. A study point out that such agroecology tailored programs are essential in fragile geographies like Odisha, where average rice yield still lags national benchmarks largely due to structural and climatic constraints (21).

Despite recent improvements of paddy in Odisha cultivation remains exposed to chronic risks, especially from climatic extremes. Academic consensus points to high frequency of cyclones, floods, and irregular rainfall as central factors hindering sustainable agricultural progression of Odisha (16). These disasters not only inflict direct yield losses but also catalysed long term ecological degradation, including salinity, sedimentation and reduced soil fertility.

Moreover, challenges such as fragmented land parcels, limited irrigation and scarce mechanization increase farmers' exposure to risk. These constraints are frequently highlighted in both localized econometric studies and wider evaluations of the Eastern Gangetic Plains (22). Absent upgrades to infrastructure, extension services and access to protective measures like crop insurance and advanced weather forecasting, agriculture of Odisha will remain under persistent systemic strain.

Consistent with recent studies (23), a dual track strategy is essential: advancing technological intensification precision agriculture and resilient varieties while simultaneously strengthening institutional resilience (disaster response systems, input access and land reforms). This shift toward climate smart agriculture is essential not only for sustainability but also for equity and long term food security.

Green gram

Over the past five decades, green gram farming in Odisha has evolved under the influence of technological innovations, shifting government policies and unforeseen disruptions. Integrating statistical trends with scholarly studies highlights how each stage growth, plateau, downturn and resurgence mirrors the wider developments seen across the state's pulse sector.

The initial decades after the green revolution were defined by the widespread adoption of high yielding cereal varieties, which fundamentally altered the agricultural landscape. Extensive research demonstrates that this transformation disproportionately favored irrigated cereals, sidelining pulses such as green gram (8, 15). In a study, the state level analysis quantifies a substantial negative impact on pulse area documenting that nearly a quarter of wheat expansion post 1960s occurred at the direct expense of pulses (8). This displacement is echoed in our data, which show that the green gram area in Odisha grew primarily by spreading to marginal, less fertile, rainfed lands, a phenomenon termed the "marginal land effect" (8).

The "Pulses Development Scheme" (1969-74) represented the first national effort to counterbalance cereal centric development, but as emphasised in reviews of pulse policy (Directorate of Pulses Development, 2018), these interventions were under resourced and failed to provide the necessary technological or infrastructural support. Empirical decomposition analysis further shows that area expansion contributed positively to output, whereas stagnating or declining yields consistently limited productivity, reflecting national trends for pulses (24).

By the 1990s, the limits of an area driven growth model became starkly apparent. Peer reviewed decadal analyses (24) confirm that productivity in pulses plateaued or declined without technological breakthroughs and amidst continued policy neglect. Experience in Odisha was exacerbated by acute exogenous shocks notably the catastrophic 1999 super cyclone leading to a sharp contraction in area, yield and production, consistent with the vulnerability of rainfed systems described in national studies.

The profound impact of such shocks fostered a new sense of political and institutional urgency, inaugurating entities like the Odisha State Disaster Mitigation Authority (OSDMA) and creating a policy environment conducive to more robust, coordinated interventions (Government of Odisha, 2000).

The early 2000s marked a paradigm shift. Nationally, the Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPOM) and subsequently, the National Food Security Mission (NFSM) represented evidence-based departures from earlier fragmented approaches (Directorate of Pulses Development, 2018. For the first time, the enhancement of pulse productivity was made a policy priority on par with area expansion.

Rigorous impact studies conducted in various states including pulse growing pockets comparable to Odisha demonstrate that NFSM interventions improved access to high yielding varieties, extension services and farm inputs (25). These programs were associated with statistically significant increases in area, yield and technology adoption among beneficiary farmers, including notable gains in green gram productivity. Another study corroborates that districts with higher rates of technological adoption achieved both stronger growth and greater yield stability (24).

Recent research emphasizes the importance of integrating technological, institutional and market innovations to secure pulse systems against climate and price shocks (26, 27) collaboration between Odisha and ICARDA and state-level missions has accelerated the spread of climate smart green gram varieties, precision agronomic practices and participatory seed systems. Comprehensive assessments emphasize that, when integrated with farmer collectives and decentralized extension, these solutions foster both resilience and inclusive growth among smallholder pulse growers (26, 27).

In summary, the green gram production in the Odisha narrative from post green revolution marginalization to recent resilience directly reflects major empirical trends and lessons documented in the broader pulse's literature (8, 15, 24, 25). The path forward lies in sustaining momentum on technology diffusion, value chain integration and climate adaptation, as echoed throughout the latest scientific assessments.

Groundnut

The 50-year quantitative record of groundnut cultivation in Odisha is marked by volatility, policy flux and the evolving interplay of climate and technology. Peer-reviewed research deeply validates the complexity and multidimensionality observed in our findings, from persistent climatic risk to the repercussions of policy and innovation.

The consistently low R^2 values in yield and production trends highlight what identify as structural production instability in rain fed agriculture of Odisha, especially groundnut. Such instability stems primarily from profound climatic vulnerability: groundnut yields correlate strongly with monsoon performance, as confirmed by land suitability analyses and state level time series models. The state's documented exposure to 22 droughts and 35 floods between 1951 and 2010, alongside near annual cyclonic disturbances, translates into extreme inter annual yield fluctuations (1). These climate induced shocks are a fundamental, quantifiable driver of the statistical volatility we observe, mirroring broader patterns found in regional and national studies (16).

In the 1970s and 1980s, expansion in groundnut output relied overwhelmingly on extensive growth i.e., bringing additional, often rain-fed, marginal land under cultivation. Studies corroborate this land abundant, technology scarce model, where high area growth masks yield stagnation or decline as cropping expanded into suboptimal environments, yield variability increased, and the sector remained highly vulnerable to rainfall deficits and floods a process widely echoed in the Indian literature on pulse and oilseed expansion (16).

The sector wide contraction of the 1990s represents not merely a cyclical downturn but a systemic shock, as shown by a rapid retreat in area, falling yields and a near 7 % annual decline in production. Empirical microstudies underline that farmers, facing repeated climatic adversities, poor seed quality and price instability, made withdrawal decisions in sequence first on marginal and risk prone lands, then in coastal zones affected by frequent flooding. This aligns with both our decomposition results and state level analyses tracing widespread area loss to climatic and market risk

The post 2000 period marks a yield driven resurgence, with improved varieties and policy interventions at the core. Participatory field trials and multiyear technology assessment studies demonstrate that new high yielding, drought and disease resistant varieties ('Smruti', 'Dharani', 'TG 51', among others) combined with nutrient and pest management delivered yield increases of up to 47 % over traditional practices (28). These advances were made possible by scaling up front line demonstrations and strengthening extension services factors shown to be vital in Odisha's groundnut intensification, particularly where irrigation and input access aligned with previous studies (28, 29).

Concurrently, targeted state (30) and national programs (e.g., RKVY) channelled investments into mechanization, input availability and market development. Crop insurance and price support mechanisms, as analysed previously (31), provided risk mitigation that was critical to building farmer confidence and sustaining technology adoption.

Decomposition of output growth reveals a striking paradox: widespread withdrawal from marginal land (-57 % area effect) occurs alongside a large, positive interaction between area and yield (+153 %). This is emblematic of the sector's consolidation. Groundnut farming is retreating from the most vulnerable rainfed fields, yet concentrating and intensifying on higher potential, better managed plots. Peer-reviewed studies substantiate this finding, demonstrating that access to irrigation, fertile soils, improved seeds and proximity to markets are the main determinants of continued cultivation and technical intensification (7).

This synergy targeting technology on better land has been powerful enough to reverse overall productivity declines despite shrinking area, echoing similar transitions identified in groundnut and broader oilseed sectors across India.

The literature converges on three intervention priorities: (a) strengthening value chain clusters that connect producers to processors (32), (b) sustaining MSP procurement and market infrastructure for price stabilization (31) and (c) scaling up comprehensive risk mitigation via crop insurance (PMFBY) and social safety nets (e.g., KALIA) (33) to encourage continued investment in groundnut (34). Technology adoption will only fully translate to sectoral resilience if these economic and institutional supports are robust and inclusive.

In sum, the groundnut experience in Odisha with major field crops cultivation illustrates not just periodic growth or contraction, but an adaptive restructuring of the sector. The path forward, as affirmed by the research literature, rests on integrating climate smart technology, effective policy and economic security to build a more stable, profitable and resilient groundnut economy. The results obtained are in line with observations of previous studies (7, 35-37).

Conclusion

This comprehensive analysis of 50 years of agricultural dynamics in Odisha reveals complex, nonlinear growth patterns across three major field crops viz. paddy, green gram and groundnut, as they are highlighting both the resilience and vulnerabilities of the state's agrarian economy. The study's findings illuminate distinct trajectories for these crops reflecting unique responses to technological innovations, policy interventions, and climatic challenges that have shaped Odisha's agricultural landscape from

1970 to 2020. Future research should integrate climate-resilient modeling, micro-level farm analytics, and rigorous policy impact assessments to formulate adaptive, technology-driven frameworks that enhance the sustainability, productivity, and resilience of Odisha's agricultural systems.

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Authors' contributions

The research work was conceptualized, and the methodology was designed by PPT in consultation with SNM, PBB, CN and SKD; all contributed to the development of research methodology, data validation and manuscript refinement. PBB, AKG and SD supported the statistical analysis, interpretation of findings and visualization of results. PBB and RKR were responsible for drafting the manuscript and ensuring coherence in the discussion. JA participated in design and coordination. All authors actively participated in reviewing, editing and approving the final manuscript. All the authors read and approved the final manuscript.

Compliance with ethical standards

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Ethical issues: None

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