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Growth, decomposition and yield convergence of paddy production in India: Evidence from state-level panel data, 2000-01 to 2021-22

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Abstract
Paddy (rice) is essential for India's food security and the livelihoods of rural communities. This study looks at the growth rates, sources of growth, and inequalities in yields among states for paddy in India from 2000-01 to 2021-22, using data from the Directorate of Economics and Statistics (DES), Government of India. Compound annual growth rates for area, production, and yield were estimated over two sub-periods: from 2000-01 to 2011-12 and from 2012-13 to 2021-22, as well as for the entire period. Production growth was decomposed into area, yield, and interaction effects. Inter-state yield differences were analysed using measures like CV, Gini, and Theil's T for both sigma and beta convergence. The total area in India stayed almost unchanged at 0.18% per year, while production growth increased from 1.82 to 2.39% per year. This growth was largely due to yield contribution, which accounted for 91.7% of overall production growth during the full period. Yield inequalities decreased consistently, with CV falling from 43.6% in 2000-01 to 25.4% in 2021-22. Sigma-convergence was confirmed through a negative coefficient in CV, Gini, and Theil ($p < 0.01$) along with beta-convergence ($\beta = -2.45$, $R^2 = 0.62$ for the entire period). Madhya Pradesh, Chhattisgarh, Gujarat, and Rajasthan stood out as states that were catching up. In contrast, Punjab, Haryana, Kerala, and Tamil Nadu were experiencing yield stagnation. Policy should focus on improving yield in lagging states rather than expanding area, while also considering resource sustainability in high-yield regions.

Keywords: Compound annual growth rate, decomposition analysis, sigma convergence, beta convergence, Gini coefficient, Theil index

1. Introduction

Rice, grown in India as paddy, is the staple food for nearly half the country's population. It is also the largest user of net sown area among foodgrains. India produced an estimated 150 million tonnes of rice in 2024-25 from over 500 lakh hectares of land across 614 districts, overtaking China as the world's top producer. This achievement hides two key concerns. First, the balance between area expansion and yield improvement has changed since the Green Revolution era. In a land-limited economy, future growth relies on how quickly yields improve. Recent farm-level evidence shows that average rice yields across major producing states remained 1.7-2.4 tonnes per hectare below attainable levels, leaving considerable scope for productivity-led growth (H. S. Nayak *et al.*, 2024) [14]. Second, the technology that boosts yields has not been shared fairly. Punjab, Haryana, and parts of Andhra Pradesh and Tamil Nadu saw high yields early on, while much of eastern and central India fell behind, despite having good agro-climatic conditions. Whether this gap has closed in the last two decades is important for food security, fairness between regions, and the direction of investment.

A large body of research has looked at rice growth and its components in India. (Laitonjam *et al.*, 2018) [11] found that yield effects accounted for over 92% of production growth between 1980 and 2014, a result supported by several state-specific studies like (Faldu *et al.*, 2024) [7]. (Banerjee & Kumar Kuri, 2014) [2] and (Kumar *et al.*, 2014) [10] reported mixed and fluctuating evidence of convergence, while (Chatterjee, 2017) [3] found beta-convergence, but not sigma-convergence, in per-hectare agricultural income from 1967 to 2010. At the crop level, (Mukhopadhyay, 2021) [12] found that convergence in cereal yields was stronger for wheat than for rice.

(Balaji & Gopinath, 2023) [1] revealed that farm incomes were converging across Indian districts, but at a slower pace in recent years, while (Sinha, 2021) [17] reported robust district-level convergence in rice yields particularly in Bihar, but wheat and maize showed limited and divergent trends. The present study aims to: (i) estimate compound annual growth rates of paddy area, production, and yield across Indian states for three periods: 2000-01 to 2011-12, 2012-13 to 2021-22, and the entire period; (ii) break down production growth into area, yield, and interaction effects; (iii) measure inter-state yield inequality using measures like CV, Gini, and Theil's T while tracking its trend; and (iv) test sigma- and beta-convergence and categorize states into catch-up, moderate, and stagnating groups.

2. Materials and Methods

2.1 Data and Study Period

The study uses secondary, state-wise annual data on paddy area ('000 Hectares), production ('000 Tonnes) and yield (Kg. /Hectare) for 2000-01 to 2021-22 from the Directorate of Economics and Statistics (DES), Government of India. The period was split into Period I (2000-01 to 2011-12) and Period II (2012-13 to 2021-22) and the full 22-year period.

2.2 Compound (Exponential) Growth Rate

Compound annual growth rates of area, production and yield were estimated for each state using the log-linear growth model (Dandekar, 1980) [4]:

$$\ln Y_t = a + b \cdot t + u_t \quad \ldots\ldots(1)$$

where Y_t is the area, production or yield in year t; a is the intercept; b is the regression coefficient; t is the time variable (year); and u_t is the random disturbance term. The compound annual growth rate, expressed as a percentage, was computed as:

$$\text{CAGR}(\%) = (e^b - 1) \times 100 \quad \ldots\ldots(2)$$

2.3 Decomposition Analysis

The contributions of area, yield and their interaction to production growth was examined using the additive decomposition model of Sharma (1977) [16] where the total change in production is decomposed as:

$$\Delta P = (A_n - A_0)Y_0 + (Y_n - Y_0)A_0 + (A_n - A_0)(Y_n - Y_0) \quad \ldots\ldots(3)$$

With A = area, Y = yield, P = production ($P = A \times Y$), and subscripts 0 and n denoting the base and terminal years, respectively. Each component was expressed as a percentage of ΔP:

$$\text{Component share}(\%) = (\text{Component} / \Delta P) \times 100 \quad \ldots\ldots(4)$$

2.4 Yield Inequality Measures

Inter-state inequality in paddy yield in each year was measured using three broad indicators.

Coefficient of variation:

$$\text{CV}(\%) = (\sigma / \mu) \times 100 \quad \ldots\ldots(5)$$

Where, σ is the standard deviation and μ is the mean of state-wise yield in that year.

Gini coefficient (Gini, 1921) [8], computed from the Lorenz curve of state-wise yield:

$$G = 1 - \Sigma_{k=1}^{n} (X_k - X_{k-1})(Y_k + Y_{k-1}) \quad \ldots\ldots(6)$$

where X_k and Y_k are the cumulative proportions of states and of yield respectively, ranked from lowest to highest yield, and n is the number of states.

Theil's T index ((Theil, 167 C.E.)):

$$T = (1/n)\, \Sigma_{i=1}^{n} (y_i / \bar{y}) \ln(y_i / \bar{y}) \quad \ldots\ldots(7)$$

where y_i is the yield of the i-th state and $\bar{y}$ is the mean yield across all n states.

2.5 Sigma- and Beta-Convergence

The Sigma-convergence tests were conducted to see whether the interstate inequalities decline over time, by regressing each inequality indicator on a linear time trend:

$$I_t = \alpha + \beta \cdot t + \varepsilon_t \quad \ldots\ldots(8)$$

where I_t is the inequality indicator (CV, Gini, or Theil's T) in year t. A negative, statistically significant β indicates sigma-convergence.

Beta-convergence (Barro and Sala-I-Martin, 1992) tests whether low-performing states cadtch-up with the high-yield states, using cross-sectional regression:

$$g_i = \alpha + \beta \cdot \ln(Y_{i,0}) + \varepsilon_i \quad \ldots\ldots(9)$$

where g_i is the compound annual growth rate of yield for state i over the relevant period, and $Y_{i,0}$ is state i's yield in the initial year. A negative, statistically significant β indicates beta-convergence.

2.6 State Clustering by Convergence Performance

Each state in all the three periods was classified based on the Beta- convergence results into: (i) Catch-up (Low initial yield, High growth), (ii) Moderate/Neutral, and (iii) Stagnating (High yield, Low growth). All the maps in the paper were produced using R software and Survey of India Shapefiles.

3. Results and Discussion

3.1 Growth in Area, Production and Yield of Paddy

The compound annual growth rates (CAGR) of area, production and yield for Period I (2000-01 to 2011-12, 'P-I'), Period II (2012-13 to 2021-22, 'P-II') and the overall period were reported in Table 1. The area growth remained stable at the all-India level (0.00% in P-I, 0.58% in P-II, 0.18% overall), while production grew at the rate from 1.82% to 2.39% per annum, and yield growth remained steady (1.82%, 1.80%, 1.84%). It is evident that the significant growth in the paddy production in India has been largely contributed by the yield improvements, rather than area expansion during the study period.

The growth of area under paddy in Telangana was 10.08% per annum after becoming a separate state in 2014, largely due to new lift-irrigation schemes such as Kaleshwaram, which helped to increase the state's irrigated command area severalfold (Panjala *et al.*, 2024) [15]. Rajasthan (3.48% overall, and 5.49% in Period II) and Gujarat (2.03%) also experienced irrigation-led area expansion story. On the other hand, Kerala (-4.48% in Period I, -2.76% overall), Goa (-2.40%), Puducherry (-2.22%) and the Andaman & Nicobar Islands (-3.60%) have been lost paddy land - a mix of urbanisation, rising labour costs, and farmers shifting to more profitable non-paddy uses (Jose & Padmanabhan, 2016). Andhra Pradesh's area actually grew in Period I (2.00%) but sharply declined after bifurcation (-3.09% overall). Telangana recorded the highest production growth (11.51%), largely due to irrigation-led area expansion (Panjala *et al.*, 2024) [15]. Madhya Pradesh (8.17%) and Rajasthan (7.78%) also recorded significant production growths, largely due to yield enhancements (Faldu *et al.*, 2024) [7]. The Andaman & Nicobar Islands (−4.78%) recorded negative growth, still recovering land lost to the 2004 tsunami, which left paddy soils saline and waterlogged in many low-lying areas (Raja *et al.*, 2009). Madhya Pradesh's 6.48% yield growth - could be achieved largely due push into hybrid and short-duration varieties and expanding canal and tube-well irrigation (Faldu *et al.*, 2024; A. K. Nayak *et al.*, 2023) [7, 13]. Rajasthan, Chhattisgarh, Bihar and Jharkhand all recorded more than 3% yield growth, a catch-up pattern similar to district-level convergence evidence for rice in many eastern states. Punjab (0.79%) and Haryana (1.06%) recorded yield growths well below the national 1.84% average, owing to decades of intensive paddy cultivation and falling water tables (Dangar & Mishra, 2024) [5].

Table 1: Compound growth rates of paddy area, production and yield, by Indian state and period

State	Area P-I	Area P-II	Area Full	Prod. P-I	Prod. P-II	Prod. Full	Yield P-I	Yield P-II	Yield Full
Andhra Pradesh	2.00%	-0.09%	-3.09%***	2.97%*	1.99%***	-2.00%**	0.95%*	2.08%**	1.12%***
Arunachal Pradesh	0.28%*	0.70%***	0.61%***	5.52%***	-0.82%	3.55%***	5.23%***	-1.52%	2.92%***
Assam	-0.25%	-0.77%***	-0.23%	1.43%	-0.66%	2.02%***	1.69%**	0.12%	2.26%***
Bihar	-1.23%**	-0.92%*	-0.70%***	-0.64%NS	0.78%	2.92%***	0.60%	1.72%	3.64%***
Chhattisgarh	-0.20%**	-0.28%	-0.04%	5.23%**	1.47%	3.63%***	5.45%**	1.75%	3.68%***
Goa	-1.16%**	-3.82%***	-2.40%***	-2.38%**	-4.35%***	-2.19%***	-1.23%	-0.55%	0.21%
Gujarat	3.26%***	2.53%***	2.03%***	9.02%***	3.34%***	5.11%***	5.58%***	0.79%*	3.02%***
Haryana	2.29%***	1.12%NS	1.89%***	3.54%***	2.00%***	2.97%***	1.23%*	0.87%*	1.06%***
Himachal Pradesh	-0.66%***	-1.23%***	-0.87%***	0.52%NS	2.30%*	1.03%**	1.18%NS	3.57%**	1.91%***
Jammu & Kashmir	0.68%***	-0.17%	0.61%***	2.40%***	-2.71%*	1.25%**	1.70%**	-2.54%	0.63%
Jharkhand	-2.46%	0.24%	0.30%	2.85%	-0.79%	3.45%***	5.45%***	-1.03%	3.14%***
Karnataka	1.37%	0.35%	-0.64%	2.59%	2.57%	0.36%	1.20%	2.22%***	1.01%**
Kerala	-4.48%***	0.14%	-2.76%***	-2.50%***	1.13%	-1.25%***	2.08%***	0.98%	1.56%***
Madhya Pradesh	-0.87%**	1.05%	1.59%***	3.82%*	6.31%***	8.17%***	4.73%**	5.21%***	6.48%***
Maharashtra	0.03%	0.11%	0.11%	1.91%	1.42%	1.95%***	1.87%	1.32%	1.84%***
Manipur	2.68%***	1.95%	1.96%***	2.55%*	7.26%**	1.28%*	-0.12%	5.21%**	-0.67%
Meghalaya	0.05%	-0.10%	0.17%**	1.38%*	1.26%	2.55%***	1.33%**	1.36%	2.38%***
Mizoram	-2.83%***	4.20%	-3.00%***	-10.63%**	3.96%	-2.08%	-8.03%	-0.23%	0.95%
Nagaland	1.82%***	-1.15%	1.35%***	4.40%***	-6.30%**	1.54%*	2.53%**	-5.21%***	0.19%
Orissa	-0.56%**	-0.47%	-0.80%***	2.79%	2.34%	2.22%***	3.37%*	2.82%*	3.04%***
Punjab	1.02%***	0.48%	0.90%***	2.02%***	1.64%**	1.70%***	0.99%**	1.15%**	0.79%***
Rajasthan	1.07%	5.49%***	3.48%***	7.61%**	8.72%***	7.78%***	6.48%***	3.07%***	4.16%***
Sikkim	-2.04%***	-3.81%***	-3.06%***	0.15%	-2.71%*	-1.66%***	2.24%***	1.14%	1.44%***
Tamil Nadu	0.39%	2.96%**	0.18%	1.69%	5.81%	1.14%	1.29%	2.78%	0.96%
Telangana	NA	10.08%***	10.08%***	NA	11.51%***	11.51%***	NA	1.30%*	1.30%*
Tripura	0.52%	0.28%	0.55%***	2.56%***	1.46%***	2.34%***	2.02%***	1.18%***	1.78%***
Uttar Pradesh	-0.09%	-0.49%***	0.08%	1.01%	1.69%*	1.68%***	1.10%*	2.19%**	1.59%***
Uttarakhand	-0.50%*	-0.35%	-1.02%***	0.10%	2.29%***	0.90%***	0.60%	2.65%***	1.94%***
West Bengal	-0.73%	0.21%	-0.35%**	0.16%	1.16%***	0.72%***	0.89%***	0.94%***	1.07%***
A & N Islands	-3.21%***	-2.77%	-3.60%***	-3.01%***	-2.57%	-4.78%***	0.20%	0.21%	-1.23%**
Delhi	1.47%**	-0.57%	-0.57%**	12.88%***	-3.22%	1.37%	11.24%***	-2.67%	1.95%
Puducherry	-3.42%***	1.97%***	-2.22%***	-3.25%***	2.06%	-1.06%**	0.18%	0.09%	1.19%***
All India	0.00%NS	0.58%**	0.18%*	1.82%**	2.39%***	2.02%***	1.82%***	1.80%***	1.84%***

P-I = 2000-01 to 2011-12; P-II = 2012-13 to 2021-22; Full = 2000-01 to 2021-22
*** Sig. at 1%, ** Sig. at 5%, * Sig. at 10%

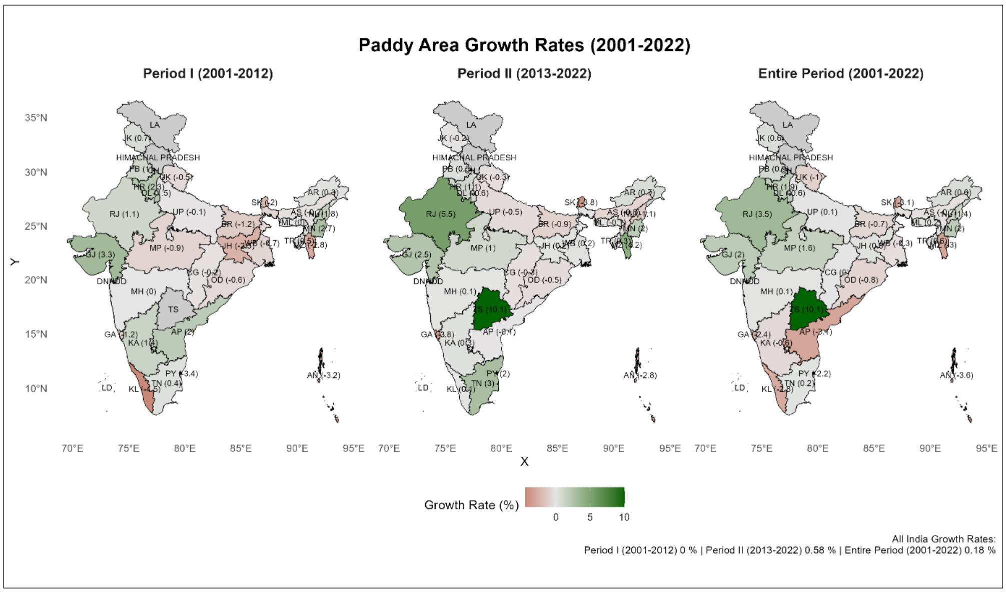

Fig 1: Spatial distribution of paddy area growth rates, by period

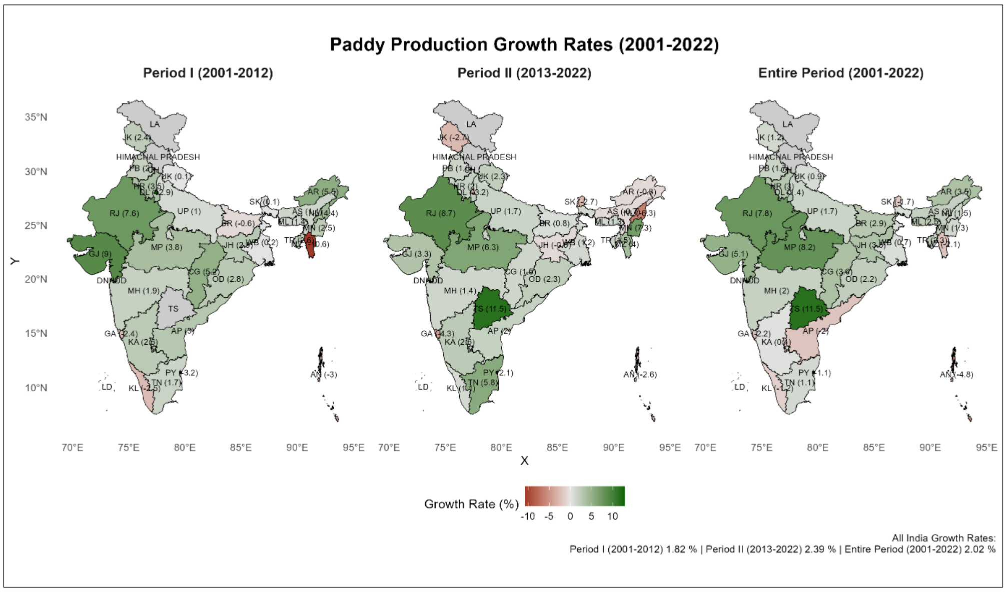

Fig 2: Spatial distribution of paddy production growth rates, by period

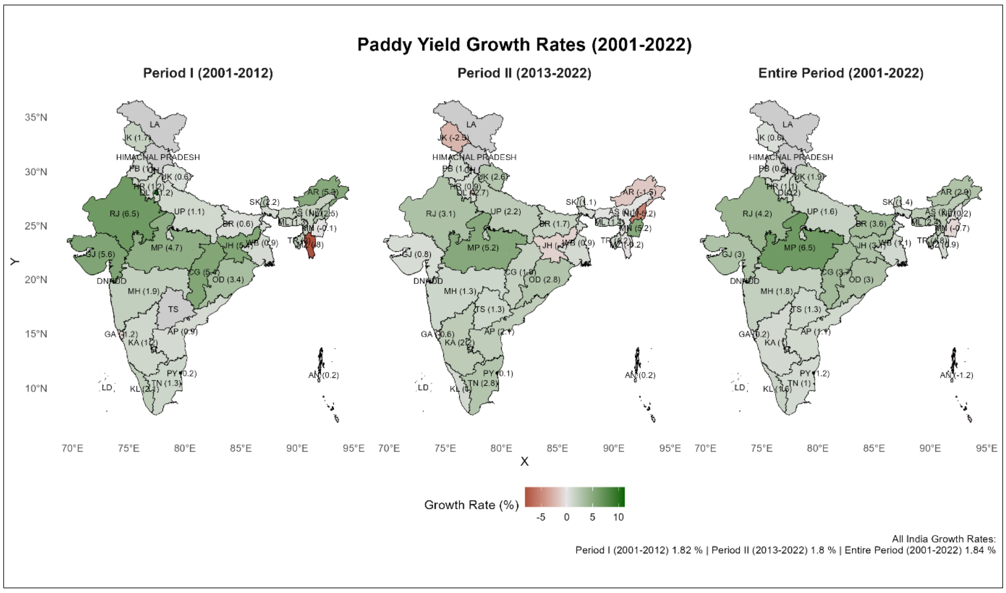

Fig 3: Spatial distribution of paddy yield growth rates, by period

3.2 Decomposition Analysis of Production Growth

The growth in production of paddy was decomposed into area effect, yield effect and interaction effects and the results are presented in Table 2 and Table 3. At the all-India level, the yield effect accounts for 91.7% of production growth, area for only 8.3% in the entire time period, confirming that growth was largely due to productivity gains. In period I, area decreased at the all-India level, and the yield effect (107.5%) more than offset a negative area effect (-7.5%); and in period II, area was a large contributor (38.2%) alongside the yield effect (61.8%).

Table 2: All-India decomposition of paddy production growth, by period

Period	Prod. Growth (%)	Area Effect (%)	Yield Effect (%)	Interaction (%)
2000-01 to 2011-12	1.82**	-7.45	107.45	-1.71
2012-13 to 2021-22	2.39***	38.24	61.76	4.89
2000-01 to 2021-22	2.02***	8.27	91.73	3.16

Across most states, the yield effect clearly outweighs the area effect as the source of production growth over the full period. Madhya Pradesh (85.03%), Rajasthan (84.25%), Punjab (62.36%), Haryana (63.63%) and Assam (228.83%) all show yield as the dominant contributor. This confirms that productivity gains have led to growth in production in these states rather than area enhancements. Area effect was relatively modest in almost every state. Gujarat (29.98%), Haryana (36.37%) and Manipur (61.04%) experienced a larger area contribution than other states.

Table 3: State-wise decomposition of paddy production growth, 2000-01 to 2021-22

State	Prod. Growth (%)	Area Effect (%)	Yield Effect (%)	Interaction (%)
Andhra Pradesh	-2.00	131.7	-31.7	18.96
Arunachal Pradesh	3.55	22.17	77.83	10.91
Assam	2.02	-128.83	228.83	-26.82
Bihar	2.92	-49.49	149.49	-25.03
Chhattisgarh	3.63	-0.26	100.26	-0.28
Goa	-2.19	126.93	-26.93	14.94
Gujarat	5.11	29.98	70.02	29.27
Haryana	2.97	36.37	63.63	12.37
Himachal Pradesh	1.03	-73.08	173.08	-35.94
Jammu and Kashmir	1.25	55.86	44.14	4.25
Jharkhand	3.45	-4.39	104.39	-2.57
Karnataka	0.36	-51.5	151.5	-8.99
Kerala	-1.25	133.49	-33.49	18.71
Madhya Pradesh	8.17	14.97	85.03	17.89
Maharashtra	1.95	14.53	85.47	7.58
Manipur	1.28	61.04	38.96	9.39
Meghalaya	2.55	3.53	96.47	1.7
Mizoram	-2.08	74.21	25.79	-10.09
Nagaland	1.54	48.7	51.3	-10.53
Odisha	2.22	-17.64	117.64	-13.65
Punjab	1.70	37.64	62.36	8
Rajasthan	7.78	15.75	84.25	14.01
Sikkim	-1.66	200.63	-100.63	55.7
Tamil Nadu	1.14	90.28	9.72	0.62
Telangana	11.51	50	50	100
Tripura	2.34	13.04	86.96	5.12
Uttar Pradesh	1.68	-13.22	113.22	-3.98
Uttarakhand	0.90	-140.61	240.61	-47.05
West Bengal	0.72	9.24	90.76	2.48
Andaman and Nicobar	-4.78	62.55	37.45	-20.25
Delhi	1.37	0.28	99.72	0.33
Puducherry	-1.06	294.53	-194.53	59.95
All India	2.02	8.27	91.73	3.16

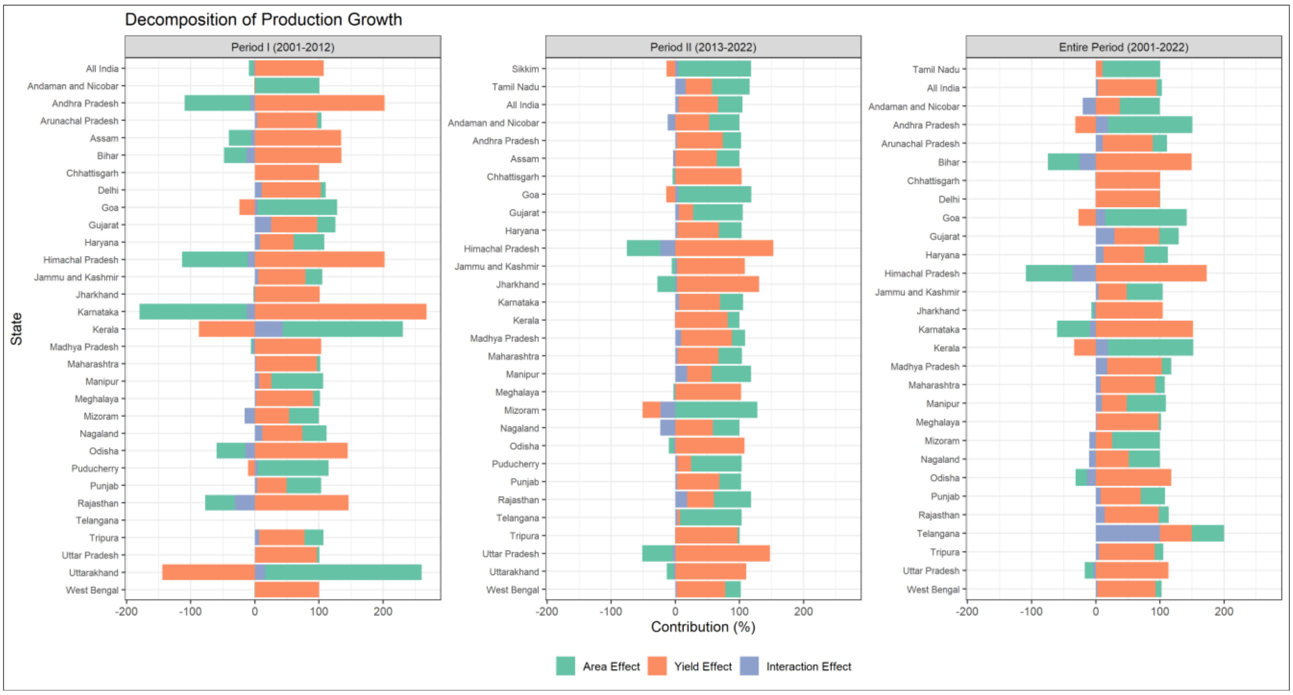

Fig 4: Decomposition of paddy production growth into area, yield and interaction effects, by state and period

3.3 Inter-State Yield Inequality, and Sigma-Convergence

The inter-state yield inequalities were measured over the period of time and results are presented in Table 4. Average paddy yield across all the states increased by almost 41% from 1,843 kg/ha to 2,603 kg/ha during the study period. However, all three inequality measures declined during the entire period. CV decreased from 43.6% to 25.4%, the Gini coefficient from 0.25 to 0.14, and Theil's T from 0.09 to 0.03. This highlights a continuous fall in yield inequalities across states in the country.

Table 4: Year-wise inequality indicators of paddy yield across Indian states, 2001-2022

Year	Mean Yield (kg/ha)	SD	CV (%)	Gini	Theil T
2001	1843.39	804.37	43.64	0.25	0.09
2002	2022.61	659.34	32.60	0.19	0.05
2003	1843.08	769.55	41.75	0.24	0.09
2004	2048.40	618.49	30.19	0.17	0.04
2005	2006.23	738.10	36.79	0.21	0.07
2006	2091.65	779.91	37.29	0.21	0.07
2007	2116.28	841.44	39.76	0.22	0.08
2008	2177.80	851.42	39.10	0.22	0.08
2009	2143.25	783.25	36.55	0.20	0.06
2010	2110.75	823.57	39.02	0.22	0.07
2011	2215.59	721.42	32.56	0.18	0.05
2012	2377.22	728.65	30.65	0.17	0.04
2013	2428.50	569.64	23.46	0.13	0.03
2014	2432.10	733.35	30.15	0.16	0.04
2015	2438.53	666.69	27.34	0.15	0.03
2016	2325.65	702.52	30.21	0.17	0.04
2017	2380.95	595.73	25.02	0.14	0.03
2018	2501.67	701.45	28.04	0.16	0.04
2019	2474.83	698.19	28.21	0.16	0.04
2020	2597.74	668.59	25.74	0.15	0.03
2021	2584.66	618.42	23.93	0.14	0.03
2022	2602.54	661.57	25.42	0.14	0.03

The above trend of decrease in yield inequalities across the states was statistically confirmed using the Sigma-convergence tests of the inequality measures (Table 5). The slope coefficients of all the inequality measures (CV: -0.0237, Gini: -0.0241, Theil's T: -0.0493) were negative and statistically significant at 1% level providing strong evidence of sigma-convergence in paddy yield across the states. The results are stronger than the mixed sigma-convergence evidence reported for broader agricultural income measures (e.g., Chatterjee, 2017) [3] which reflects a more standardised, rapid spread of rice-specific technologies in the country.

Table 5: Sigma-convergence test results for paddy yield inequality indicators

Statistic	Slope	Std. Error	t-value	p-value
CV	-0.0237	0.0039	-6.09	0.000
Gini	-0.0241	0.0039	-6.233	0.000
Theil's T	-0.0493	0.0081	-6.086	0.000

3.4 Beta-Convergence and State Clusters

Beta-convergence was tested by regressing the yield growth with the log of initial yield (Table 6) to test if the low performing states eventually caught up with the high performing states. During Period I, low-yield states grew significantly faster as evident from the negative β Coefficient (-4.2638 (significant at 1% level). During the Period II, β remained negative (-3.1549) but R^2 fell to 0.116, indicating the catch-up was continued but initial yield could not sufficiently predict, as other factors may have gained relative importance. The results over the entire period indicated strong catch-up (β = -2.4469) by the low-yield states. The catch-up effects are plotted in Figure 5 where initially low-yield states (Chhattisgarh, Madhya Pradesh, Rajasthan, Gujarat) cluster in the high-growth region indicating a strong catch-up effect, while initial high-yield states (Punjab, Haryana, Andhra Pradesh, Tamil Nadu, Kerala) cluster in the low-growth region indicating a yield stagnation situation.

Table 6: Beta-convergence test results for paddy yield across Indian states

Study Period	Const. (α)	Slope (β)	Std. Error	t-value	p-value	R^2
2000-01 to 2011-12	33.6935	-4.2638***	0.8887	-4.798	0.000	0.434
2012-13 to 2021-22	25.5677	-3.1549*	1.5629	-2.019	0.052	0.116
2000-01 to 2021-22	19.9627	-2.4469***	0.3494	-7.003	0.000	0.620

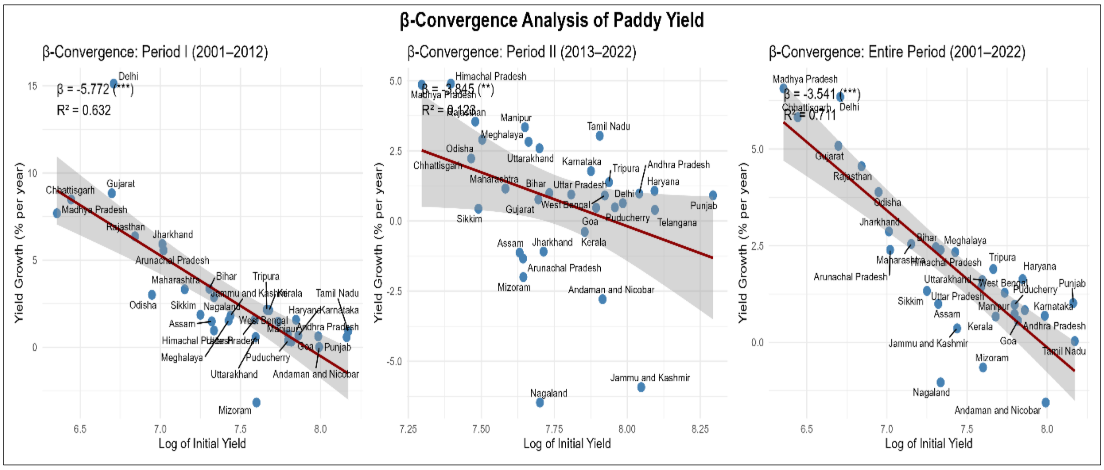

Fig 5: Beta-convergence scatterplots of yield growth against log of initial yield, by period

Based on the Beta Convergence analysis plots (Table 6), the states were classified into catch-up, moderate/neutral and stagnating clusters (Table 7). In Period I, the catch-up cluster (Chhattisgarh, Delhi, Gujarat, Madhya Pradesh, Rajasthan) was localised in central/western India indicating faster yield growth. The major paddy producing and high-yield states (Punjab, Haryana, Uttar Pradesh, West Bengal, Tamil Nadu, Karnataka, Kerala) plus several smaller states/UTs were classified into stagnating cluster. In Period II the catch-up cluster also included some of the hill and north-eastern states (Himachal Pradesh, Meghalaya, Sikkim) along with Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Manipur, Odisha, Rajasthan and Uttarakhand. The stagnating cluster included the Green Revolution belt and also included Telangana. Telangana's yield stagnation reflects that its outstanding production growth was largely area driven.

Table 7: State clusters by convergence category and period

Category	Period I (2000-01 to 2011-12)	Period II (2012-13 to 2021-22)
Catch-up (Low initial yield, High growth)	Chhattisgarh, Delhi, Gujarat, Madhya Pradesh, Rajasthan	Chhattisgarh, Gujarat, Himachal Pradesh, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Odisha, Rajasthan, Sikkim, Uttarakhand
Moderate/Neutral	Arunachal Pradesh, Assam, Bihar, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Maharashtra, Meghalaya, Nagaland, Odisha, Sikkim	Andaman and Nicobar, Arunachal Pradesh, Assam, Jammu and Kashmir, Jharkhand, Mizoram, Nagaland
Stagnating (High yield, Low growth)	Andaman and Nicobar, Andhra Pradesh, Goa, Haryana, Karnataka, Kerala, Manipur, Mizoram, Puducherry, Punjab, Tamil Nadu, Tripura, Uttar Pradesh, Uttarakhand, West Bengal	Andhra Pradesh, Bihar, Delhi, Goa, Haryana, Karnataka, Kerala, Puducherry, Punjab, Tamil Nadu, Telangana, Tripura, Uttar Pradesh, West Bengal

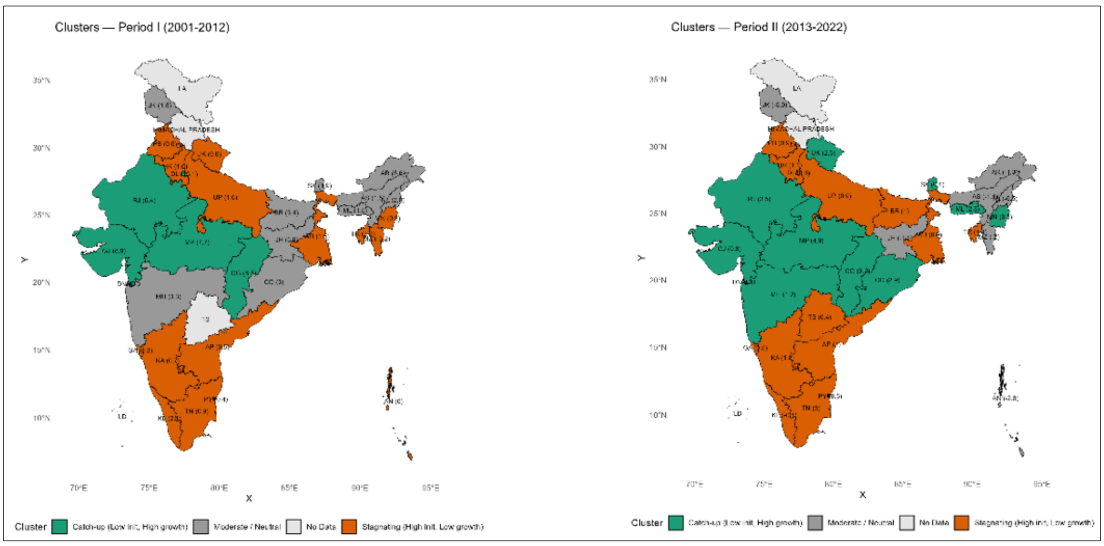

Fig 6: Spatial classification of states by convergence cluster

The above findings have revealed that paddy production growth in India over 2000-01 to 2021-22 was largely contributed by yield improvement rather than area expansion. The yield effect accounted for almost 92% of the production growth across the country. inter-state yield inequality declined steadily, with significant sigma- and beta-convergence. Madhya Pradesh, Chhattisgarh, Gujarat and Rajasthan were the strongest catch-up performers, while Punjab, Haryana, Uttar Pradesh, Andhra Pradesh, Kerala and Tamil Nadu stagnated in terms of yield growth. Accordingly, policy formulations should focus on yield-enhancing investments (improved varieties, soil health, precision inputs) over further area expansion as there are chances of an increase in yield gaps due to climate change effects (Debnath *et al*., 2021) [6]. Extended irrigation, seed replacement, and extension support should be improved for the catch-up and moderate-cluster states to sustain the growth. Yield stagnation and resource sustainability in Punjab, Haryana and Uttar Pradesh should be focused through diversification incentives and water-saving technologies. The state-level yield performance shall be judged by decomposing growth into its area and yield sources instead of only focusing on the production numbers.

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