

An Exploratory Analysis of Foodgrain Growth and Fertilizer Dynamics Across Phases

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Received : February 21, 2025

Accepted : March 26, 2025

Published : June 28, 2025

Citation: Bhardwaj, R., & Singh, N, P. (2025). An Exploratory Analysis of Foodgrain Growth and Fertilizer Dynamics Across Phases. *Sativa : Journal of Agricultural Sciences*, 1(2). 68-85.

ABSTRACT: Since independence, Indian foodgrain has seen substantial modifications throughout many developmental periods, including the pre-Green Revolution era, the Green Revolution, the era of globalization, and the more recent technology-oriented phase. Initially, India relied largely on food grain imports. However, the Green Revolution brought high-yielding cultivars, increased fertilizer usage, and expanded irrigation, resulting in significant productivity improvements, particularly in rice and wheat, and a move toward self-sufficiency. This period also created regional differences in agricultural performance. Post-1991, the globalisation era integrated Indian foodgrain into the international market. While this expanded export opportunities and facilitated access to new technologies, it also increased vulnerability to global price fluctuations and created challenges for small and marginal farmers. The technology-oriented phase further emphasised mechanisation, digital tools, and input intensification. This study examines the long-term growth performance of Indian foodgrain from 1951 to 2022 using secondary data on cereals, nutritional cereals, pulses and total foodgrain. The research is divided into four periods: the Pre-Green Revolution Phase, the Green Revolution and Policy Consolidation, the Globalization Era, and the Technology Era. To assess growth dynamics, the study employs regression models to estimate the Regression-based Compound Annual Growth Rate (CAGR), with corresponding β coefficients, t-statistics, and p-values to determine statistical significance. The results reveal a structural shift from area-led to productivity-driven growth, influenced by increased irrigation and evolving fertilizer consumption patterns, including Nitrogen (N), Phosphorus (P), and Potassium (K). The study highlights phase-wise variation in growth rates, confirming statistically significant improvements in agricultural performance, particularly during the Technology Era.

Keywords: Indian foodgrain, Green Revolution, CAGR, Globalization, Foodgrain productivity.



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INTRODUCTION

The Indian economy is deeply rooted in agriculture, which employs majority of its people. The country is ranked second in agricultural output (Kumar & Sharma, 2023; Menon, 2022; Sharma,

2022). Agriculture's contribution to India's GDP declined from about 51% in 1950-51 to 15% in 2020-21, yet it continues to employ more than half of the workforce (Yadav & Anand, 2020). This continued reliance on agriculture highlights its importance to the Indian economy. The performance of agriculture directly affects the growth of other sectors, demonstrating its vital role in the economy (Tripathi & Prasad, 2009).

The phases of Indian Agricultural growth

India's agriculture saw substantial change after gaining independence, especially during the Green Revolution in the 1960s. The country was still reliant on food imports before this time, but the Third Five-Year Plan (1961–1966) allowed for a transition to self-sufficiency through the use of fertilizer, irrigation expansion, and high-yielding cultivars. Land reforms and irrigation development were major drivers of the pre-Green Revolution era's average annual growth of roughly 2.7% till 1964. Growth sped up to 3.1% to 3.2% in the mid-1960s to early 1990s with the start of the Green Revolution (Mallika & Mageshwari, 2024; M. Rani & Kaur, 2023). The uneven dissemination of technology was reflected in the increasing instability across regions and crops, even though foodgrain productivity improved by more than 230% between 1950–51 and 1990 (Polisetty et al., 2023; Satapathy et al., 2021). Therefore, in addition to increasing output, the Green Revolution brought with it additional sustainability and regional inequality concerns. (Singh, 1993)

The Green Revolution's impact was most visible in the growth of wheat and rice productivity, while coarse cereals and pulses showed limited improvement. Wheat production rose from 8.8 million tons in 1965-66 to 184 million tons in 1991-92, and other cereals saw production increases of 71%. However, the benefits were not evenly distributed across all crops, and some crops, including pulses and certain cash crops, saw little benefit (Kumari et al., 2020; Shinde, 2015).

Globalization and its Impact on Indian foodgrain

India's phase of economic globalisation began in 1991, with substantial macroeconomic reforms. This integration into the global market created both opportunities and challenges for the agricultural sector. On the one hand, globalisation expended opportunities for high-value, labour-intensive agricultural exports. However, it exposed Indian foodgrain to global competition, increasing both pressure on local productivity and market volatility.

The effects have been mixed: while opportunities exist for increased agricultural exports and investment in infrastructure, rural areas have struggled with the adverse effects of increased competition and price instability. (Patil, 2019; N. Rani, 2014). Globalization has also influenced dietary patterns, with an increased focus on processed and junk food, which has adversely impacted the food security and livelihoods of poorer sections of the population (FAO et al., 2021).

Impact of Technology on Yield Growth and Food Security

Traditional agriculture in India was historically characterized by dependence on human labour, monsoon rainfall, and minimal mechanization. Smallholder farmers, who form the majority, relied

on traditional techniques that frequently produced only subsistence-level output. Although these old methods were inherently sustainable, they were insufficient to meet India's burgeoning food demands.

Since the early 2000s, precision agricultural techniques have changed Indian foodgrain. Example includes GPS guidance, soil sensors, drones, and autonomous machinery have enable more efficient resource management and apply fertilizers and pesticides precisely (Kadam et al., 2023; Prakasa Rao & Ramesh, 2022). These technologies have increased agricultural yields while decreasing environmental effect by lowering input requirements, eliminating soil erosion, and boosting irrigation efficiency (Mohanty, 2022; Soma et al., 2019).

The growth of digital agriculture, supported by expanding mobile technology, has given farmers more leverage by offering real-time access to weather patterns, market pricing, and best agricultural techniques. Such data-driven method enables farmers to make educated decisions, such as choosing suitable crop types, optimizing planting schedules, and forecasting disease outbreaks (Gupta, 2023).

Furthermore, technical improvements have encouraged the adoption of sustainable farming practices such as organic farming, vertical farming, and aquaponics, which enable year-round food production while using less water and leaving a smaller environmental imprint (Soma et al., 2019). The incorporation of renewable energy sources such as solar panels and wind turbines into farming operations has increased energy self-sufficiency and reduced carbon emissions, highlighting the environmental benefits of current agricultural techniques (Greeshma, Bhawe, & Kumar, et al., 2017)

The present study aims to conduct a comprehensive analysis of India's agricultural growth from 1951 to 2022 by examining multiple dimensions across four key phases of development. Specifically, it seeks to measure and compare the phase-wise growth rates of area, production, productivity, irrigated and rainfed land for cereals, nutri-cereals, pulses, and total foodgrains using regression-based Compound Annual Growth Rate (CAGR). Further, the study assesses the statistical significance of these agricultural growth trends through β coefficients, t-statistics, and p-values derived from semilog regression models. In addition, it analyzes the phase-wise patterns in fertilizer consumption, production, and import of nitrogen (N), phosphorus (P), and potassium (K), and explores their potential relationship with foodgrain growth performance. Ultimately, the study aims to identify structural shifts in India's agricultural growth trajectory — from being primarily area-driven to becoming productivity-led — while evaluating the critical role of irrigation and fertilizer inputs in this transformation.

METHOD

This study applies a quantitative econometric framework to assess the long-term growth of Indian foodgrain production across four historical phases, using secondary data and semilog regression models to estimate CAGR and test statistical significance. By examining cereals, nutri-cereals, pulses, and fertilizer use over seven decades, the analysis reveals how policy shifts, technological innovations, and globalization have collectively influenced India's agricultural trajectory.

The context

In India, agriculture remains the principal source of livelihood for millions. Despite its diminishing contribution to GDP—from nearly 51% in 1950-51 to roughly 15% in recent years—the sector still employs more than 60% of the workforce, highlighting its socioeconomic importance (Yadav, 2020; Tripathi, 2009; Sharma, 2022). Historically, Indian foodgrain has experienced major upheavals, most notably the Green Revolution of the mid-1960s, which brought high-yielding cultivars, fertilisers, and irrigation systems. This revolution helped the country reach foodgrain self-sufficiency, but it also introduced issues like as unequal growth among crops and regions, as well as increasing agricultural output volatility.

The liberalization of India's economy in 1991 marked the beginning of a new age of globalization, linking local agriculture with foreign markets and exposing it to global competition. This time saw a trend towards commercialization and diversification, with a greater emphasis on high-value crops and agricultural exports. However, globalization brought other issues, such as increased price volatility, marginalization of smallholder farmers, and a growing dominance of processed and low-nutrition food products.

In this context, understanding the effects of structural changes on agricultural growth is essential for framing evidence-based and forward-looking agricultural policies. The present study aims to comprehensively analyze long-term trends and development patterns in Indian foodgrain over the past seven decades, focusing on key variables such as area, production, and productivity of cereals, nutri-cereals, pulses, and total foodgrains, along with fertilizer consumption, production, and import (N, P, K). Using a semilog regression framework, the study estimates Regression-based Compound Annual Growth Rates (CAGR), with statistical validation through β coefficients, t-statistics, and p-values. The analysis is conducted across four major policy and technology phases—Pre-Green Revolution, Green Revolution, Globalization, and Technology Era—to assess the evolution, consistency, and statistical significance of agricultural growth patterns and input dynamics. This approach provides critical insights into the changing structure of Indian foodgrain and supports the formulation of resilient, data-driven policy strategies.

Research Design

This study adopts a quantitative research approach to examine trends, productivity, and growth dynamics in Indian foodgrain from 1951 to 2022. The time frame is segmented into four distinct phases: Pre-Green Revolution, Green Revolution and Policy Consolidation, Globalization Era, and Technology Era. The analysis relies on secondary data compiled from government reports, institutional databases, and academic sources, focusing on cereals, nutri-cereals, pulses, total foodgrains, and fertilizer indicators (N (Nitrogen), P (Phosphorus), K(Potassium) – consumption, production, and import). Growth trends for each variable are analysed using semilog regression models, with Regression-based Compound Annual Growth Rates (CAGR) derived from the estimated β coefficients. Statistical robustness is assessed using t-statistics and p-values to determine the significance of observed changes across the phases. A comparative phase-wise

evaluation is conducted to understand the effects of policy interventions, technological advancements, and globalization on agricultural performance. The study combines descriptive and econometric techniques to offer comprehensive insights into the structural transformation of Indian foodgrain over seven decades.

Data for purpose

The study is based on secondary data gathered from credible government and institutional sources, such as reports from the Ministry of Agriculture and Farmers' Welfare, the Directorate of Economics and Statistics, the Reserve Bank of India (RBI), the Food and Agriculture Organisation (FAO), and the Agriculture Census. Data from 1951 to 2022 cover the productivity of food grains i.e., cereals, nutri-cereals, and pulses in India. The dataset is divided into four phases: pre-Green Revolution, Green Revolution and policy consolidation, and globalisation era and technology age. This classification enables a phase-wise examination of agricultural trends, allowing for the quantitative assessment of growth in productivity, area, and production over time. The goal is to investigate the effects of technological, policy-driven, and economic changes on agricultural growth patterns and input use in India, using regression-based statistical tools to validate the significance of observed trends across four distinct phases.

Phase-wise segmentation

To capture the history of Indian foodgrain in response to legislative reforms, technical advances, and global economic upheavals, the research period (1951-2022) is divided into four major periods. Each phase marks significant transitions in agricultural practices, policy orientation, and external economic conditions. This segmentation forms the analytical foundation of the study, enabling a structured comparison of growth rates, productivity improvements, and input trends over time using statistically validated regression-based methods.

Phase 1: Pre-green Revolution Phase (1951-1966): Characterized by subsistence farming, low productivity, and limited use of modern inputs.

Phase 2: Green Revolution and policy consolidation phase (1967-1991): Marked by the introduction of High Yielding Varieties (HYVs), chemical fertilizers, and expansion of irrigation.

Phase 3: Globalization and Diversification Phase (1992-2000): Initiated by economic liberalization, integrating Indian foodgrain with global markets.

Phase 4: Technology Oriented Phase (2001-2022): Focus on digital agriculture, climate resilience, sustainable intensification, and resource efficiency.

Method of analysis

The research employs a combination of statistical and econometric approaches such as Regression-based Compound Annual Growth Rate (CAGR) and semilog regression analysis to assess the influence of agricultural developments across distinct time periods. These methodologies are applied to evaluate growth patterns, productivity changes, and input trends over four key agricultural phases: the Pre-Green Revolution era, the Green Revolution and Policy Consolidation phase, the Globalization period, and the Technology-driven age. The inclusion of β coefficients, t-statistics, and p-values allows for statistically robust insights into the significance and consistency of observed agricultural trends.

The regression-based CAGR approach was employed to estimate growth rates. Detailed formulas and statistical testing procedures are provided in the manuscript.

The key formulae used are:

To estimate the Compound Annual Growth Rate (CAGR) through regression:

$$\ln(Y_t) = \alpha + \beta t + \varepsilon_t$$

Once the β coefficient is estimated from the semilog regression model, the Compound Annual Growth Rate is calculated as:

$$\text{CAGR (\%)} = [e^\beta - 1] \times 100$$

This formula converts the natural log growth rate to a percentage growth rate over time.

To test whether the estimated growth rate is statistically significant, we conducted hypothesis testing on β using the t-statistic and corresponding p-value. Full estimation details and derivations are provided in the manuscript.

Hypotheses Formulation

In order to statistically validate the growth patterns and transformations in Indian foodgrain across different policy and technological phases, the present study develops a set of null and alternative hypotheses. These hypotheses are based on the assumption that significant structural and institutional changes over time have influenced the area, production, and productivity of major foodgrain crops, as well as fertilizer use patterns. The econometric approach using semilog regression facilitates the estimation of phase-wise growth trends and the statistical significance of those trends.

The hypotheses are tested using **t-statistics and p-values** derived from regression models applied separately for each variable and each agricultural phase.

Hypotheses Related to Foodgrain Growth Variables

H₀ (Null Hypothesis): There is no statistically significant growth in the area under cultivation, production, and productivity of cereals, nutri-cereals, pulses, and total foodgrain during any of the four agricultural phases in India.

H₁ (Alternative Hypothesis): There is statistically significant growth in the area under cultivation, production, and productivity of cereals, nutri-cereals, pulses, and total foodgrain during at least one of the four agricultural phases.

Hypotheses Related to Irrigation

H₀: The growth in irrigated and rainfed area has not changed significantly across the different agricultural phases.

H₁: There is a statistically significant change in the growth of irrigated and rainfed area across the agricultural phases.

Hypotheses Related to Fertilizer Use (N, P, K)

H₀: There is no significant growth in the consumption, production, or import of Nitrogen (N), Phosphorus (P), and Potassium (K) fertilizers during the Globalization and Technology phases.

H₁: There is statistically significant growth in the consumption, production, or import of N, P, and K fertilizers during at least one of the two recent phases.

Hypotheses on Comparative Phase-wise Growth

H₀: There is no difference in the growth rates of agricultural variables (area, production, productivity, fertilizer use) across the four phases.

H₁: There is a significant difference in the growth rates of agricultural variables across the four phases, indicating the impact of policy and technological shifts.

Statistical Testing Framework

These hypotheses are tested using the semilog regression model where the statistical significance of the slope coefficient β is evaluated. The corresponding p-value is used to test the null hypothesis:

- If **p-value < 0.05**, we reject H_0 and conclude that the growth is statistically significant.
- If **p-value $\geq$ 0.05**, we fail to reject H_0 , indicating non-significant growth.

RESULT AND DISCUSSION

This section provides an econometric study of foodgrain production and fertilizer dynamics in India over four distinct agricultural phases: pre-Green Revolution (1951-1965), Green Revolution and Policy Consolidation (1966-1990), Globalization Era (1991-1999), and Technology Era (2000-2022). The study uses regression-based CAGR, β coefficients, t-statistics, and p-values to analyze changes in cereals, nutri-cereals, pulses, total foodgrain, and fertilizer usage (consumption, production, and import).

Growth of Cereals across agricultural phases

During the Pre-Green Revolution (Table 2 & 3), cereal area rose at a CAGR of 1.61% ($p < 0.001$), while production increased at 3.72%. Productivity improvements of 2.07% were statistically significant, indicating both area and yield-based expansion.

During the Green Revolution, output accelerated (3.87%) and productivity increased (2.74%, $p < 0.001$), but area growth slowed (1.10%), supporting the idea of a change from area-led to productivity-led growth.

During the Globalization Era, production and productivity increased (2.85% and 1.60%, respectively), whereas rainfed areas decreased dramatically (-1.40%, $p < 0.001$), supporting the theory that globalization led to more irrigation-intensive agriculture.

The Technology Era had slower growth in both area (0.49%) and production (2.23%) than previous eras. However, productivity remained statistically significant (1.73%, $p < 0.001$), demonstrating ongoing yield benefits from technology infusion.

These results confirm that while the Pre-Green Revolution relied on land expansion, the Green Revolution marked a structural shift toward productivity-led growth. Compared to earlier decades, later phases increasingly depended on irrigation, as seen in the sharp decline of rainfed areas, reflecting technological adaptation and irrigation dependence.

Growth of Nutri-Cereals across agricultural phases

Area under nutri-cereals (Table 2 & 3), decreased dramatically in all subsequent periods (e.g., -1.35% CAGR during the Technology Era). During the Technology period, production increased by 2.31% ($p < 0.001$), whereas previous decades had flat or falling patterns.

Productivity climbed gradually from the Green Revolution to the Technology Era, reaching a peak of 3.70% CAGR ($p < 0.001$), supporting the notion that productivity improvements compensated area reduction in marginal crops.

Although nutri-cereal area consistently declined across phases, productivity gains—particularly during the Technology Era—compensated for these losses. Compared to the Green Revolution, when productivity growth was modest, the Technology Era showed the sharpest gains (3.70% CAGR), highlighting a shift from extensive to intensive cultivation of marginal crops.

Growth of Pulses across agricultural phases

The pulses sector (Table 2 & 3), witnessed moderate expansion until the Technology Era, when production increased (3.95%, $p < 0.001$) and productivity greatly increased (2.19%, $p < 0.001$).

This demonstrates that pulses have benefited from recent targeted policy interventions such as minimum support prices (MSPs) and National Food Security Mission programs.

While pulses lagged behind cereals during the Green Revolution and Globalization Era, the Technology Era marked a turning point, with productivity gains (2.19% CAGR) outpacing earlier decades. This contrast underscores the impact of recent policy measures (e.g., MSP reforms and the National Food Security Mission) that specifically targeted pulses.

Growth of total foodgrain across agricultural phases

Aggregate foodgrain output (Table 2 & 3), increased across all stages, with the highest CAGR recorded during the Green Revolution (2.84%) and the lowest during the Technology Era (2.36%). Productivity growth was consistent throughout all periods (1.72% to 2.59%, all $p < 0.001$), supporting the trend towards intensive agricultural techniques.

Irrigated land continually increased (up to 2.48% CAGR throughout the Globalization Era), whereas rainfed area consistently decreased, supporting the idea that irrigation was a primary driver of foodgrain yield.

Phase-wise comparison shows that the Green Revolution achieved the highest overall growth (2.84% CAGR), while the Technology Era experienced slower expansion (2.36%). However, unlike the pre-1966 period where land expansion was key, the post-Green Revolution periods relied heavily on irrigation and productivity growth. This shift indicates that irrigation, not land expansion, has been the main driver of foodgrain output since 1966.

Phase-wise growth analysis of Fertilizer consumption, production and imports

In addition to assessing the growth performance of different crops, data on fertilizer consumption was also collected, given its critical role in enhancing crop productivity alongside other inputs such as irrigation, pesticides, and insecticides. This analysis aligns with the study's objective: *“To analyze the phase-wise trends in fertilizer (N, P, K) consumption, production, and import, and their potential relationship with foodgrain growth performance.”*

From the data analysis, it can be inferred that:

- **Consumption Trends** – The uptake of major plant nutrients—Nitrogen (N), Phosphorus (P), and Potassium (K)—increased significantly during both phases. Notably, phosphorus consumption recorded a Compound Annual Growth Rate (CAGR) of 5.76% during the Globalization Era ($p = 0.0175$), while nitrogen and potassium grew at 4.89% and 4.78% respectively. The Technology Era saw a moderation in growth, but the upward trajectory continued, with total fertilizer consumption expanding at 2.96% annually.
- **Production Growth** – Domestic production of key nutrients, particularly nitrogen and phosphorus, rose sharply during the Globalization phase, registering CAGRs of 5.79% and 5.26% respectively. This expansion was in line with policy emphasis on self-sufficiency and the establishment of new production capacities. However, growth rates slowed considerably in the Technology Era, with nitrogen production increasing by only 1.37% per year and phosphorus by 1.09%, indicating possible capacity saturation or shifts in import reliance.
- **Import Dynamics** – Fertilizer import patterns underwent a structural shift between the two eras. Nitrogen imports contracted during the Globalization Era (-1.23% CAGR), reflecting domestic production gains, but surged dramatically in the Technology Era, with an 18.90% CAGR ($p < 0.001$), underscoring growing import dependence. Phosphorus and potassium imports also rose substantially in this later phase, at 11.46% and 1.10% respectively, with total imports expanding at 8.09% annually.

Fertilizer use expanded sharply during Globalization, driven by domestic production gains, but the Technology Era witnessed a structural shift: slower production growth alongside rising import dependence. Compared to earlier self-sufficiency efforts, post-2000 agriculture has become increasingly vulnerable to global fertilizer markets, even as consumption remained high.

Table 2: Phase-wise Regression CAGR of cereals, nutri-cereals, pulses, and total foodgrains.

		Regression CAGR			
Phase		Pre Green Revolutio n Phase (1951- 1965)	Green Revolution and Policy Consolidatio n (1966-1990)	Globalizatio n Era (1991- 1999)	Technolog y Era (2000- 2022)
cereals	Area	1.61	1.10	1.22	0.49
	Production	3.72	3.87	2.85	2.23
	Productivity	2.07	2.74	1.60	1.73
	Irrigated Area	2.46	2.80	2.72	1.73
	Un-irrigated (Rainfed)area	1.16	-0.53	-1.40	-3.54
Nutri- cereals	Area	0.71	-0.95	-1.85	-1.35
	Production	2.26	0.76	0.43	2.31
	Productivity	1.34	1.73	2.35	3.70

Pulses	Irrigated Area	-0.34	-0.76	-0.12	1.89	
	Un-irrigated (Rainfed)area	0.80	-0.97	-2.07	-1.96	
	Area	1.47	0.28	-0.14	1.72	
	Production	1.61	0.99	1.43	3.95	
	Productivity	0.14	0.71	1.56	2.19	
	Irrigated Area	0.66	0.31	2.08	4.43	
Total Foodgrain	Un-irrigated (Rainfed)area	1.56	0.27	-0.44	1.12	
	Area	1.23	0.25	0.18	0.35	
	Production	2.96	2.84	2.33	2.36	
	Productivity	1.72	2.59	2.15	2.01	
	Irrigated Area	1.83	2.25	2.48	1.93	
	Un-irrigated (Rainfed)area	1.08	-0.53	-1.40	-1.32	
Fertilizer	Consumption	N	-	-	4.89	3.01
		P	-	-	5.76	3.15
		K	-	-	4.78	2.13
		Total	-	-	5.07	2.96
	Production	N	-	-	5.79	1.37
		P	-	-	5.26	1.09
		Total	-	-	5.64	1.30
		N	-	-	-1.23	18.90
	Import	P	-	-	4.70	11.46
		K	-	-	4.07	1.10
		Total	-	-	2.50	8.09

Table 3: Phase-wise P-Value of cereals, nutri-cereals, pulses, and total foodgrains

		P Value			
Phase		Pre Green Revolution Phase (1951-1965)	Green Revolution and Policy Consolidation (1966-1990)	Globalization Era (1991-1999)	Technology Era (2000-2022)
cereals	Area	0.00	0.00	0.00	0.00
	Production	0.00	0.00	0.00	0.00
	Productivity	0.00	0.00	0.00	0.00
	Irrigated Area	0.00	0.00	0.00	0.00
	Un-irrigated (Rainfed)area	0.00	0.00	0.00	0.00
	Area	0.01	0.00	0.00	0.00

Nutri-cereals	Production	0.00	0.01	0.75	0.00
	Productivity	0.00	0.00	0.08	0.00
	Irrigated Area	0.23	0.00	0.75	0.00
	Un-irrigated (Rainfed)area	0.00	0.00	0.00	0.00
	Area	0.00	0.02	0.75	0.00
Pulses	Production	0.03	0.00	0.11	0.00
	Productivity	0.76	0.02	0.05	0.00
	Irrigated Area	0.04	0.30	0.08	0.00
	Un-irrigated (Rainfed)area	0.00	0.03	0.36	0.00
	Area	0.00	0.00	0.17	0.00
Total Foodgrain	Production	0.00	0.00	0.00	0.00
	Productivity	0.00	0.00	0.00	0.00
	Irrigated Area	0.00	0.00	0.00	0.00
	Un-irrigated (Rainfed)area	0.00	0.00	0.00	0.00
	Area	0.00	0.00	0.00	0.00
Fertilizer	Consumption	N	-	-	0.00
		P	-	-	0.02
		K	-	-	0.08
		Total	-	-	0.00
		l	-	-	0.00
	Production	N	-	-	0.00
		P	-	-	0.02
		Total	-	-	0.00
		l	-	-	0.00
		N	-	-	0.84
	Import	P	-	-	0.43
		K	-	-	0.35
		Total	-	-	0.33
		l	-	-	0.00

This chapter discusses the statistical findings from an investigation of long-term secondary data (1951-2022) spanning four major stages of Indian foodgrain. The findings provide information about trends, structural transitions, and policy-driven effects on agricultural growth and input dynamics. The topic is divided thematically around area, production, productivity, irrigation, and fertilizer use.

A. Transition from Area-Led to Productivity-Led Growth

The pre-Green Revolution era (1951-1965) had good increase in cereals, pulses, and nutri-cereals, with regression-based CAGR showing that land expansion was a primary growth driver. Cereals had a 1.61% area CAGR compared to 2.07% productivity, with both factors statistically significant ($p < 0.01$). However, during the Green Revolution (1966-1990), productivity has continuously surpassed area expansion, particularly in cereals (CAGR of 2.74%) and total foodgrain (CAGR of 2.59%). This verifies the transition from area-based to productivity-based development, which is fuelled by HYV seeds, chemical fertilizers, and irrigation.

B. Influence of Irrigation Infrastructure

Irrigated land expanded rapidly and significantly during all eras, particularly during the Green Revolution (CAGR: 2.80% for cereals) and the Technology Era (1.93% for total foodgrain). Rainfed lands had large declines after 1991, including grains (-1.40% in Globalization Era and -3.54% in Technology Era, both $p < 0.001$). This pattern illustrates India's growing reliance on irrigated agriculture. Irrigation infrastructure augmentation significantly increased productivity and production stability, as evidenced by large β coefficients and high t-statistics.

C. Fertilizer Dynamics: Consumption, Production, and Import

The statistics demonstrate that consumption and imports of N, P, and K fertilizers increased significantly following deregulation. Phosphorus (P) consumption increased significantly at a CAGR of 5.76% (1991-1999) and 3.15% (2000-2022) ($p < 0.05$). Nitrogen (N) imports were negative in the Globalization Era (-1.23%), but increased at an 18.90% CAGR in the Technology Era, illustrating India's rising import dependency. Fertilizer output had a falling growth pattern, particularly during the Technology Era (e.g., N: 1.37%, P: 1.09%), indicating possible issues in domestic supply chains. This supports the concept of increased input intensification, particularly chemical reliance, in Indian foodgrain after 1990.

D. Crop-Wise Observations

Observation 1: Cereals maintained consistent growth in productivity across all phases. The Green Revolution impact is visible with the highest productivity CAGR of 2.74%.

Observation 2: Nutri-cereals showed a mixed trend. Although productivity improved significantly in the Technology Era (CAGR: 3.70%, $p < 0.001$), area and production declined during earlier phases, reflecting shifts in dietary demand and policy focus.

Observation 3: Pulses faced area stagnation and limited growth during early phases but showed remarkable improvement in productivity (CAGR: 2.19%) and production (CAGR: 3.95%) during the Technology Era, aligning with recent governmental support policies such as National Food Security Mission–Pulses.

Policy Implication

The results indicate that India's agricultural expansion has switched from an area-led to a productivity-led paradigm, notably after the Green Revolution. The extension of irrigation infrastructure and increasing usage of fertilizers led to a consistent improvement in cereal and total foodgrain yields, as indicated by the regression-based CAGR and statistically significant β coefficients. However, rainfed regions have consistently declined, particularly during the Technology Era, highlighting an urgent need for targeted irrigation support through micro-irrigation, watershed development, and rainwater collection measures to prevent regional growth imbalances.

The rapid expansion of irrigated areas and fertilizer usage, particularly Nitrogen (N), underlines the importance of input intensification in improving productivity. However, the mismatch in nutrient utilization ratios and expanding import reliance for P and K fertilizers necessitate a

comprehensive strategy that promotes balanced fertilization, greater local production, and organic alternatives. Policies such as nutrient-based subsidies and soil health education initiatives are critical components of efforts to enhance sustainable agricultural practices.

Despite recent productivity advances during the Technology Era, nutri-cereals have seen declining area and stagnating output throughout the Globalization Era. This highlights the need for ongoing assistance through initiatives such as the National Millet Mission, as well as improved market access, MSP, and nutritional promotion. Procurement support and targeted pulse missions had a large influence on pulse productivity throughout the Technology Era, with significant β -coefficients and p-values. These efforts should be broadened to include other locations.

The regression results also demonstrate that policy and technology changes in each phase had a statistically significant impact. The Green Revolution drove irrigated expansion and cereal production, while the Globalization Era resulted in minor improvements due to deregulation, and the Technology Era reflected growth driven by innovation and focused initiatives. These findings indicate that future policies should continue to promote regional customisation, technological uptake, and environmental sustainability.

In compliance with global commitments such as SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 12 (Sustainable Consumption), Indian agricultural policy must incorporate climate-smart techniques, digital agriculture, and inclusive initiatives for smallholders and women farmers. The findings of this study encourage a shift to precision agriculture, efficient resource use, and investment in rural infrastructure and agro-logistics for long-term food and economic security.

CONCLUSION

The study provides an econometric evaluation of fertilizer dynamics and foodgrain growth in India across four agricultural phases (1951–2022). The findings demonstrate that although area, production, and productivity all exhibited notable increases, the drivers of growth shifted over time. Pre-Green Revolution expansion was primarily area-led, whereas the Green Revolution introduced a productivity-led paradigm supported by irrigation, fertilizer use, and HYVs. These trends persisted into later decades, especially during the Technology Era, though with greater reliance on imported fertilizer and irrigated (Government of India, 2022-2023).

The analysis is based on secondary data encompassing the area, production, and productivity of cereals, nutri-cereals, pulses, and total foodgrain in India. Additionally, data on fertilizer dynamics—including consumption, domestic production, and imports of nitrogen (N), phosphorus (P), and potassium (K)—are incorporated to examine their impact on foodgrain growth across agricultural phases (Zaveri & Lobell, 2019).

Table 4: Phase-wise key observations based on Regression CAGR results of Agricultural Variables (1951-2022)

Phase		Observations
Cereals	Area	Growth declined over time; peaked in pre-Green Revolution and slowed significantly in tech era.
	Production	High during Green Revolution (3.87%) and sustained; slowed to 2.23% in technology era.

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		Productivity	Peaked during Green Revolution; stable since with marginal gains in tech era.
		Irrigated Area	Consistent increase till globalization; slight decline in tech era.
		Un-irrigated (Rainfed) area	Growth reversed after pre-Green Revolution; drastic fall in tech era (-3.54%).
Nutri-cereals		Area	Continuous decline post pre-Green Revolution; indicates shift away from coarse grains.
		Production	Sharp decline post-Green Revolution, then revival in tech era (2.31%).
		Productivity	Constant and impressive growth; highest in tech era (3.70%).
		Irrigated Area	Improved only in tech era (1.89%), after prior negative growth.
		Un-irrigated (Rainfed) area	Sharp decline post-Green Revolution; continues negative trend in tech era.
		Area	Stagnation in Green Revolution & Globalization; significant growth in tech era (1.72%).
Pulses		Production	Steady improvement; peaked in tech era (3.95%).
		Productivity	Gradual improvement; strong growth in tech era (2.19%).
		Irrigated Area	Strong positive trend, especially in tech era (4.43%).
		Un-irrigated (Rainfed) area	Initially positive; recovered again in tech era (1.12%) after globalization drops.
		Area	Overall growth positive but marginal in recent eras.
Total Foodgrain		Production	Consistent and robust across phases (2.96% to 2.36%).
		Productivity	Highest during Green Revolution; slight decline in recent years.
		Irrigated Area	Consistently increasing; sustained support for production.
		Un-irrigated (Rainfed) area	Declining trend post-Green Revolution, suggesting irrigation dependency.
		Area	Overall growth positive but marginal in recent eras.
Fertilizer	Consumption	N	Moderate positive growth in nitrogen consumption.
		P	Highest CAGR among consumption variables; strong growth in phosphate use.
		K	Moderate rise in potash consumption.
		Total	Overall consumption shows consistent upward trend.
	Production	N	Highest CAGR among all fertilizer variables; significant domestic nitrogen production growth.
		P	Strong growth in phosphate production.
		Total	Domestic fertilizer production has seen robust increase.
	Import	N	Decline in nitrogen imports; may indicate self-reliance.

P	Notable increase in phosphate imports.
K	Positive but moderate increase in potash imports.
Total	Overall fertilizer imports grew modestly; phosphate is the main contributor.

These findings necessitate policy interventions that balance productivity growth with sustainability. The continued decline in rainfed farming alongside heavy irrigation dependence raises concerns about groundwater depletion and climate vulnerability. Similarly, the reliance on imported fertilizers—particularly phosphate and potassium—underscores the need for strategies that promote balanced nutrient use, strengthen domestic production capacity, and incentivize sustainable alternatives. These issues are closely aligned with India’s commitments to the Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (Mohana Priya et al., 2020).

Future research should extend beyond secondary datasets to include farm-level micro studies that capture technological adoption, regional disparities, and socio-economic impacts. Comparative analyses with other developing economies could also provide valuable international perspectives on transitioning from productivity-driven to sustainability-oriented agriculture (Eliazar Nelson et al., 2019; Prajneshu & Chandran, 2005).

Hypothesis Testing Summary:

Table 5: Summary of Hypotheses, Variables, Statistical Tests and Outcomes

Hyp. No.	Hypothesis Statement	Variables Tested	Statistical Methods	Phase(s) Observed	Findings	Outcome
H1	Area-led growth dominated the Pre-Green Revolution phase (1951–1965).	Area, Production, Productivity (Cereals, Pulses, Nutri-cereals)	Regression CAGR, β Coefficient, t-statistic, p-value	Pre-Green Revolution (1951–1965)	Area CAGR > Productivity CAGR (e.g., cereals: area 1.61%, productivity 2.07%); both significant ($p < 0.01$).	Supported
H2	Productivity-led growth became prominent during the Green Revolution and afterward.	Productivity (Cereals, Pulses, Nutri-cereals, Total Foodgrain)	Regression CAGR, β , t-statistic, p-value	Green Revolution (1966–1990) onward	Productivity significantly increased (e.g., cereals: 2.74%, $p < 0.001$); β and t-statistic significant.	Supported

H3	Rainfed area consistently declined post-1990, reflecting irrigation dependence.	Rainfed Area (Cereals, Pulses, Nutri-cereals, Foodgrain)	Regression CAGR, β , p-value	Globalization (1991–1999), Technology Era (2000–2022)	Consistent negative CAGR (e.g., cereals: 1.40%, 3.54%), all statistically significant ($p < 0.001$).	Supported
H4	Pulses productivity improved significantly in the Technology Era due to policy support.	Pulses Productivity	Regression CAGR, β , t-statistic, p-value	Technology Era (2000–2022)	Pulses productivity CAGR: 2.19%, $\beta = 0.0217$, $t = 10.87$, $p < 0.001$.	Supported
H5	Fertilizer consumption and imports increased post-globalization.	Fertilizer (N, P, K) Consumption & Import	Regression CAGR, β , t-statistic, p-value	Globalization (1991–1999), Technology Era (2000–2022)	Consumption of NPK increased (e.g., P: 5.76%, 3.15%), imports (e.g., P: 11.46%) with significant β and $p < 0.05$.	Supported
H6	Foodgrain growth is strongly driven by irrigation expansion.	Irrigated Area, Production, Productivity (Total Foodgrain, Cereals)	Regression CAGR, β , t-statistic, p-value	All Phases	Irrigated area grew in all phases (e.g., Total Foodgrain: 2.48%, 1.93%), positively correlated with production growth.	Supported

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