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Impact of Agricultural Inputs on Gross Value Added by Agriculture in Indian Economy

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Abstract

This study analyses secondary data for 2011-12 to 2022-23 to quantify the role of agricultural inputs in India's productivity and economic growth. Our objective is to assess how variability in input use particularly fertilizers, pesticides, irrigation, and seeds affects agricultural gross value added (GVA) and production stability. using a combination of variability metrics and ridge regression. We document substantial variability in fertilizer and pesticide consumption relative to irrigation and seeds availability, indicating higher production risk associated with fluctuations in these inputs. The Instability Index shows that fertilizer and pesticide use are the main sources of input-related volatility, whereas irrigation and seeds availability exhibit comparatively greater stability. Ridge regression results indicate that irrigation ($\beta = 0.22$, $p < 0.05$) positively influence agricultural GVA, with quality seeds availability also contributing ($\beta = 0.05$, $p < 0.1$) to GVA by crops. These estimates support the view that expanding and stabilizing core inputs can enhance output, while input variability poses a material constraint. To promote sustainable growth, the focus should be on improving input use efficiency through precision agriculture, stabilizing critical inputs (notably irrigation), and implementing risk management strategies. Integrated input subsidies, increased R&D via PPP arrangements, and targeted farmer education can mitigate volatility and strengthen producer resilience, contributing to more stable agricultural growth and economic performance.

Keywords: Agricultural Inputs, GVA, Impact, India and Productivity

Introduction

Agriculture serves as a primary source of raw materials for numerous allied industries such as food processing, textiles, and biofuels, underscoring its critical role in the overall economic framework besides employment generation (Shareya *et al.*, 2024). Indian agriculture demonstrated resilience, employing about 55 per cent of the workforce and contributing nearly 18 per cent to GDP during 2019–2020 despite the COVID-19 outbreak, (Raghu, 2022). Further, agricultural inputs including seeds, fertilizers, pesticides, irrigation, machinery, and labour are essential drivers of productivity and efficiency in agriculture. The efficient and optimal use of these inputs contributes directly to increasing the GVA by enhancing crop yields, reducing input costs, and improving crop quality (Government of India, 2025). Numerous studies have examined the impact of these inputs on agricultural output and GVA in India. Irrigation expansion significantly raised productivity in rainfed areas, contributing 25–30% to GVA growth through yield stabilization (Birthal *et al.*, 2014). Public investments in fertilizers and electricity generated high returns, with each rupee invested yielding ₹9–12 in agricultural GVA (Fan *et al.*, 2000). Rainfall and electricity volatility linked to GVA fluctuations via input instability (Bhattacharya and Mitra, 2013).

In recent decades, the use of advanced agricultural technologies such as precision farming, genetically improved seeds, micro-irrigation techniques, and integrated pest management has further enhanced productivity (Gawande *et al*., 2023). The availability of agricultural credit and government subsidies for inputs have played a crucial role in enabling farmers to adopt these technologies, leading to a more resilient and sustainable agricultural sector (Choudhary and Kumar, 2023).

However, challenges such as regional disparities in input availability, inefficient input use, environmental concerns from excessive fertilizer and pesticide use, and climate variability affect the consistent growth of agricultural GVA. Therefore, policy measures focused on promoting balanced and sustainable usage of inputs, improving input quality, and ensuring timely availability are vital to sustaining growth in agricultural output and its contribution to the economy. In this context, analysing the impact of various agricultural inputs on the Gross Value Added by agriculture is critical to understanding sectoral dynamics and framing targeted interventions. With this backdrop, present study aims to assess how different inputs contribute to agricultural productivity and thus to value addition in the Indian economy.

Materials and Methods

This study focuses on the Indian agricultural sector as a whole, utilizing secondary data covering the time period from 2011–12 to 2022–23. Data were sourced from reputed publications including FAOSTAT, *Agricultural Statistics at a Glance* (Government of India) and Indiastat.com.

Analytical Framework

The analysis employed three key tools:

- Compound Annual Growth Rate (CAGR) to measure temporal growth trends in agricultural inputs and GVA.
- Cuddy-Della Index to quantify instability in input usage and outputs.
- Ridge regression to estimate the impact of key inputs on agricultural GVA, addressing multi-collinearity among explanatory variables.

Ridge Regression Model

The relationship between agricultural inputs and GVA was estimated using the following ridge regression equation:

$$GVA_t = \beta_0 + \beta_1 Area_t + \beta_2 Fertilizer_t + \beta_3 Pesticide_t + \beta_4 Irrigation_t + \beta_5 Seeds_t + \beta_6 Rainfall_t + \epsilon_t$$

where:

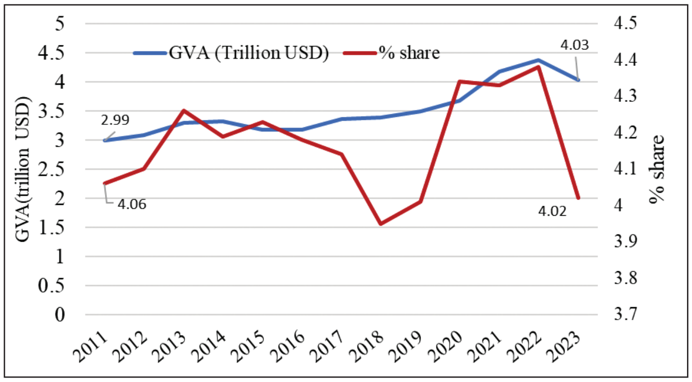
- GVA_t: Gross Value Added by agriculture (in Rs Billions)
- $Area_t$: Net sown area (in million hectares)
- $Fertilizer_t$: Fertilizer consumption (in Lakh tonnes)
- $Pesticide_t$: Pesticide consumption (in 000 tonnes)
- $Irrigation_t$: Net irrigated area (in million hectares)
- $Seeds_t$: Quality Seeds Availability for agriculture (in lakh quintals)
- $Rainfall_t$: Average annual rainfall (in mm)
- ϵ_t: Error term

Ridge regression parameters were estimated using R statistical software, selecting the optimal shrinkage parameter (λ) via cross-validation.

Results and Discussion

A. Contribution of Agriculture to Gross Value Added

The percentage share of agriculture, forestry, and fishing in global GDP and GVA reflects the economic contribution of these sectors over time (**Figure 1**). From 2011 to 2023, the share of GVA in global GDP indicated a relatively stable share, fluctuating between 4.01 to 4.38 per cent. During 2011, the share was 4.06% with a Gross Value Added (GVA) of $2.99 trillion out of a total GDP of $73.63 trillion which increased slightly to 4.10% in 2012 as GVA rose to $3.08 trillion while GDP grew to $75.19 trillion.

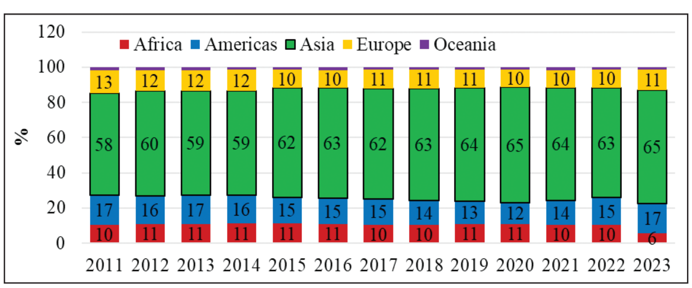


Source: FAOSTAT

Figure 1: Percentage Share of Agriculture, Forestry, and Fishing in Global GDP

The COVID-19 pandemic in 2020 caused an artificial spike in the agriculture sector's contribution to GDP as non-agricultural sectors experienced declines while agriculture-maintained growth, resulting in a share of 4.34 per cent. By 2023, the percentage share had slightly decreased to 4.02 per cent, with a GVA of $4.03 trillion and a GDP of $100.13 trillion. Overall, these figures illustrate that while agriculture, forestry, and fishing continue to play a critical role in the global economy, their relative contribution has faced pressures from the growth of other sectors, highlighting the ongoing dynamics within global economic structures and the importance of these sectors for food security and rural livelihoods.

The data presented in **figure 2** outlines the percentage share of agriculture, forestry, and fishing across different global regions from 2011 to 2023. In Africa, the share has remained relatively stable, being 10.42% in 2011 and 2022 but declined to 5.65% by 2023. This decrease may reflect broader economic changes and diversification efforts within African economies.



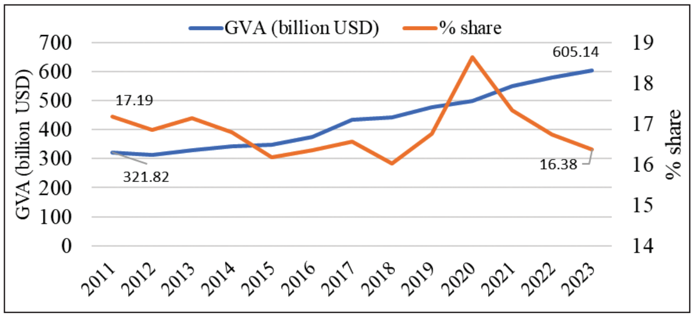
Source: FAOSTAT

Figure 2: Region-wise percentage share to the GVA by Agriculture, Forestry and Fishing

In the Americas, the percentage share has varied, beginning at 16.81% in 2011 and showing a slight increase to 16.75% in 2023 indicating that agriculture continues to play a significant role in the region's economy, despite pressures from industrialization and service sector growth. Asia exhibited a rising trend in agricultural share, increasing from 57.91% in 2011 to 64.74% in 2023 indicating a strong reliance on agriculture within many Asian economies, likely due to the significant agricultural populations and their importance in food security. In Europe, a decline in its agricultural share from 13.17% in 2011 to 11.34% in 2023 was observed reflecting a shift towards more industrial and service-oriented economic activities within the region. Oceania showed a decreasing trend as well, with its agricultural share dropping from 1.70% in 2011 to 1.50% in 2023. This decline may indicate a transition towards other economic sectors or changes in agricultural productivity. Overall, these trends highlight the varying importance of agriculture across different regions, influenced by factors such as economic development, population dynamics, and policy changes related to agricultural practices and food security.

The percentage share of agriculture, forestry, and fishing in India's GDP exhibited notable trends from 2011 to 2023 which were shown in **figure 3**. In 2011, the sector contributed significantly to the economy with a Gross Value Added (GVA) of $321.82 billion, (17.19% of the total GDP of $1,871.92 billion). A significant increase was observed in 2020, where the share rose sharply to 18.64%, likely due to the impact of the COVID-19 pandemic, which affected various sectors differently and may have led to increased reliance on agriculture for food security during that period. However, this was followed by a return to a lower percentage share in the following years, with contributions of 17.33% in 2021 and further declining to 16.73% in 2022 and 16.38% in 2023.Throughout this period, while the absolute GVA from agriculture has generally increased from $321.82 billion in 2011 to $605.14 billion in 2023 the relative contribution to

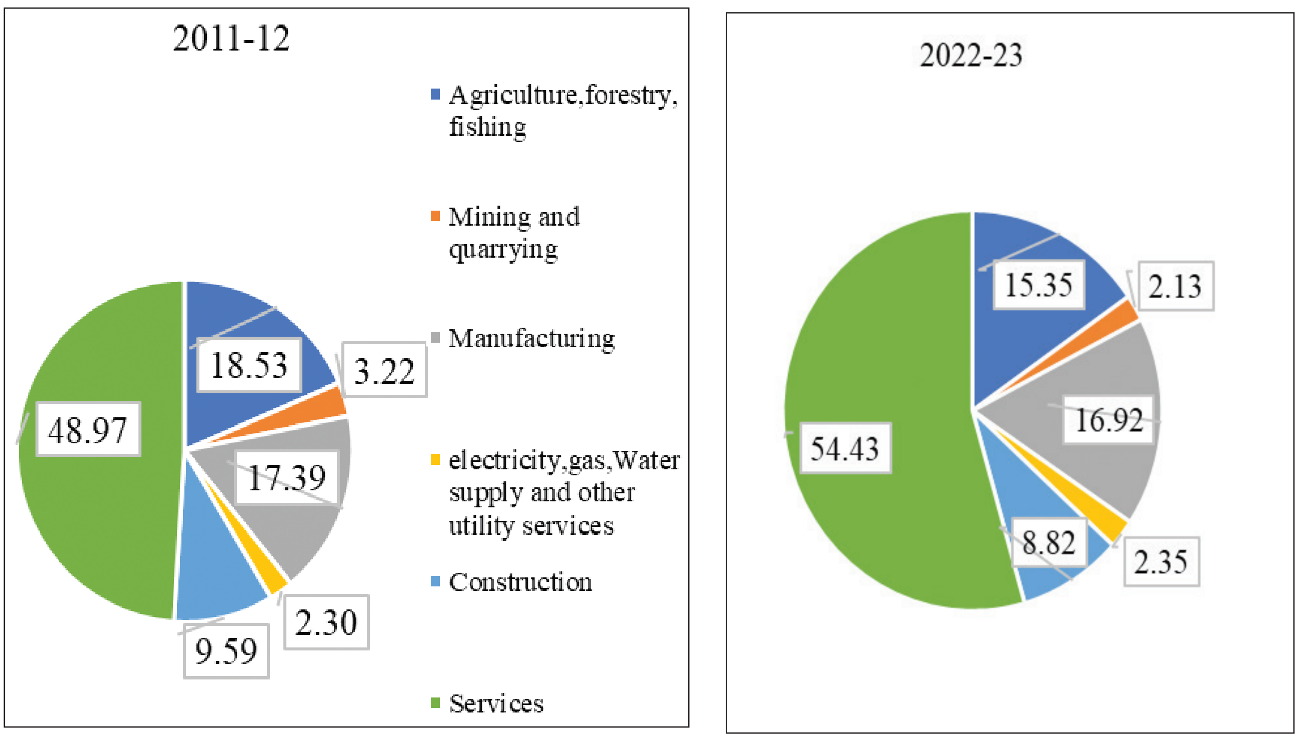
GDP has been affected by faster growth rates in other sectors such as services and manufacturing. Overall, these figures illustrate the dynamic nature of India's economic landscape, where agriculture remains a vital sector but faces challenges from competing industries and changing economic priorities.



Source: FAOSTAT

Figure 3: Percentage Share of Agriculture, Forestry and Fishing in India's GDP

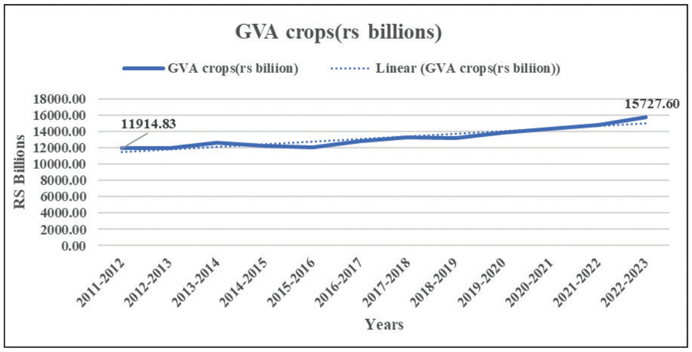
The percentage of Gross Value Added (GVA) by economic activities at constant (2011-12) basic prices provides insight into the structural changes in the Indian economy from 2011-12 to 2022-23 (**Figure 4**). In this period, the contribution of agriculture, forestry, and fishing decreased from 18.53% in 2011-12 to 15.35% in 2022-23 reflecting a gradual shift towards more industrial and service-oriented sectors, indicating that agriculture's relative importance in the economy is diminishing despite its essential role in food security and employment. Overall, these changes reflect significant economic transformations within India, highlighting a shift away from traditional sectors like agriculture towards more modern industries and services, which are becoming increasingly vital for economic growth and development.



Source: Agricultural Statistics at a Glance 2023

Figure 4: Percentage of Gross Value Added by Economic Activities at Constant (2011-12) Basic Prices

GVA by agriculture crops at constant 2011-12 prices shows a steady upward trajectory from ₹9,822 billion (2011-12) to ₹12,301 billion (2022-23), achieving a 25.2% cumulative increase over 12 years (average ~1.9% annual growth). The series exhibits two distinct phases: modest gains during 2011-16 (₹9,822 → ₹9,693; slight dip in 2015-16 due to possible weather/input shocks) followed by consistent acceleration post-2017 (₹10,751 → ₹12,301; +14.4%). Notable yearly jumps occurred in 2013-14 (+5.4%), 2017-18 (+5.3%), and 2022-23 (+4.6%), reflecting policy interventions and productivity improvements. Despite minor fluctuations (e.g., 2014-16 dip), the long-term trend is unambiguously positive, with GVA crossing ₹12,000 billion in the final year confirming sustained agricultural sector resilience amid stable prices and gradual intensification rather than area expansion **(Figure 5)**.



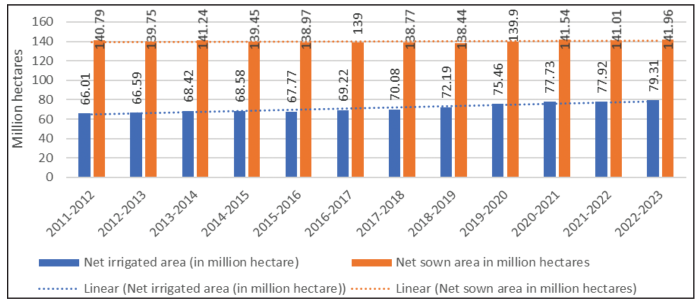
Source: Indiastat.com

Figure 5: Trends in Gross Value Added (GVA) by Agriculture Crops at constant 2011-12 prices in India, 2011-12 to 2022-23

B. Utilisation of different inputs at national level

In agriculture sector, different inputs are crucial for successful crop production and overall farm productivity. These inputs can be broadly categorized into consumable inputs like seeds, fertilizers, and pesticides, and capital inputs like machinery and irrigation systems.

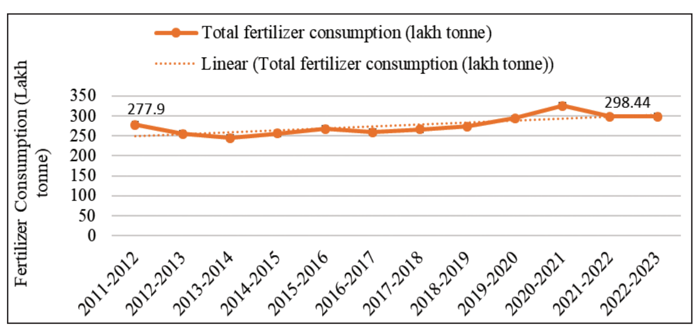
It was observed that the net sown area in India exhibited fluctuations over the years. Being at 140.79 million hectares in 2011-12, it reached a peak of 141.54 million hectares in 2020-21 before stabilizing at 141.96 million hectares in 2022-23. These fluctuations may be influenced by factors such as climatic conditions, market demands, and farmers' decisions regarding crop planting. On the other hand, the net irrigated area has shown a consistent upward trend, increasing from 66.01 million hectares in 2011-12 to 79.31 million hectares in 2022-23 (**Figure 6**). This increase signifies ongoing efforts to improve irrigation infrastructure and expand water availability for agriculture.



Source: Indiastat.com

Figure 6: Trends in net sown area and net irrigated area in India, 2011-12 to 2022-23

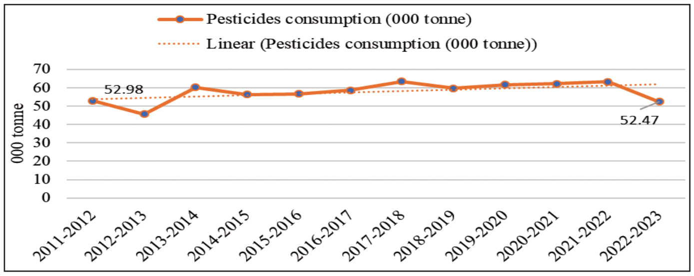
Data on fertiliser consumption revealed an upward trend which continued through 2018-19, culminating in a consumption of 273.75 lakh tonnes (**Figure 7**). The increase during these years suggests a renewed focus on fertilizer application as farmers sought to improve yields amidst rising food demand. The most notable increase occurred between 2019-20 and 2020-21, where fertilizer consumption surged from 293.69 lakh tonnes to 325.36 lakh tonnes. This sharp rise can be attributed to several factors: Increased agricultural activity due to heightened food security concerns during the COVID-19 pandemic, Government initiatives aimed at ensuring the availability of fertilizers and enhancing subsidies, A greater emphasis on high-yielding varieties that require more fertilizer input. Following the peak in 2020-21, fertilizer consumption slightly decreased to 297.96 lakh tonnes in 2021-22, and then stabilized at 298.44 lakh tonnes in 2022-23. This stabilization may reflect a return to pre-pandemic agricultural practices and market conditions, as well as potential challenges related to fertilizer availability and pricing.



Source: Indiastat.com

Figure 7: Trends in Fertilizer consumption in India, 2011-12 to 2022-23

Further, the trends in pesticide consumption in India from 2011-12 to 2022-23 reveal a complex landscape characterized by initial stability, fluctuations, and a significant decline in recent years. Starting at 52.98 thousand tonnes in 2011-12, pesticide use dropped to 45.62 thousand tonnes in 2012-13 (**Figure 8**), likely reflecting growing awareness of the health and environmental impacts of pesticides.

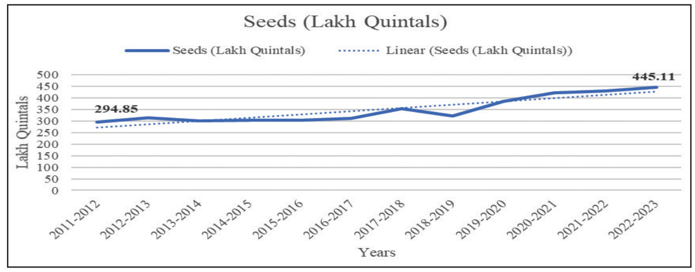


Source: Indiastat.com

Figure 8: Trends in Pesticides consumption in India

A recovery phase began in 2013-14, with consumption rising to 63.41 thousand tonnes by 2017-18 due to increased reliance on pesticides to combat pest pressures, particularly in high-value crops. This trend continued with sustained high usage, peaking at 63.28 thousand tonnes in 2021-22, driven by crop intensification and government initiatives promoting pesticide availability. However, a notable decline to 52.47 thousand tonnes in 2022-23 suggests a shift towards integrated pest management practices and heightened awareness of the adverse effects of chemical pesticides. Overall, these trends highlight the need for sustainable agricultural practices that balance productivity with environmental health, emphasizing the importance of education and policy support for farmers to adopt safer pest management strategies moving forward.

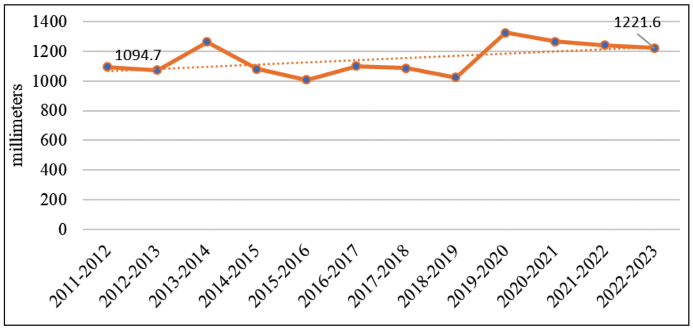
Quality seed availability in Indian agriculture shows a steady upward trend from 294.85 Lakh Quintals (2011-12) to 445.11 Lakh Quintals (2022-23), achieving a 51% cumulative increase over 12 years. The series exhibits two phases: gradual growth during 2011-17 (294-311 range, ~5.6% total) followed by sharp acceleration post-2017 with major jumps in 2017-18 (+13%), 2019-20 (+20%), and consistent 5-8% annual gains thereafter. Minor dips in 2013-14 and 2018-19 reflect possible supply chain disruptions, but the long-term trajectory confirms successful seed sector modernization. This expansion parallels GVA growth acceleration, indicating policy-driven improvements in hybrid/high-yield varieties that boosted productivity without area expansion. Average annual growth accelerated from 0.8% (2011-17) to 5.8% (2018-23), underscoring seeds as a key driver of agricultural efficiency gains (**Figure 9**).



Source: Indiastat.com

Figure 9: Trends in availability of quality seeds for agriculture in India,2011-12 to 2022-23

The trends in actual rainfall in India from 2011-12 to 2022-23 reveal significant fluctuations, which have implications for agricultural productivity and water resource management **(Figure 10).** In 2011-12, actual rainfall was recorded at 1,094.7 mm, setting a relatively high baseline. However, this figure declined slightly to 1,073.4 mm in 2012-13, indicating a minor decrease in precipitation. The following year, 2013-14, saw a notable increase to 1,262.4 mm, likely benefiting agricultural output due to improved water availability. However, this was followed by another decline in 2014-15, with rainfall dropping to 1,081.8 mm. The trend of fluctuating rainfall continued, with 1,007.3 mm recorded in 2015-16, marking one of the lower points in the period under review. From 2016-17 onward, rainfall figures began to stabilize somewhat, with 1,099.4mm in 2016-17 and slight variations thereafter: 1,086.4 mm in 2017-18, and a further drop to 1,025.6 mm in 2018-19. The years 2019-20 and 2020-21 experienced higher rainfall levels again, with 1,327 mm and 1,265.2 mm, respectively. This resurgence may have been influenced by favourable monsoon conditions.



Source: Indiastat.com

Figure 10: Trends in actual rainfall in India, 20o11-12 to 2022-23

In the subsequent years, rainfall levels slightly decreased again, recording 1,241.7 mm in 2021-22, followed by 1,221.6 mm in 2022-23. Overall, these trends illustrate the variability of rainfall patterns in India over the years and highlight the importance of effective water management strategies to cope with both droughts and excessive rainfall events that can impact agriculture and livelihoods across the country.

The Compound Annual Growth Rates (CAGR) of various agricultural inputs and Gross Value Added (GVA) by agriculture in India from 2011-12 to 2022-23 reveal significant trends. In the first period (2011-12 to 2016-17), fertilizer consumption declined slightly at -0.45%, while pesticides consumption grew modestly at 3.17%. Net irrigated area increased by 0.83%, but net sown area experienced a slight decline of -0.27%. The quality seeds availability for agriculture rose at 0.54%, despite a decline in actual rainfall by -0.92%, leading to minimal GVA growth of 0.99%. In the second period (2017-18 to 2022-23), fertilizer consumption increased by 2.70%, while pesticides consumption declined by -2.16%. Net irrigated area saw robust growth at 2.54%, and quality seeds availability surged dramatically to 6.34%. Actual rainfall improved by 3.23%, contributing to a stronger GVA growth of 3.51%. Overall, from 2011-12 to 2022-23, fertilizer consumption grew modestly at 1.74%, net irrigated area increased by 1.77%, and quality seeds emerged as a key productivity driver (3.99% CAGR) to achieve sustained GVA growth (2.40%), confirming policy effectiveness in input modernization over the period (**Table 1**).

Table 1: Compound annual growth rates (CAGR) of different Agricultural Inputs and GVA by Agriculture in India, 2011-12 to 2022-23

Period	Years	Fertilizer consumption	Pesticides consumption	Net irrigated area	Net sown area	Quality Seeds Availability	Actual rainfall	GVA by Agriculture crops at Constant (2011-12) Basic Prices
I	2011-12 to 2016-17	-0.45	3.17	0.83**	-0.27*	0.54	-0.92	0.99
II	2017-18 to 2022-23	2.7	-2.16	2.54***	0.52***	6.34**	3.23	3.51***
Overall	2011-12 to 2022-23	1.74**	1.32	1.77***	0.07	3.99***	1.26	2.40***

Note: ***, ** and * denote significance at 1 % ,5% and 10 %, respectively

The Instability Index of various agricultural inputs and Gross Value Added (GVA) by agriculture at national level from 2011-12 to 2022-23 indicates varying levels of volatility across different factors. In the first period (2011-12 to 2016-17), fertilizer consumption had an instability index of 4.78, while pesticides consumption was higher at 8.63, reflecting greater variability in pesticide use. The net irrigated area showed low instability at 1.07, and net sown area had an index of 0.51, suggesting stability in land cultivation practices (**Table 2**). In the second period (2017-18 to 2022-23), fertilizer consumption's instability rose to 5.89, while pesticides decreased to 6.34.

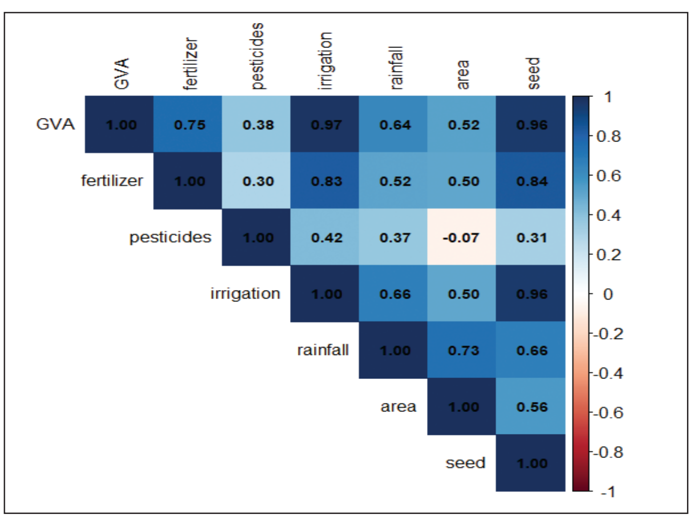
Overall, from 2011-12 to 2022-23, fertilizer consumption had the highest overall instability at 8.82, followed by pesticides at 8.41 and actual rainfall at 8.55. These variations highlight the challenges faced in agricultural practices and inputs over the years, emphasizing the need for strategic interventions to enhance stability and productivity in the sector (**Table 2**).

Table 2: Instability in use of different Agricultural inputs and GVA by Agriculture in India

Periods	Years	Fertilizer consumption	Pesticides consumption	Net irrigated area	Net sown area	Quality Seeds Availability	Actual rainfall	GVA by Agriculture Crops at Constant (2011-12) Basic Prices
I	2011-12 to 2016-17	4.78	8.63	1.07	0.51	0.39	8.38	0.25
II	2017-18 to 2022-23	5.89	6.34	1.35	0.45	1.07	8.68	0.20
Overall	2011-12 to 2022-23	8.82	8.41	1.96	0.86	1.18	8.55	0.32

The correlation matrix reveals severe multi-collinearity among agricultural inputs that compromises OLS regression reliability. GVA exhibits very strong positive correlations with irrigation (r=0.971) and seeds (r=0.958), indicating these are primary productivity drivers, while irrigation and seeds themselves show near-perfect collinearity (r=0.956), directly explaining the high VIF values (>14) observed earlier. Moderate correlations exist with fertilizer (r=0.752), rainfall (r=0.639), and area (r=0.523), suggesting supplementary roles, whereas pesticides display consistently weak relationships (r<0.42 across all variables), confirming its limited explanatory power (**Table 3**). This pattern underscores the need to either drop one of irrigation or seeds from the model preferably retaining irrigation as the broader infrastructure measure or rely on ridge regression results, which effectively handle shrinkage. Pesticides can be safely excluded, while a composite irrigation-seed index represents a theoretically sound alternative for capturing shared variance in GVA determination.

Table 3: Correlation matrix of GVA by Agriculture and Agricultural Inputs in India



The diagnostic tests reveal critical violations of OLS assumptions that undermine model reliability. The ADF test confirms non-stationarity in GVA levels (test statistic = -0.79, p=0.95), necessitating first-differenced specification for valid inference. Severe multi-collinearity exists with irrigation (VIF=14.82) and seeds (VIF=14.81), both exceeding the critical threshold of 10, confirming their near-perfect correlation (r=0.956) and rendering individual coefficients unstable. Other VIFs (fertilizer=3.80, rainfall=4.05, area=3.46) indicate moderate collinearity concerns, while pesticides (VIF=1.97) show no issue. The Durbin-Watson test (DW=1.71, p=0.08) suggests mild positive autocorrelation but fails conventional significance (p>0.05). Breusch-Pagan test confirms homoskedasticity (BP=6.62, p=0.36), satisfying that assumption (**Table 4**).

Table 4: Diagnostic Tests for Regression Model Analysis

Test		p-Value
ADF (GVA levels)	-0.79	0.95
VIF (Fertilizers)	3.80	<5
VIF (Pesticides)	1.97	<5
VIF (Irrigation)	14.82	>5
VIF (Area)	3.46	<5
VIF (Seed)	14.81	>5
VIF (Rainfall)	4.05	<5
Durbin-Watson	1.71	0.08
Breusch-Pagan	6.62	0.36

The ridge regression results (K=0.047, R^2=54.95%) reveal area expansion as the dominant driver of GVA growth (coefficient=0.79), with irrigation showing statistical significance at 5% level (0.22**), confirming its critical infrastructure role despite multicollinearity concerns. Fertilizer exhibits a surprising negative effect (-0.05), suggesting possible over-application or diminishing returns, while seeds (0.05*) and rainfall (0.04) show marginal positive contributions at 10% significance. Pesticides remain negligible (0.01), consistent with weak correlations.

Table 5: The estimates of regression coefficients through ridge regression model with ridge constant K=0.047

R^2=54.95%

Parameters	Coefficients
Intercept	0.02
Fertilizers	-0.05
Pesticides	0.01
Irrigation	0.22**
Area	0.79
Seeds	0.05*
Rainfall	0.04

Note: ***, ** and * denote significance at 1 % ,5% and 10 %, respectively

Conclusion

Despite varied consumption levels of fertilizer and pesticide, significant increases in electricity consumption and a positive overall GVA growth rate of about two per cent highlight the critical role of agricultural inputs in enhancing productivity and sustaining economic growth in India's agricultural sector. Further, the Instability Index for agricultural inputs and GVA revealed heightened variability, particularly in fertilizer and pesticide consumption, highlighting the challenges of production volatility driven by fluctuations in critical inputs like rainfall and electricity consumption, which ultimately affect agricultural productivity and economic stability. The ridge regression analysis indicated that area under cultivation and electricity consumption significantly enhance the GVA from agriculture, while irrigation also positively impacts GVA, highlighting the importance of these factors in boosting agricultural productivity.

Policy implications

1. Enhancement of Input Efficiency: Given the significant role of fertilizers, pesticides, seeds and irrigation in boosting Gross Value Added (GVA), policies should focus on improving the input use efficiency by promoting precision agriculture techniques, which optimize input usage and minimize waste, thereby enhancing productivity while reducing costs.

2. Stabilization Measures: The observed instability in agricultural input consumption and GVA highlights the need for policies aimed at stabilizing production. Implementing risk management strategies, such as crop insurance and weather-indexed insurance products, can help farmers mitigate the impacts of fluctuations in rainfall and electricity consumption.

3. Integrated Input Subsidy Programs: Given the rising costs of agricultural inputs, a comprehensive subsidy program that integrates fertilizers, pesticides, irrigation, and seeds could provide farmers with the necessary support to enhance productivity without incurring excessive costs. Such programs should be carefully designed to avoid over-reliance on inputs that may lead to environmental degradation.

4. Research and Development: Increased investment in agricultural research and development is essential to innovate new practices that can improve crop yields while ensuring sustainability. Collaborative efforts between public institutions and private sectors can foster advancements in high-yield varieties (HYVs), pest-resistant crops, and efficient irrigation methods.

5. Education and Training: Implementing educational programs aimed at training farmers on best practices for input usage can lead to more informed decisions regarding fertilizer and pesticide applications, ultimately enhancing productivity while minimizing negative environmental impacts.

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