INTERNATIONAL JOURNAL OF BUSINESS AND MANAGEMENT (IJBM)
ISSN: 2815-9330 (Online)

VOL. 5, NO. 2 2026 https://iessociety.org/

A comparative study of chemical, organic, and biofertilizers in Indian agriculture: Productivity, cost, and environmental sustainability

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Abstract

Fertilizers play a central role in sustaining agricultural productivity and food security in India, yet the environmental and economic tradeoffs across fertilizer types remain a pressing policy concern. This study compares chemical, organic, and biofertilizers used in Indian agriculture with respect to nutrient composition, cost efficiency, yield performance, and environmental impact, drawing on secondary data from government reports, research journals, and agricultural institutions. The analysis shows that chemical fertilizers such as urea, DAP, and NPK deliver rapid nutrient availability and higher short term yields in crops like rice, wheat, and vegetables, but their sustained use is linked to soil degradation, water pollution, carbon emissions, and biodiversity loss. Organic fertilizers, including compost, farmyard manure, and vermicompost, enhance soil structure, water retention, and long term fertility, though nutrient release is slower and initial yield gains are modest. Biofertilizers, based on microorganisms such as Rhizobium, Azotobacter, and Azospirillum, improve nutrient availability at low cost with minimal ecological damage, but face storage and shelf life constraints. Fertilizer consumption data from 2013 to 2025 indicate that chemical fertilizers continue to dominate the Indian market, accounting for roughly 83 percent of market share, even as awareness of organic and biofertilizer alternatives grows. The comparative evidence suggests that integrated nutrient management, combining all three fertilizer types, yields better productivity and soil sustainability outcomes than reliance on any single type. The study concludes that balanced and integrated fertilizer policy is essential for achieving productivity growth alongside environmental protection and long term soil health in India.

***Keywords*:** Chemical Fertilizers, Organic Fertilizers, Biofertilizers, Integrated Nutrient Management, Soil Fertility, Sustainable Agriculture, Indian Agriculture

JEL Classification: Q10, Q56, Q01

DOI: https://doi.org/10.56879/ijbm.v5i2.70

1. Introduction

Agriculture continues to serve as a foundation of the Indian economy, supplying food, employment, and raw material for allied industries, while a substantial share of the population depends on it directly or indirectly for livelihood. Rising population and growing food demand have made productivity growth a national priority, and fertilizers rank among the most important inputs used to strengthen soil fertility and raise crop output. Fertilizers supply nitrogen, phosphorus, and potassium along with other nutrients essential for plant growth. Indian farmers rely on three broad categories, namely chemical fertilizers, organic fertilizers, and biofertilizers, each carrying distinct characteristics, benefits, limitations, and consequences for soil health and productivity. Chemical fertilizers such as urea, DAP, and NPK are widely adopted because they release nutrients quickly and support higher yields within a short period. The Green Revolution demonstrated the productivity gains achievable through extensive chemical fertilizer use, yet prolonged and excessive application has since been associated with soil degradation, water pollution, nutrient imbalance, and declining microbial activity. Organic fertilizers, including compost, farmyard manure, and vermicompost, are derived from natural materials and are valued for improving soil structure, water retention, and fertility over time. Growing awareness of environmental sustainability and food safety has increased interest in organic farming, although nutrient release is comparatively slow and short term yield gains may lag behind those achieved with chemical alternatives. Biofertilizers consist of living microorganisms, such as Rhizobium, Azotobacter, and Azospirillum, that enhance nutrient availability through biological processes including nitrogen fixation and phosphate solubilisation. They are generally low cost, environmentally sound, and supportive of soil microbial activity, positioning them as a practical complement to sustainable farming practices. Concerns over the environmental consequences of intensive chemical fertilizer use have pushed researchers, policymakers, and farmers toward integrated nutrient management strategies that combine chemical, organic, and biofertilizers. Such integration is increasingly viewed as a pathway to reconcile productivity goals with soil health and environmental protection, and it forms the central motivation for the present study, which compares the three fertilizer categories across nutrient composition, cost, yield performance, environmental impact, and consumption patterns in India between 2013 and 2025.

2. Review of Literature

A growing body of research has examined how chemical, organic, and biofertilizers influence crop yield, soil fertility, environmental outcomes, and farmer welfare in India. The following review organizes this evidence by fertilizer category before turning to comparative studies and the gap that motivates the present analysis.

2.1 Chemical Fertilizers

Early accounts of the Green Revolution attribute much of the period's productivity growth to the extensive adoption of chemical fertilizers such as urea, DAP, and NPK, which supply nutrients

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directly to crops and support rapid growth and higher yields. Assessments by national agricultural research bodies confirm that chemical fertilizers have contributed substantially to output gains in staple crops such as rice and wheat, while also cautioning that sustained and excessive use is linked to soil degradation, nutrient imbalance, reduced microbial activity, and water pollution. International assessments of fertilizer practice echo this concern, pointing to groundwater contamination, greenhouse gas emissions, and declining soil biodiversity as consequences of indiscriminate application, and calling for more balanced nutrient management.

2.2 Organic Fertilizers

Research on organic inputs, including compost, farmyard manure, and vermicompost, consistently finds improvements in soil structure, organic carbon content, and water retention capacity. Studies of organic farming programs report that these practices help sustain soil fertility over the long run while reducing environmental pollution, as nutrients are released gradually and microbial activity in the soil is supported. Evidence from Sikkim, India's first fully organic state, illustrates ecological gains and improved product quality associated with organic methods, although researchers note that organic fertilizers alone may not match the immediate yield levels achieved with chemical inputs, particularly during the transition period.

2.3 Biofertilizers

Biofertilizers such as Rhizobium, Azotobacter, and Azospirillum have been studied for their capacity to improve nutrient availability through biological nitrogen fixation and phosphate solubilisation. Findings from soil science research indicate that biofertilizers strengthen microbial activity and plant growth while lowering dependence on chemical inputs, and that they remain cost effective and environmentally sustainable. Other studies report gains in root development, seed germination, and nutrient absorption efficiency, while also noting that biofertilizer performance is sensitive to soil condition, storage quality, temperature, and moisture.

2.4 Comparative Studies on Fertilizers

A smaller set of studies has compared chemical, organic, and biofertilizers directly. Work on integrated nutrient management concludes that combining the three categories produces better crop yield and soil fertility outcomes than any single fertilizer type used alone. Comparative field studies on rice and wheat find that chemical fertilizers deliver quicker nutrient availability and higher short term productivity, whereas organic and biofertilizers contribute more to long term soil sustainability and environmental protection. Related research suggests that integrated application also lowers production costs and improves soil microbial balance, leading several researchers to recommend balanced fertilizer usage as a policy priority.

Although chemical, organic, and biofertilizers have each been studied extensively in isolation, comparatively few studies analyze all three together within the context of Indian agriculture, and fewer still extend the analysis to recent years. There remains a need for updated research that

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jointly examines fertilizer efficiency, environmental sustainability, farmer awareness, and long term soil health through 2025. The present study addresses this gap by comparatively evaluating chemical, organic, and biofertilizers in Indian agriculture with reference to productivity, cost, environmental impact, and sustainability.

The present study is designed with several interrelated objectives. It seeks to examine the types of fertilizers used in Indian agriculture, namely chemical, organic, and biofertilizers, and to compare their nutrient composition and characteristics. It further aims to analyze the advantages and disadvantages of each fertilizer type in agricultural production and to evaluate how fertilizer choice affects yield performance in crops such as rice, wheat, and vegetables. The study also examines the cost and maintenance differences among the three fertilizer categories and studies the environmental effects of fertilizer usage, including soil fertility, water pollution, carbon emission, and biodiversity impact. In addition, the study analyzes the trend in fertilizer consumption in India from 2013 to 2025 and examines the market share of chemical, organic, and biofertilizers in the country. It also studies state wise patterns of fertilizer usage and the dominant fertilizer type in each case, and finally assesses the importance of integrated fertilizer management for sustainable agricultural development in India.

3. Research Methodology

3.1 Research Design

The study follows a descriptive and comparative research design, comparing chemical, organic, and biofertilizers used in Indian agriculture with respect to nutrient content, cost, yield performance, environmental impact, and market usage.

3.2 Nature and Sources of Data

The study relies entirely on secondary data compiled from government agriculture reports, publications of the Ministry of Agriculture and Farmers Welfare, reports of the Fertilizer Association of India, peer reviewed research journals and articles, books and websites related to agriculture, and reports from ICAR and affiliated agricultural universities.

3.3 Method of Data Collection

Information on fertilizer usage, consumption trends, crop yield, environmental impact, and market share was compiled from these published sources and organized systematically for comparative analysis.

3.4 Tools and Techniques

The collected data were examined using comparative analysis, percentage analysis, tabular presentation, and trend analysis to identify patterns across fertilizer categories and over time.

3.5 Scope and Area of the Study

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The study covers chemical, organic, and biofertilizers used in Indian agriculture during the period 2013 to 2025, and examines fertilizer usage patterns and agricultural practices across different states in India.

4. Results and Discussion

This section presents the comparative evidence gathered from secondary sources across nine dimensions: fertilizer types, advantages and disadvantages, nutrient content, yield performance, cost, environmental impact, consumption trends, market share, and state wise usage patterns.

Table 1. Types of Fertilizers Used in Indian Agriculture

Fertilizer Type	Examples	Nutrient Source	Speed of Action	Cost Level	Environmental Impact
Chemical Fertilizers	Urea, DAP, NPK	Synthetic chemicals	Fast	Medium	High pollution risk
Organic Fertilizers	Compost, FYM, Vermicompost	Natural organic matter	Slow	Low to Medium	Eco friendly
Biofertilizers	Rhizobium, Azotobacter	Living microorganisms	Moderate	Low	Sustainable

Table 1 shows that chemical fertilizers are manufactured from synthetic compounds and act quickly, which explains their popularity among farmers seeking immediate yield gains, though continuous use raises pollution and degradation risks. Organic fertilizers, drawn from natural material, release nutrients gradually while improving soil structure and water holding capacity, making them well suited to sustainable farming. Biofertilizers work through beneficial microorganisms that improve nutrient availability at low cost and with limited ecological cost. Taken together, the comparison indicates a clear tradeoff between speed of action and environmental sustainability across the three categories.

Table 2. Advantages and Disadvantages

Fertilizer Type	Advantages	Disadvantages
Chemical	Immediate yield increase	Soil degradation, water pollution
Organic	Improves soil health	Slow nutrient release
Bio	Eco friendly and cost effective	Storage and shelf life issues

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Table 2 shows that each fertilizer category presents a distinct balance of benefits and constraints. Chemical fertilizers offer the fastest route to higher output but at the cost of soil and water quality over time. Organic fertilizers strengthen soil texture, fertility, and microbial activity, supporting sustainable farming, although farmers may need to wait longer to see yield benefits. Biofertilizers are economical and environmentally sound but face practical limitations related to shelf life, storage, and sensitivity to climatic conditions. This pattern reinforces the case for integrated management that draws on the strengths of each type while limiting their respective weaknesses.

Table 3. Nutrient Content Comparison

Fertilizer Type	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Organic Carbon
Urea	46	0	0	Nil
DAP	18	46	0	Nil
Vermicompost	1 to 3	1 to 2	1 to 2	High
Biofertilizer	Low direct nutrients	Enhances availability	Enhances availability	Medium

Table 2 shows that Urea supplies a very high concentration of nitrogen, making it a primary nitrogen source for crop growth, while DAP delivers substantial nitrogen and, in particular, phosphorus that supports root development and flowering. Vermicompost contains lower direct concentrations of nitrogen, phosphorus, and potassium but compensates with high organic carbon content that benefits soil structure and fertility. Biofertilizers do not supply large quantities of nutrients directly; instead, they raise the availability of existing nutrients and stimulate microbial activity. Chemical fertilizers therefore remain the most concentrated nutrient sources, while organic and biofertilizers contribute mainly to longer term soil health.

Table 4. Yield Performance

Crop	Chemical Fertilizer Yield	Organic Fertilizer Yield	Bio Fertilizer Yield	Integrated Method Yield
Rice	High	Medium	Medium	Very High
Wheat	High	Medium	Medium	High
Vegetables	Very High	High quality produce	Medium	Best quality and yield

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Table 4 shows that chemical fertilizers generate high yields in rice, wheat, and vegetables because nutrients become available to plants almost immediately. Organic fertilizers produce moderate yields but tend to improve the quality of the resulting produce, an outcome particularly valued in vegetable cultivation. Biofertilizers similarly deliver moderate yields by enhancing nutrient absorption and supporting natural plant growth. Across all three crops, the integrated approach that combines chemical, organic, and biofertilizers achieves the strongest overall outcome for both productivity and quality, underscoring the value of combined nutrient strategies over reliance on a single input.

Table 5. Cost Comparison per Acre

Fertilizer Type	Average Cost per Acre	Maintenance Cost	Long Term Soil Benefit
Chemical	High	High	Low
Organic	Medium	Low	High
Bio	Low	Low	High

Table 5 shows that chemical fertilizers involve the highest per acre and maintenance costs, reflecting the need for repeated application and ongoing soil management, and they deliver comparatively limited long term soil benefit. Organic fertilizers occupy a middle ground, with moderate initial costs offset by lower maintenance requirements as soil fertility improves naturally. Biofertilizers are the least expensive option and provide strong long term soil benefits by enhancing microbial activity and nutrient cycling. While chemical fertilizers may support short term productivity gains, organic and biofertilizers appear more economical and sustainable over the longer horizon.

Table 6. Environmental Impact

Indicator	Chemical	Organic	Bio
Soil Fertility	Reduces over time	Improves	Improves
Water Pollution	High	Very Low	Very Low
Carbon Emission	High	Low	Very Low
Biodiversity Impact	Negative	Positive	Positive

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Table 6 shows that sustained chemical fertilizer use is associated with declining soil fertility, elevated water pollution, high carbon emissions, and negative effects on biodiversity through the loss of beneficial soil organisms. Organic fertilizers, in contrast, improve soil fertility, generate very little pollution, and support biodiversity, while biofertilizers show the mildest environmental footprint of the three categories owing to their reliance on natural microbial processes. This comparison reinforces organic and biofertilizers as the more environmentally sustainable options within an integrated fertilizer strategy.

Table 7. Fertilizer Consumption Trend, 2013 to 2025

Year	Chemical Fertilizer Consumption (Million MT)	Per Hectare Consumption (kg/ha)
2013	24.4	121.8
2020	27.2	136.0
2023	30.6	139.8
2025 (estimated)	approximately 31 and above	approximately 150

Table 7 shows that chemical fertilizer consumption in India rose from 24.4 million metric tonnes in 2013 to an estimated figure above 31 million metric tonnes by 2025, while per hectare consumption climbed from 121.8 kg to approximately 150 kg over the same period. This steady upward trend reflects the continued dependence of Indian agriculture on chemical inputs to sustain productivity and food security, but it also signals growing risk of soil degradation and environmental strain, strengthening the case for balanced and integrated nutrient management going forward.

Table 8. Market Share of Fertilizers in India, 2025

Fertilizer Category	Market Share
Chemical Fertilizers	83%
Bio and Organic Fertilizers (combined)	17%

Table 8 shows that chemical fertilizers continue to dominate the Indian market with an estimated 83 percent share in 2025, while organic and biofertilizers together account for the remaining 17 percent. This distribution shows that most farmers still favor chemical inputs for their speed and accessibility, even as rising awareness of sustainable agriculture and soil health gradually expands

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demand for organic and biological alternatives, pointing to a slow but discernible shift in the market over time.

Table 9. State Wise Fertilizer Usage

State	Fertilizer Consumption Level	Dominant Type
Punjab	Very High	Chemical
Haryana	High	Chemical
Andhra Pradesh	Increasing biofertilizer usage	Mixed
Sikkim	Fully organic model	Organic

Table 9 shows that Punjab and Haryana report very high fertilizer consumption dominated by chemical inputs, consistent with their intensive, high yield cropping systems. Andhra Pradesh is gradually moving toward mixed usage, incorporating more biofertilizers alongside conventional inputs, while Sikkim stands out as India's fully organic state, where organic fertilizers dominate agricultural practice. These regional differences suggest that state level policy and farming systems play a significant role in shaping fertilizer adoption across the country.

5. Conclusion, Implications, Limitations, and Recommendations of the Study

The evidence assembled in this study confirms that chemical fertilizers remain effective for achieving rapid and substantial crop yields, but their continued and excessive use carries clear environmental and soil health costs, including pollution, degradation, and biodiversity loss. Organic and biofertilizers, while slower to act, offer meaningful advantages in long term soil fertility, cost efficiency, and environmental protection, and are gaining gradual acceptance among Indian farmers as awareness of sustainability grows. Across yield, cost, and environmental indicators alike, integrated nutrient management, which combines chemical, organic, and biofertilizers rather than relying on any single type, consistently produces the strongest overall outcomes for productivity, soil health, and ecological balance. Given that chemical fertilizers still account for the large majority of market share in India as of 2025, a deliberate policy push toward balanced and integrated fertilizer usage appears essential for reconciling the country's productivity needs with long term environmental protection and soil sustainability.

5.1 Implications of the Study

The comparative evidence carries several practical implications for farmers, policymakers, and the fertilizer industry. For farmers, the findings suggest that no single fertilizer type offers an unqualified solution, and that combining chemical inputs with organic and biological sources can protect yield in the near term while preserving soil productivity for future seasons. For

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policymakers, the continued dominance of chemical fertilizers in market share, alongside their documented environmental costs, points to a need for incentive structures, such as targeted subsidies, extension support, and awareness campaigns, that make organic and biofertilizers more accessible and attractive relative to chemical alternatives. The state wise differences observed between Punjab, Haryana, Andhra Pradesh, and Sikkim also imply that fertilizer policy may be more effective when tailored to regional cropping patterns and existing adoption levels rather than applied uniformly across the country. For the fertilizer industry and research institutions, the results imply a continuing need for innovation in biofertilizer formulation and storage, since shelf life and handling constraints remain a barrier to wider adoption despite the cost and environmental advantages these products offer.

5.2 Recommendations

Building on the findings, the study recommends that Indian agricultural policy actively promote integrated nutrient management as the preferred approach for farmers, rather than treating chemical, organic, and biofertilizers as competing alternatives. Extension services and agricultural universities should expand farmer training on the correct combination and timing of chemical, organic, and biological inputs, since the benefits of integration depend heavily on proper application. Government support, including subsidies, price incentives, and easier access to certification, should be extended to organic and biofertilizer producers to help narrow the cost and convenience gap with chemical fertilizers. Given the storage and shelf life limitations identified for biofertilizers, continued investment in research on formulation, packaging, and cold chain infrastructure would help these products realize their full potential in the field. States with heavy chemical fertilizer dependence, such as Punjab and Haryana, would benefit from targeted programs that gradually introduce organic and biological inputs without disrupting existing productivity, while the experience of fully organic states such as Sikkim could be studied further and adapted, where feasible, for other regions. Finally, given the pace at which consumption and market conditions are changing, periodic updates to national fertilizer statistics and continued research combining secondary analysis with field level studies would strengthen the evidence base for future policy decisions.

5.3 Limitations of the Study

As with any study based entirely on secondary sources, the conclusions drawn here are only as reliable as the underlying reports and statistics, and figures on consumption, cost, and market share may shift as newer official data become available, particularly for the 2025 estimates used in this analysis. The absence of primary data collection means that farmer level experiences, regional soil variation, and crop specific responses to fertilizer combinations could not be verified directly, and the comparative assessments of yield, cost, and environmental impact rely on general patterns reported in the literature rather than controlled field trials conducted for this study. In addition, the analysis treats organic and biofertilizers as broad categories, which may understate meaningful

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differences between individual products, such as the performance of vermicompost relative to farmyard manure or Rhizobium relative to Azospirillum. Finally, because the study focuses on the national and select state level picture, its findings may not fully capture the variation present across India's diverse agro climatic zones.

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DOI: https://doi.org/10.56879/ijbm.v5i2.70