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Bio-Fertilizers and Chemical Fertilizers - Prospects, Challenges, Issues and Way Forward

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ABSTRACT

The global agricultural sector is increasingly challenged by the dual objectives of ensuring food security and promoting environmental sustainability. This review paper examines the prospects, challenges, and future pathways for bio-fertilizers and chemical fertilizers. Bio-fertilizers, characterized by their cost-effectiveness, environmental benefits, and capacity to enhance soil fertility through microbial activity, are compared with chemical fertilizers, which offer high nutrient concentrations but raise concerns over long-term sustainability, soil degradation, and environmental health. The paper delves into the classification, production patterns, and regulatory frameworks governing both fertilizer types, with a focus on their adoption in India and globally. Furthermore, it highlights critical challenges, including quality control, farmer awareness, and environmental impact, while exploring innovative solutions such as precision agriculture, sustainable formulations, and bio-based alternatives. This comprehensive analysis provides actionable insights for policymakers, researchers, and agricultural stakeholders to advance sustainable fertilizer practices for future generations.

Keywords: *Bio-fertilizers, Chemical fertilizers, Sustainable agriculture, Soil health, Nutrient management, Environmental impact, Fertilizer market trends, Microbial inoculants*.

INTRODUCTION OF BIO AND CHEMICAL FERTILIZER

Applied to seeds, plant surfaces, or soil, a product called "biofertilizer" contains living microbes that colonize the plant's interior, or rhizosphere, increasing the host plant's supply or availability of primary nutrients and so boosting development [1].

The natural processes of nitrogen fixation, phosphorus solubilization, and growth-promoting chemical synthesis are how biofertilizers supply nutrients to plants. Biofertilizers contain microorganisms that generate soil organic matter and restore the soil's natural nutrition cycle. In addition to improving soil health and sustainability, biofertilizers can be used to grow healthy plants. Although they can't yet completely replace synthetic fertilizers and pesticides, biofertilizers should help decrease their consumption. Over 340 biofertilizer products were authorized for commercial use in the United States as of 2024[2].

Chemical Fertilizers

Chemical fertilizers are inorganic substances that have undergone partial or complete synthesis.

The goal of adding chemical fertilizers to soil is to increase macronutrients such as potassium (K), phosphorous (P), and nitrogen (N) in order to promote plant growth and development and, ultimately, plant output. (Nabi *et al.* 2023).

Types of Bio-fertilizers Based on Material/ physical Form

1. **Carrier based**
   - Enrich Soil Fertility, carrier is medium that keep organism viable, carrier based, easy to supply to farmers, selection of ideal material should be there, low investment, low cell count [4].
2. **Liquid Based**
   - Contain dormant form of micro-organism, micro-organism will be viable when come in contact of soil, cell grow on carbon material available in soil, longer shelf life, liquid based, high cell count [4].

Types of Bio-fertilizers Based on Living Organism:

Heterotrophic Bacteria

- Nitrogen Fixer and Phosphate Solubilizer

Phototrophic Bacteria

- Nitrogen fixer

Fungi

- Phosphate Solubilizing & Mobilizer

Heterotrophic Bacteria

Heterotrophic bacteria live in the soil and fix significant levels of nitrogen & phosphorus with or without the direct interaction with other organisms.

Some Example of Heterophilic Bacterial Bio-Fertilizers.

- *Frankia, Rhizobium, Azospirilum, Azatobactor, Bacillus sp., Pseudomonas sp.* (Jena *et al.*,2020)

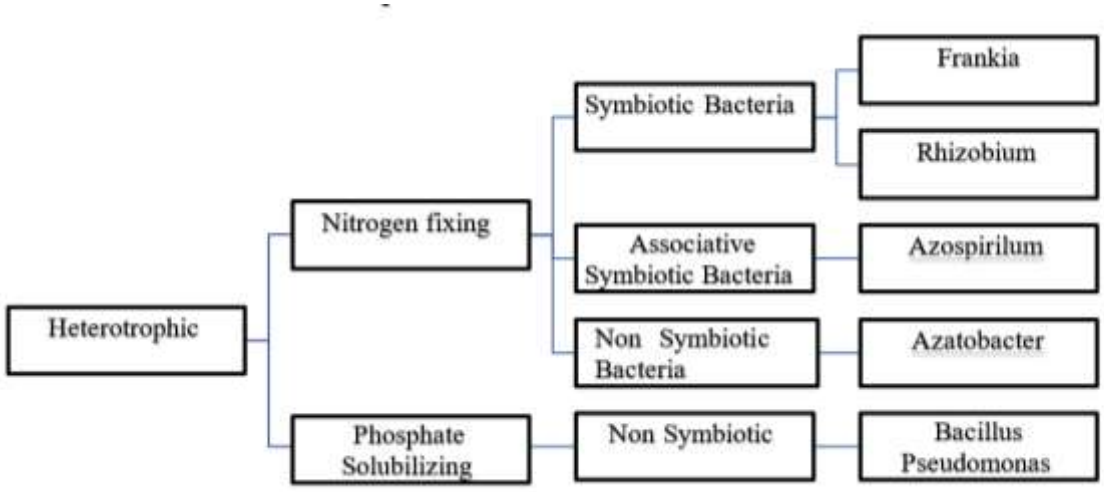
Phototrophic Bacteria

Only works in paddy that has been soaked under bright sunshine. fixing N to the tune of 2–30 kg/ha by converting the insoluble P into soluble forms. Raising the crop yield by 10-15% when applied at 10kg/ha/BGA biomass.

Types of Phototrophic Bacterial Based Bio-fertilizers

- BGA (Blue Green Algea), Frankia (Jena *et al.*,2020)

➢ **Classification of heterotrophic bacteria**



Fungal Bio-Fertilizers

Bio-fertilizers comprise microbial inocula. Benefit plant growth directly or indirectly. Decompose organic matter, oxidize sulfur, fix atmospheric nitrogen, or solubilize phosphorus. **advantageous to the nutrient supply for agricultural output.** Arbuscular mycorrhizal fungi, which are probably the most abundant fungi in agricultural soil (Rai and Shukla,2020).

Types of Chemical Fertilizer

1) Nitrogen Fertilizers
2) Phosphorus fertilizers
3) Potassium fertilizers
4) Compound fertilizers
5) Secondary macronutrient fertilizers
6) Micronutrient
7) Amide Fertilizers (https://www.fertilizerseurope.com)

Nitrogenous Fertilizers

1) Nitrate Fertilizers: Nitrogen is mixed with other components to form NO3. Such fertilizers are sodium nitrate or chilean nitrate (NaNO3) – 16% N and calcium nitrate [Ca (NO3)2] – 15.5% N.

Sodium nitrate is a commercial fertilizer that is imported.

2) Ammonica FertilizerS: In these fertilizers, nitrogen is combined in ammonical (NH4) form with other elements. Such fertilizers are ammonium sulphate [(NH4)2 SO4] – 20% N, ammonium chloride (NH4Cl) - 24 to 26% N, and anhydrous ammonia - 82% N.

3) Nitrate and ammonical Fertilizers: Both nitrate and ammonical nitrogen are included in these fertilizers. Such fertilizers are ammonium nitrate (NH4 NO3) - 33 to 34% N, calcium ammonium nitrate - 26% N, and ammonium sulphate nitrate - 26% N.

4) Amide fertilizers: These fertilizers contain nitrogen in amide or cynamide. Such fertilizers are urea [CO (NH2)2]– 46% N, and calcium cynamide (CaCN2) – 21% N.

Phosphatic Fertilizers

1) **Water soluble P containing**

    - Mono ammonium phosphate (20% N and 20% P2O5), diammonium phosphate (18% N and 46% P2O5), triple super phosphate (TSP) (46 to 48% P2O5), double super phosphate (DSP) (32 to 36% P2O5), and super phosphate (SSP) (16 to 18% P2O5).

2) **Citric acid soluble P containing**

    - Basic slags (14 to 18% P2O5), dicalcium phosphate (34 to 39% P2O5), rhenania phosphate (23 to 26% P2O5), and steamed bone meal (22% P2O5).

3) **Citrate and water insoluble-P containing**

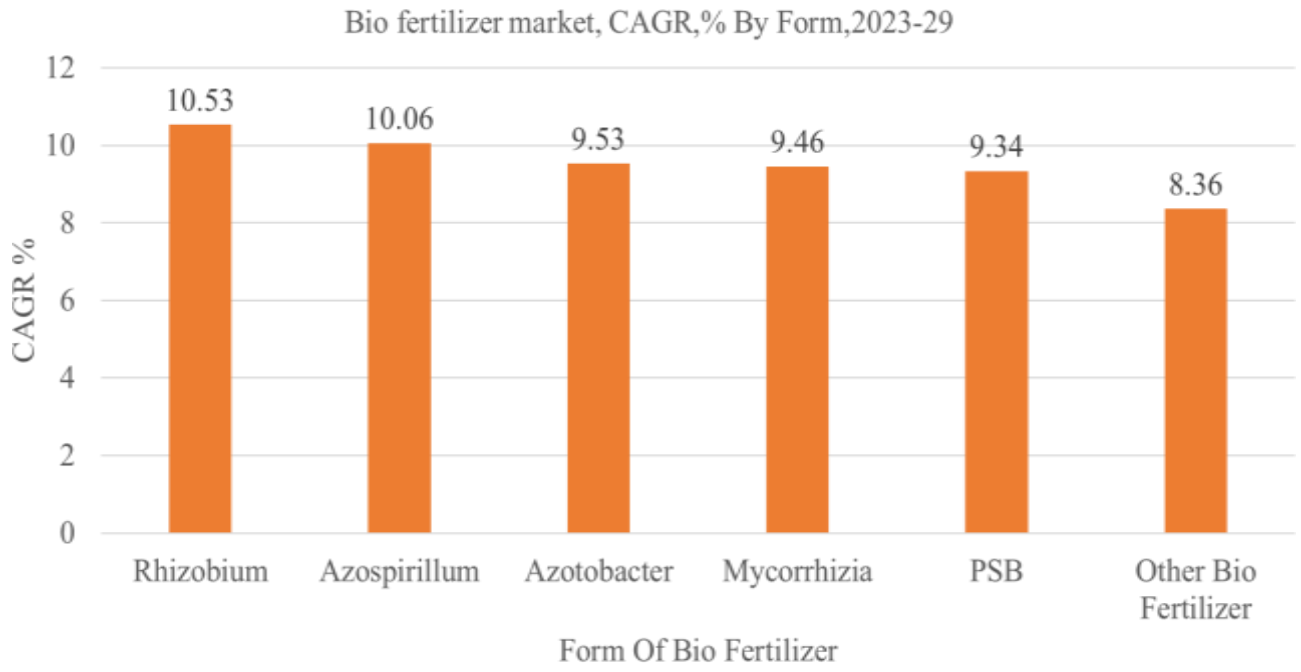
    - Rock phosphate (20 to 40% P2O5), and raw bone meal (20 to 25% P2O5 and 3 to 4% N).

Potassic Fertilizers

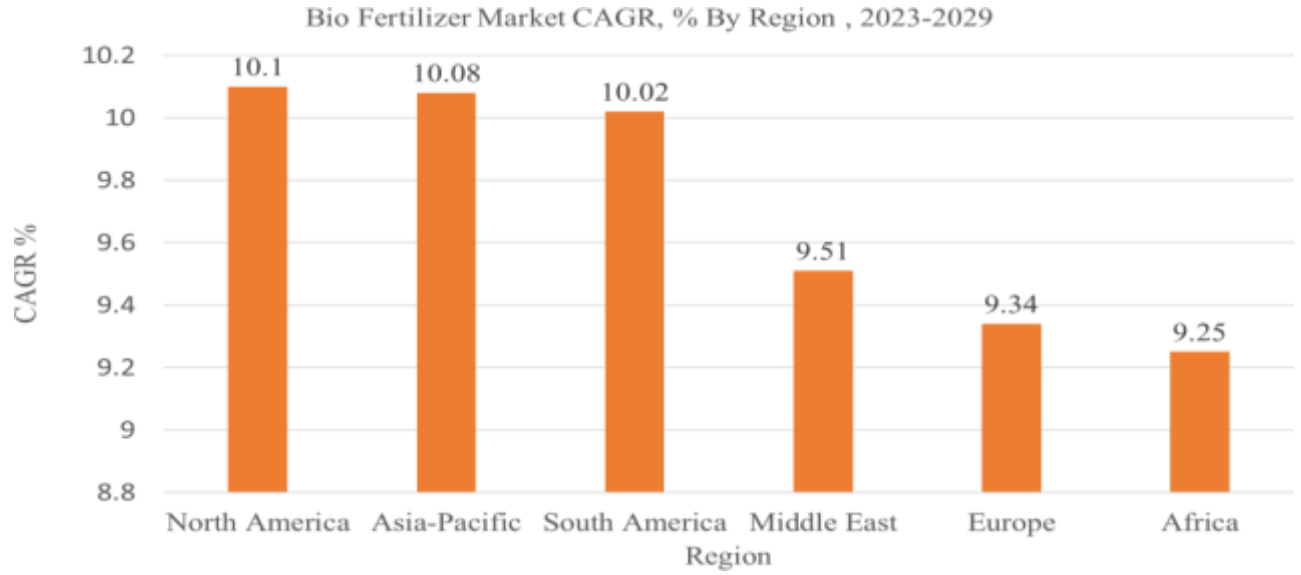
Fertilizer containing chlorine (KCL), sulphate of potash (K2SO4 48% K2O), potassium nitrate (KNO3 44% K2O, 13% N), K2SO4, and MgSO4 (25 to 30% K2O).

World Bio-Fertilizer Scenario

- The market for biofertilizers is valued at USD 3.10 billion in 2023 and is projected to increase at a compound annual growth rate (CAGR) of 9.85% from 2024 to 2029, reaching USD 5.23 billion.
- Rice, barley, corn, wheat, rapeseed, rye, soybeans, and other crops are the main row crops farmed worldwide and they accounted for **74.6% of Bio-fertilizers consumption** in 2022.
- North America is the Largest Region. From 1.4 million hectares in 2017 to 1.6 million hectares in 2021, the region's organic crop cultivation area grew by 13.5% over the historical era (mordorintelligence.com 2024).



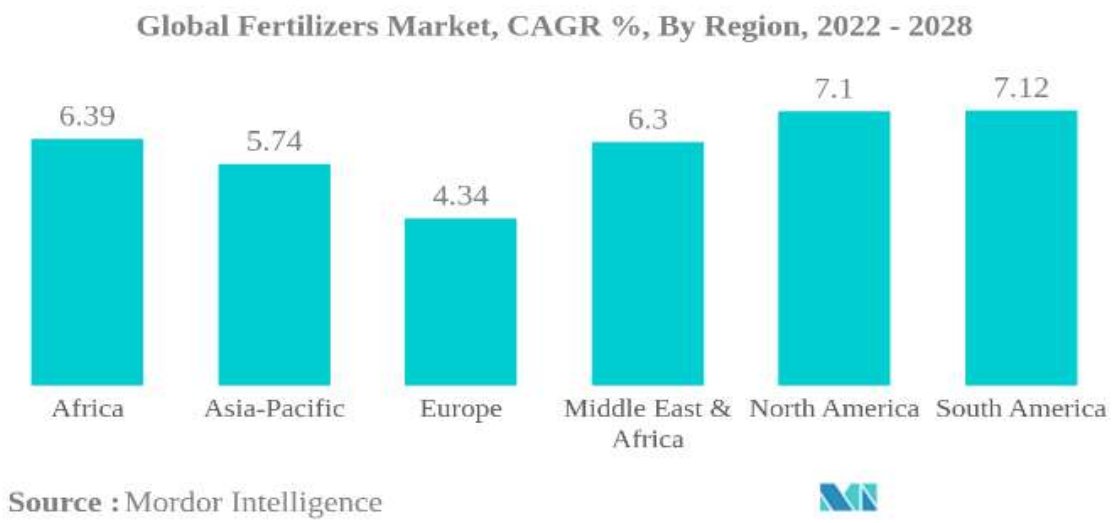
Bio fertilizers market, CAGR,% By Form,2023-29



Bio Fertilizer Market CAGR, % By Region, 2023-2029

World Chemical Fertilizer Scenario

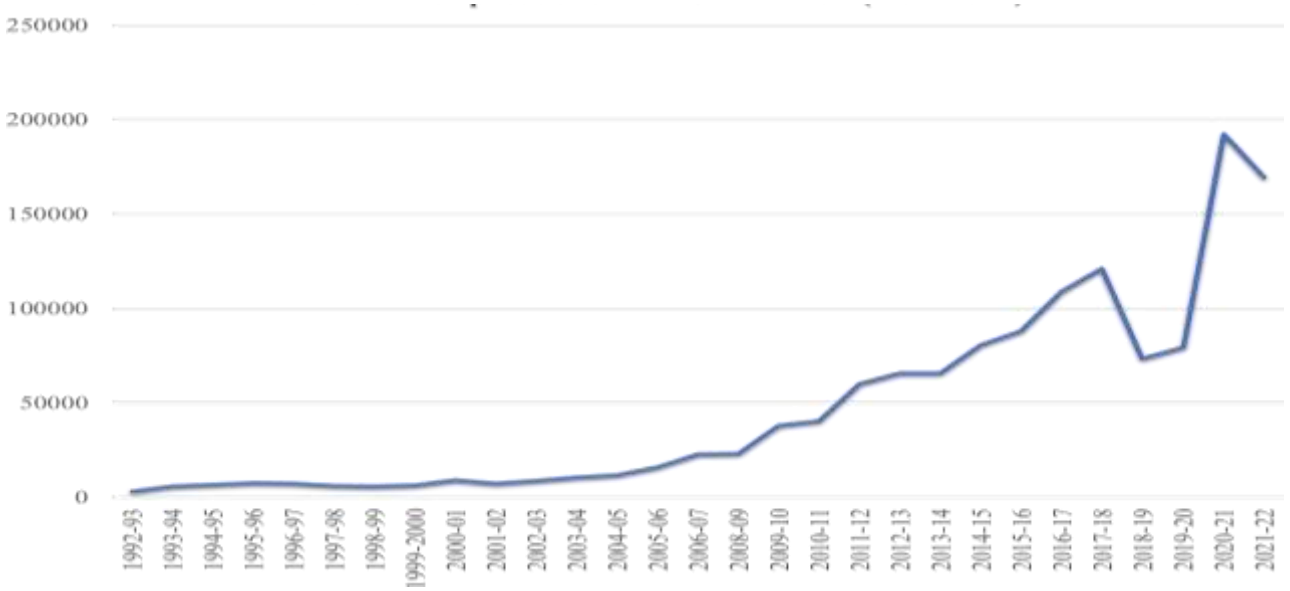
- The Global Fertilizers Market size is estimated at **USD 384.37 billion in 2024**, and is expected to reach **USD 543.20 billion by 2030,** growing at a **CAGR of 05.93%** during the forecast period (2024-2030)(mordorintelligence.com 2024).



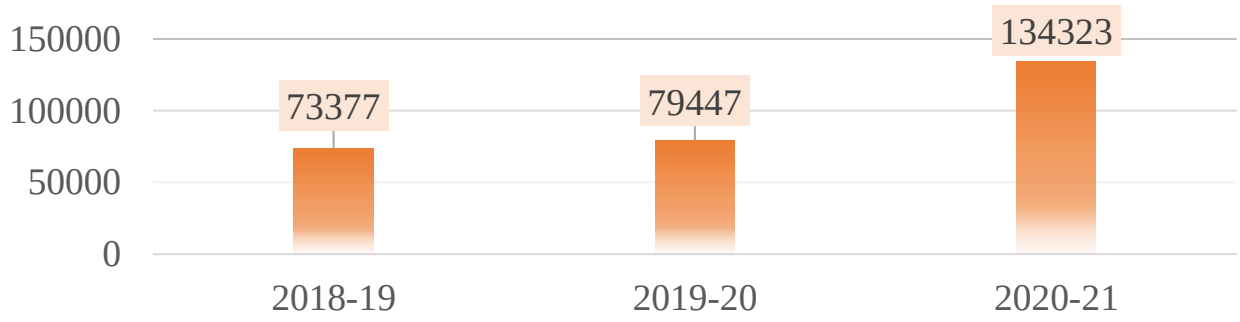
Global Fertlizers Market, CAGR %, By Region, 2022-2028 (mordorintelligence.com 2024)

Indian Bio Fertilizer Scenario

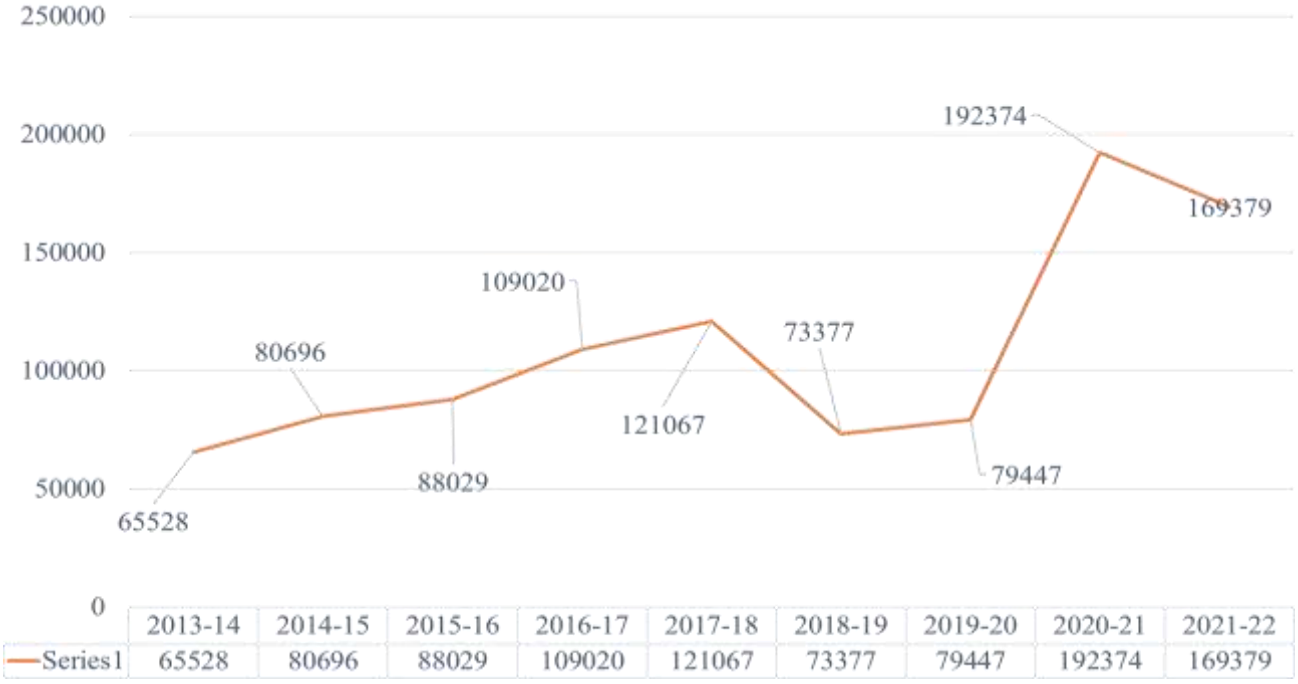
- The India Bio-fertilizers Market size is estimated at **10.63 million USD in 2024**, and is expected to reach **16.50 million USD by 2029**, growing at a **CAGR of 9.20%** during the forecast period (2024-2029).
- 10.63 Million - Market Size in 2024 (USD)
- 16.50 Million - Market Size in 2029 (USD) (mordorintelligence.com 2024)



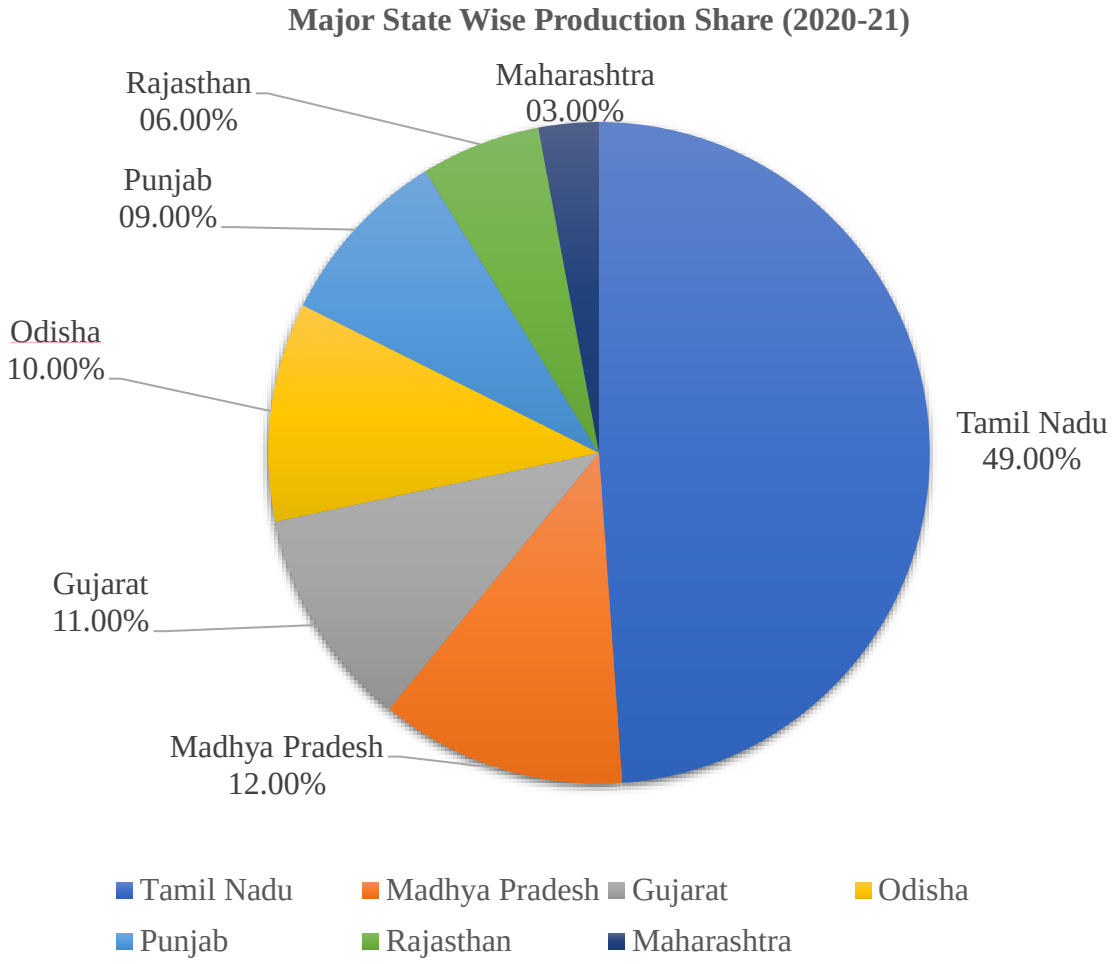
Bio Fertilizer Production Pattern in India (1992-2021) (Indiastat,2024)



Bio-Fertilizer Consumption in India (2018-2021) (Indiastat,2024)



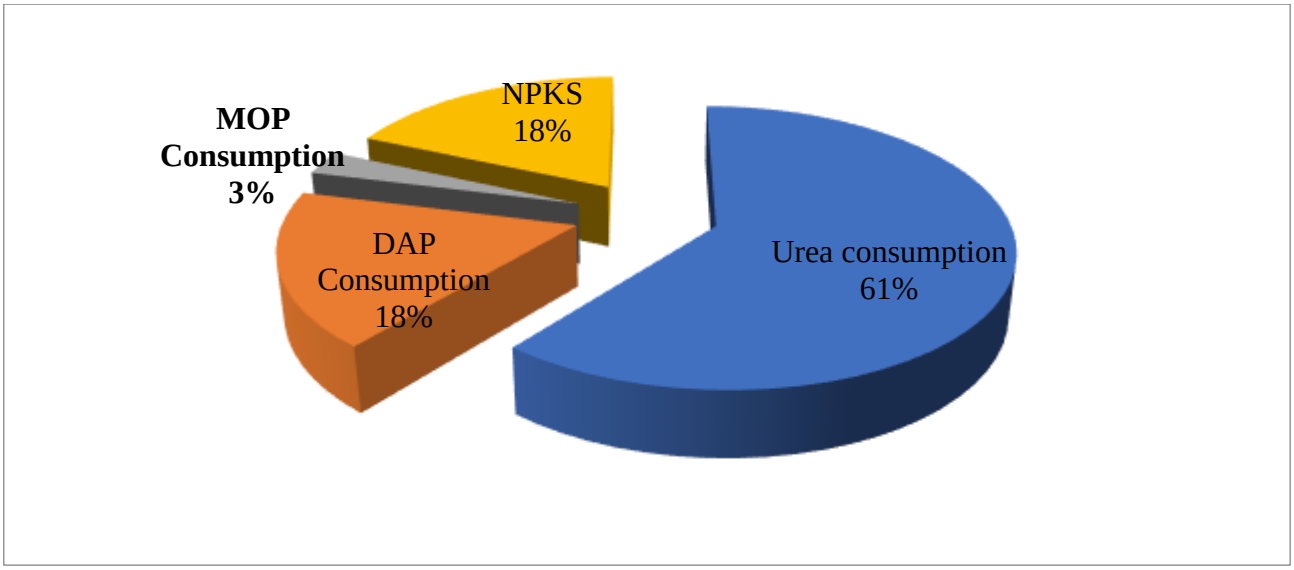
Bio-Fertlizer Production Pattern in India (2013-2021) (Indiastat,2024)



Major State Wise Production Share (2020-2021) (Indiastat,2024)

Indian Chemical Fertilizer Scenario

The India Fertilizers Market size is estimated at **43.32 billion USD in 2024**, and is expected to reach **62.83 billion USD by 2030**, growing at a **CAGR of 06.39%** during the forecast period (2024-2030) (mordorintelligence.com 2024).



Total State Wise (%) Consumption of Fertilizers (Urea/DAP/MOP/NPKS) in India

(Indiastat,2024)

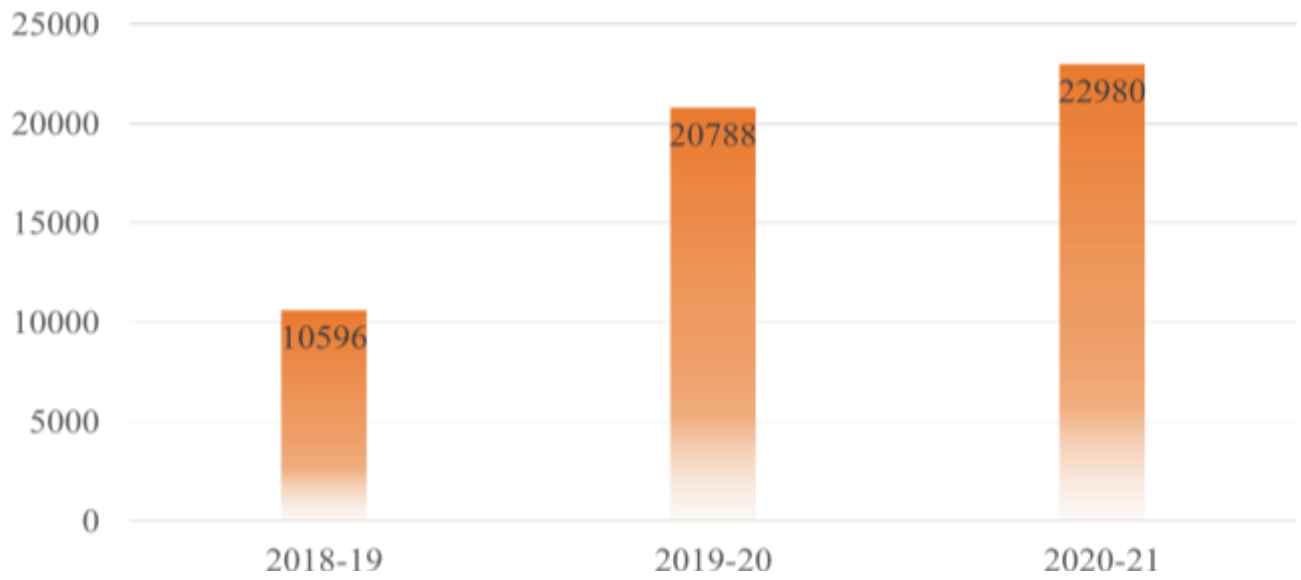
Gujarat Bio Fertilizer Scenario

Year	Production in tonne
2013-14	6411
2014-15	3668
2015-16	3963
2016-17	3910
2017-18	4248
2018-19	10596
2019-20	20788
2020-21	19483
2021-22	24772

Year	Consumption in tonne
2018-19	10596
2019-20	20788
2020-21	22980

(mordorintelligence.com 2024)

Bio-Fertilizer Production in Gujarat (2013-2022) (Indiastat,2024)



Bio-Fertilizer Consumption in Gujarat (2018-2021) (Indiastat,2024)

Bio Fertilizer Regulatory Mechanism in India

- In order to control fertilizer sales, prices, and quality, the Indian government issued the Fertilizer Control Order (FCO) in 1957 under the Essential Commodities Act (EC Act, 1955). Later, in 1973, a movement control order was established to govern fertilizer delivery.
- Bio-fertilizer manufacturers and dealers are required to register and get the certificate, valid for only three years, to be eligible for manufacturing and selling bio-fertilizers (State of Biofertilizers and Organic Fertilizers in India 2022).

Chemical Fertilizer Regulatory Mechanism in India

- The Ministry of Chemicals and Fertilizers (Department of Fertilizers) oversees and regulates the Indian fertilizer industry.
- Government of India passed Fertilizer Control Order (FCO) under the Essential Commodities Act (EC Act, 1955) in the year 1957 to regulate sale, pricing and quality of fertilizers. Subsequently, movement control order was passed in 1973 to regulate distribution of fertilizer**.**
- The Government of India established the "Central Fertilizer Pool" in 1944 to ensure equitable distribution of all fertilizers at fair prices all over the country(https://sansad.in).

Challenges for Bio-fertilizers

A. Related to governments at the Centre and in states

1. Funds, Subsidies and Support for Promotion of Bio-fertilizers

- Low budget allotment
- Farmers not focus on use of Bio-fertilizers because of heavy subsidies on chemical fertilizers
- **Funds** under schemes like **capital investment subsidy scheme, soil health management** aimed at providing support infrastructure for Bio-fertilizers manufacturing have not seen much uptake in states and **remained underutilized**
- Low budget for research and development
- There is **inadequate support** for farm-level extension, training of farmers and local small manufactures
- Production of Bio-fertilizers is concentrated in a few states. Only a handful are producing most of the total of each category of nonchemical fertilizers **(Tamilnadu 41%)** (State of Biofertilizers and Organic Fertilizers in India 2022).

2. Quality Control

- Only eight states have government-owned testing laboratories
- Overall testing capacity underutilized
- **Samples are not meeting up FCO standards**—a sign either of declining quality of tested samples or the fact that tests were not properly performed earlier

- **State procurement through tenders at low-prices** is also cited as a reason for the poor quality of Bio-fertilizers and organic fertilizers being distributed (State of Biofertilizers and Organic Fertilizers in India 2022).

3. Data Collection and Reporting

- Results of tests are not even disclosed in public domain at the state level.
- Data on production of Bio-fertilizers shows significant variations between years, with no explanation offered for the variations, and this can adversely impact policy and decisions (State of Biofertilizers and Organic Fertilizers in India 2022).

B. Related to manufacturers of Bio-fertilizers

- Farmers are not very aware of the benefits of Bio-fertilizers.
- Dealers are not very interested in buying and selling Bio-fertilizers.
- Availability of spurious and fake Bio-fertilizers products in the market leads to loss of trust among farmers and discourages genuine manufacturers.
- Corruption in securing licenses and authorizations for manufacturing, selling and quality testing of Bio-fertilizers acts as a hindrance to their manufacture and sale.
- Limited government support for production, promotion and procurement of Bio-fertilizers hampers production and sale.
- There is limited involvement of state agriculture universities and Krishi Vigyan Kendra in the production of Bio-fertilizers (State of Bio Fertilizer And Organic Fertilizers in India 2022)

C. Related to farmers

- There is a lack of awareness regarding optimum practices related to organic and natural farming.
- Adequate quantities of quality Bio-fertilizers are not available at the local level.
- There is lack of awareness among farmers regarding usage and storage conditions of Bio-fertilizers.
- Some people believe that using non-chemical methods by themselves won't produce the required crop yield. They can only play a supplementary role (State of Bio Fertilizer and Organic Fertilizers in India 2022)

Issue faced by Bio-Fertilizers

- **Survival and Shelf Life: -** Bio-fertilizers contain living microorganisms that require specific conditions to remain viable over time. (Allouzi *et al.*,2022)
- **Compatibility:-** Interactions between bio-fertilizers and chemical fertilizers or pesticides can negatively impact their effectiveness. Ensuring compatibility is crucial for optimal results.
- **Environmental Conditions:-** The performance of bio-fertilizers is influenced by environmental factors such as temperature, pH, moisture levels, and soil types. These variables can affect the stability and activity of the microbial strains used.
- **Quality Control:-** Contamination or improper handling can compromise their performance.
- **Cost :-** While bio-fertilizers can be cost-effective, the perception of higher costs compared to chemical fertilizers can deter adoption, especially among small-scale farmers with limited resources. Addressing economic concerns is vital for wider acceptance.

Future Perspective

- The most important factors which can influence Bio-fertilizers market footprint is farmer awareness and technology adoption.
- Farmer outreach programs conducted at village level.
- Disseminate knowledge about the harmful effects chemical fertilizers have on the ecosystem.
- All stake-holders primarily central and state governments, agricultural scientists, farmers and civil society must play a role in popularizing Bio-fertilizers.
- Bio-fertilizers are cheap and easy to use.
- They contribute to the restoration of the physical characteristics and health of the soil.

- Consistent availability of good quality Bio-fertilizers compliant to FCO standards can provide the essential NPK to the crops without leaving any adverse environmental footprint.
- Bio-fertilizers production can be sold as a small scale business idea to attract potential entrepreneurs.
- Technology incubation centers set up by public sector institutes and educational institutes can be made available to for production by new start ups.

Challenges in Chemical Fertilizers

1) Environmental Impact:

- **Water Pollution**: Runoff from fields treated with chemical fertilizers can lead to contamination of water bodies with nitrates and phosphates, contributing to algal blooms and ecosystem disruption.
- **Soil Degradation**: Over-reliance on chemical fertilizers can degrade soil health over time by reducing microbial diversity, affecting nutrient cycling and soil structure.

2) Health Concerns:

- **Residue in Food**: Chemical fertilizers can leave residues in crops, which can potentially accumulate in the food chain and pose health risks to humans and animals.
- **Human Health Impact**: Prolonged exposure to chemical fertilizers by farm workers or nearby residents can lead to health issues like respiratory problems and skin irritations.

3) Dependency and Cost:

- **Financial Burden**: Chemical fertilizers can be costly, especially for small-scale farmers, leading to financial strain and dependency on external suppliers.
- **Nutrient Imbalance**: Overuse of certain fertilizers can create nutrient imbalances in soils, affecting plant health and long-term productivity.

4) Long-term Sustainability:

- **Depletion of Non-renewable Resources**: Production of chemical fertilizers relies heavily on non-renewable resources like fossil fuels (for nitrogen synthesis), which raises concerns about long-term sustainability.
- **Climate Impact**: Manufacturing and application of chemical fertilizers contribute to greenhouse gas emissions, exacerbating climate change.

5) Resistance and Efficiency:

- **Resistance in Pests and Weeds**: Continuous use of chemical fertilizers can lead to the development of resistance in pests and weeds, necessitating higher doses or different chemicals.
- **Efficiency Issues**: Not all applied fertilizers are utilized by crops efficiently; a significant portion can be lost through leaching, volatilization, or runoff.

Future Perspective of Chemical Fertilizers

1) **Sustainable Formulations**:

2) Precision Agriculture:

- Advances in technology are enabling precision application of fertilizers, where nutrients are applied based on real-time data and crop needs. This approach can optimize fertilizer use, reduce wastage, and mitigate environmental impact.

3) Biological and Bio-based Fertilizers:

- There is a growing interest in biological and bio-based fertilizer research.
- These products utilize microbes, organic materials, or natural substances to enhance nutrient availability and improve soil health without the environmental drawbacks of traditional chemical fertilizers.

4) Nutrient Recovery and Recycling:

- Technologies for recovering nutrients from waste streams (such as animal manure, food waste, or wastewater) are being developed. This helps close nutrient loops, reduces dependency on mined resources, and addresses concerns about resource depletion.

5) Smart Fertilizers:

- Smart fertilizers are being designed with properties that release nutrients in response to specific triggers (like soil moisture, pH levels, or plant demand). This targeted delivery can improve efficiency and reduce environmental losses.

6) Regulation and Policy:

- Increased scrutiny and regulation around fertilizer use are expected to drive innovation towards more sustainable practices. Governments and organizations are promoting nutrient management plans, sustainable agriculture initiatives, and stricter guidelines for fertilizer application.

Conclusion

The comparative analysis of bio-fertilizers and chemical fertilizers highlights their respective contributions, challenges, and future prospects within sustainable agriculture. Bio-fertilizers offer an environmentally friendly, cost-effective, and soil health-improving alternative to chemical fertilizers, yet face hurdles such as limited awareness, quality concerns, and regulatory challenges. Conversely, chemical fertilizers remain pivotal in meeting global food demands but pose significant environmental and health risks, alongside concerns about long-term soil sustainability.

Addressing these challenges calls for integrated strategies that blend the strengths of both fertilizers. Policies should promote farmer education, ensure quality standards, and encourage innovations like precision agriculture, smart fertilizers, and nutrient recycling technologies. A collaborative approach involving governments, agricultural scientists, manufacturers, and farmers is essential to foster sustainable agricultural practices. Embracing bio-fertilizers and advancing chemical fertilizer technologies will not only ensure food security but also mitigate the ecological footprint of modern farming.

Future research should focus on enhancing the efficacy of bio-fertilizers, developing eco-friendly chemical formulations, and integrating cutting-edge technologies to achieve a balanced, sustainable agricultural ecosystem.

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