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The Advantages and Disadvantages of Using Chemical Fertilizers in Crop Production: Future Perspectives and Suitable Alternatives

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ABSTRACT

The use of chemical fertilizers in agricultural production has been a cornerstone of modern farming practices, significantly enhancing crop yields and food security. This article examines the advantages and disadvantages of chemical fertilizers, highlighting their role in increasing nutrient availability and promoting rapid plant growth. However, the reliance on these inputs has raised concerns regarding soil health, environmental pollution, and long-term sustainability. The adverse effects, such as soil degradation, waterway contamination, and the disruption of local ecosystems, necessitate a critical evaluation of their continued use. Furthermore, this article explores the future of agricultural practices in the context of rising environmental awareness and the need for sustainable alternatives. Potential substitutes, including organic fertilizers, biofertilizers, and innovative agronomic practices, are discussed as viable options that can mitigate the negative impacts associated with chemical fertilizers. By assessing current research and case studies, this article aims to provide a comprehensive overview of the implications of chemical fertilizer use in agriculture, ultimately advocating for a balanced approach that integrates both traditional and alternative methods to ensure sustainable agricultural productivity and environmental stewardship.

Keywords: Agricultural productions, Benefits, Difficulties, Inorganic fertilizer

INTRODUCTION

The global demand for agricultural products has surged in recent decades, driven by population growth, urbanization, and changing dietary patterns (Devos *et al.,* 2024). In response, farmers have increasingly turned to chemical fertilizers as a means to enhance crop yields and ensure food security (Ugwu *et al*., 2024). These synthetic inputs, which primarily consist of nitrogen, phosphorus, and potassium, have revolutionized agricultural practices by providing essential nutrients that promote rapid plant growth and increased productivity (Mirzakarami *et al.,* 2019). However, the widespread use of chemical fertilizers has also

sparked significant debate regarding their long-term sustainability and environmental impact (Mirzaei Heidari & Bagheri, 2022). On one hand, the advantages of chemical fertilizers are substantial. They enable farmers to achieve higher yields in shorter timeframes, which is crucial in meeting the food demands of a growing population (Maleki *et al.,* 2014). Moreover, the precise formulation of these fertilizers allows for targeted nutrient application, optimizing plant health and reducing the likelihood of nutrient deficiencies. This efficiency has been pivotal in the development of intensive farming systems, particularly in regions where arable land is limited (Alnaass *et al*., 2025). Conversely, the disadvantages associated with chemical fertilizers cannot be overlooked. The reliance on these inputs has led to soil degradation, as the continuous application can disrupt the natural microbial ecosystem and diminish soil fertility over time (Mirzaei Heydari & Babaei, 2022). Additionally, runoff from fertilized fields can contaminate water bodies, leading to eutrophication, which poses a threat to aquatic life and human health. The environmental implications of chemical fertilizer use have prompted calls for more sustainable agricultural practices that prioritize ecological balance (Zamani *et al*., 2025).

As the agricultural sector faces increasing scrutiny over its environmental footprint, there is a pressing need to explore suitable alternatives to chemical fertilizers (Brears, 2025). Organic fertilizers, derived from natural sources, present an appealing option, as they not only supply nutrients but also enhance soil structure and biodiversity (Qasim Saleh & Mirzaei Heydari, 2024).. Furthermore, the integration of biofertilizers and innovative agronomic practices, such as crop rotation and cover cropping, offers promising pathways to reduce dependency on synthetic inputs while maintaining productivity (Najim & Mirzaei Heydari, 2024). This article aims to provide a comprehensive analysis of the advantages and disadvantages of chemical fertilizers in agricultural production. By examining current research and case studies, we will explore the future of fertilizer use in agriculture and identify sustainable alternatives that can support both agricultural productivity and environmental health. As the agricultural landscape continues to evolve, understanding the implications of chemical fertilizer use is essential for developing resilient and sustainable farming systems that can meet the challenges of the 21st century.

Research methods

In this review, electronic searches were conducted in many of databases such as (Science Direct, Google scholar, PubMed, scientific journals, Wikipedia, eBooks) and searching in library sources, for the latest updates regarding The Advantages and Disadvantages of Using Chemical Fertilizers in Crop Production: Future Perspectives and Suitable Alternatives.

Historical Context of Chemical Fertilizers

The Green Revolution

The Green Revolution, which began in the mid-20th century, marked a pivotal shift in agricultural practices, characterized by the introduction of high-yield crop varieties, advanced irrigation techniques, and the extensive use of chemical fertilizers (Vetrivel & Arun, 2025). This movement significantly boosted food production, particularly in developing countries,

alleviating hunger and improving food security. However, while the Green Revolution demonstrated the potential of chemical fertilizers to enhance crop yields, it also highlighted the associated environmental challenges, such as soil degradation and water pollution. As the agricultural sector reflects on these outcomes, the need for sustainable alternatives becomes increasingly critical to ensure long-term ecological balance and food sustainability (Subramaniam *et al*., 2025; Mirzaeheydari *et al.*, 2024a).

Evolution of Fertilizer Technology

The evolution of fertilizer technology has significantly transformed agricultural practices over the past century. Initially, fertilizers were derived from natural sources, such as manure and bone meal, providing essential nutrients to crops (Sukanya, 2024). The advent of synthetic fertilizers in the mid-20th century introduced a new era, enabling the precise formulation of nutrients like nitrogen, phosphorus, and potassium. Innovations in production processes, such as the Haber-Bosch method for nitrogen fixation, further increased availability and efficiency. However, as reliance on chemical fertilizers grew, so did concerns about their environmental impact, prompting ongoing research into more sustainable and eco-friendly alternatives that enhance soil health and productivity.

Uses of Fertilizer

- To generate sufficient food to support the population of the world (Ghosh *et al.,* 2024).
- To supply supplementary nutrients to the plants (Maleki *et al.,* 2014).
- Fertilizers that are high in nitrogen are utilized to make lawns greener (Xu *et al.,* 2024).
- To replace the nutrients lost, fertilizer is incorporated into the soil of potted plants (Selvarajh *et al.,* 2024).
- By applying organic fertilizer, one can improve both the fertility and texture of the soil (Feilinezhad *et al.,* 2022).

Gardeners utilize fertilizers to ensure that plants receive the necessary nutrients (Panday *et al.,* 2024).

Moreover, the fertilizer can benefit the plants in the following ways:

- Fertilizers enhance a plant’s resistance to insects, resulting in reduced use of insecticides and herbicides, which leads to healthier crops. With fewer diseases, these crops also possess greater aesthetic value (Zeinivand *et al.,* 2025).
- The nitrogen content in fertilizers promotes plant growth, as indicated by the vibrant green color of the plants (Lotfi *et al.,* 2021).
- Phosphorus present in fertilizers promotes quicker seed and root development in plants (Heydari *et al.,* 2011).
- Fertilizers rich in potassium enhance the strength of the straws and stalks in plants (Rahmani i *et al.,* 2014).
- Fertilizers encourage the development of deeper roots and improve plants' capacity to hold water (Heydari *et al.,* 2019).

Advantages of Chemical Fertilizers

5.1 Increased Crop Yields

One of the most significant benefits of chemical fertilizers is their ability to enhance crop yields (Heydari *et al.*, 2009). Numerous studies have demonstrated that the application of N, P, and K can lead to substantial increases in agricultural productivity. For example, research conducted in various regions has shown yield increases of up to 50% in staple crops such as wheat and rice when chemical fertilizers are applied appropriately (Srivastav *et al.*, 2024).

5.2 Improved Crop Quality

Chemical fertilizers not only boost yields but also improve the quality of crops. Adequate nutrient supply can enhance the nutritional content, size, and appearance of produce. For instance, crops grown with balanced fertilization often exhibit higher levels of essential vitamins and minerals, making them more appealing to consumers (Qiao *et al.*, 2022).

5.3 Cost-Effectiveness

Chemical fertilizers are generally more cost-effective than organic alternatives. Their high nutrient concentration and ease of application make them attractive to farmers seeking immediate results. Additionally, the availability of various formulations allows farmers to tailor their fertilization strategies to specific crop needs (Hoseini *et al.*, 2022).

5.4 Enhanced Soil Fertility

When applied judiciously, chemical fertilizers can temporarily enhance soil fertility by replenishing essential nutrients. This can lead to improved soil structure and increased microbial activity, promoting overall soil health (Mirzaeheydari *et al.*, 2024b).

5.5 Technological Advancements

Advancements in fertilizer technology, such as slow-release and controlled-release fertilizers, have improved nutrient use efficiency. These innovations reduce nutrient losses to the environment and enhance crop uptake, further contributing to sustainable agricultural practices (Vejan *et al.*, 2021).

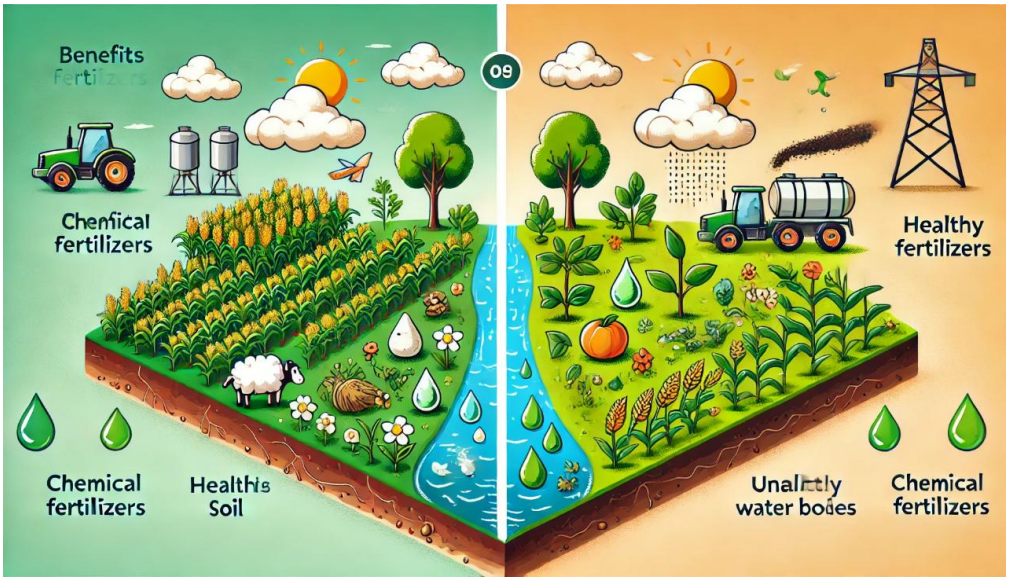

Figure 1. The Benefits and Risks of Chemical Fertilizers

Disadvantages of Chemical Fertilizers

6.1 Environmental Impact

The extensive use of chemical fertilizers has been linked to significant environmental degradation. Nutrient runoff from agricultural fields can lead to water pollution, causing eutrophication in aquatic ecosystems. This process depletes oxygen levels in water bodies, resulting in fish kills and loss of biodiversity (Penuelas *et al.,* 2023).

6.2 Soil Health Degradation

Over-reliance on chemical fertilizers can lead to soil health degradation. Continuous application without organic amendments can result in soil acidification, reduced organic matter content, and a decline in soil biodiversity. These changes compromise long-term soil fertility and agricultural sustainability (Singh *et al.,* 2024).

6.3 Health Risks

Chemical fertilizers pose health risks to farmworkers and consumers. Exposure to these substances can result in respiratory issues, skin irritation, and other health problems. Moreover, the presence of chemical residues in food raises concerns about food safety, prompting calls for stricter regulations (Thakur & Paika, 2024).

6.4 Economic Dependency

Farmers may become economically dependent on chemical fertilizers, leading to a cycle of increased input costs and decreased profitability. This dependency can limit the adoption of sustainable agricultural practices and increase vulnerability to market fluctuations (Kumar *et al.,* 2023).

6.5 Climate Change Contributions

The production and use of chemical fertilizers contribute to greenhouse gas emissions. Nitrous oxide, a potent greenhouse gas, is released during the application of nitrogen fertilizers, exacerbating climate change and its associated impacts on agriculture (Tian *et al.,* 2023).

Impacts on the use of excessive chemical fertilizer

Using chemical fertilizers leads to a marked increase in crop yields. However, runoff into lakes, rivers, and the sea also contains NO^{3-}, NH^{4+}, S_2O_4-, Na^{+}, k^{+}, etc. since nitrogen and phosphate fertilizers are soluble in water. Below are some significant effects of the overapplication of chemical fertilizers:

- The components of fertilizers can poison the skin and respiratory systems.
- Excessive use of fertilizers damages plants and reduces soil fertility.
- Excessive fertilizer use can lead to eutrophication, as it promotes the rapid growth of algae and other aquatic plants, which may clog rivers and lakes.
- A higher concentration of nitrates in drinking water may result in numerous health issues.
- The excessive application of fertilizers modifies the texture of the soil.
- As the amount of organic matter in the soil decreases due to increased use of chemical fertilizers, the soil may become more acidic.
- Denitrifying nitrates into nitrogen oxides, especially N_2O, may pose a threat to the ozone layer..

- Large amounts of nitrogen sprayed to farms over time harm the topsoil, lowering agricultural yields.

- The presence of heavy metals in chemical fertilizers can be concerning, as they may harm the kidneys, liver, and lungs. These metals include lead, mercury, cadmium, and uranium..

Overall, the overuse of chemical fertilizers has led to several problems, including significant soil deterioration, nitrogen leaching, soil compaction, a reduction in soil organic matter, and loss of soil carbon. (Jote, 2023; Beigzadeh *et al.,* 2019; Penuelas *et al.,* 2023).

Case Studies

8.1 Successful Implementation

Several case studies highlight the successful use of chemical fertilizers in boosting agricultural productivity. For example, in India, the Green Revolution, characterized by the widespread adoption of chemical fertilizers, resulted in significant yield increases in rice and wheat, contributing to food security (Penuelas *et al.,* 2023).

8.2 Negative Consequences

Conversely, case studies from regions experiencing severe eutrophication and soil degradation illustrate the negative consequences of excessive chemical fertilizer use. The Chesapeake Bay in the United States is a notable example, where nutrient runoff has led to significant ecological damage (Akinnawo *et al.,* 2023).

Sustainable Alternatives

To mitigate the disadvantages of chemical fertilizers, sustainable alternatives such as integrated nutrient management (INM), organic fertilizers, and precision agriculture are gaining traction. These methods aim to optimize nutrient use efficiency while minimizing environmental impact (Arefi *et al.,* 2025).

9.1 Integrated Nutrient Management (INM)

INM combines chemical fertilizers with organic amendments, enhancing nutrient availability while improving soil health. This approach promotes a balanced nutrient supply and reduces reliance on synthetic inputs (Bagheri & Mirzaei Heydari, 2020).

9.2 Organic Fertilizers

Organic fertilizers, derived from natural sources, offer a sustainable alternative to chemical fertilizers. They improve soil structure, enhance microbial activity, and provide a slow-release nutrient supply, contributing to long-term soil fertility (Mirzaei Heidari, & Mishkhaszadeh, 2023).

9.3 Precision Agriculture

Precision agriculture employs technology to optimize fertilizer application based on specific crop needs. This approach reduces nutrient wastage, minimizes environmental impact, and enhances overall farm profitability (Getahun *et al.,* 2024).

Policy Implications

The findings of this review underscore the need for policies that promote sustainable fertilizer use. Governments and agricultural organizations should encourage research and

development of sustainable practices, provide training for farmers, and implement regulations to minimize environmental impacts. (Athuman, 2023).

Future Directions

11.1 Research and Development

Future research should focus on developing innovative solutions that enhance nutrient use efficiency while minimizing negative consequences. This includes exploring new formulations, application methods, and the integration of biotechnology in fertilizer production (Fig 2).

11.2 Education and Training

Educating farmers about sustainable practices and the responsible use of chemical fertilizers is crucial. Extension services and training programs should be implemented to promote best practices in fertilizer application.

11.3 Policy Frameworks

Establishing robust policy frameworks that incentivize sustainable practices is essential for the long-term viability of agriculture. This includes subsidies for sustainable fertilizers, support for research initiatives, and regulations to limit environmental harm (Chandra, 2023).

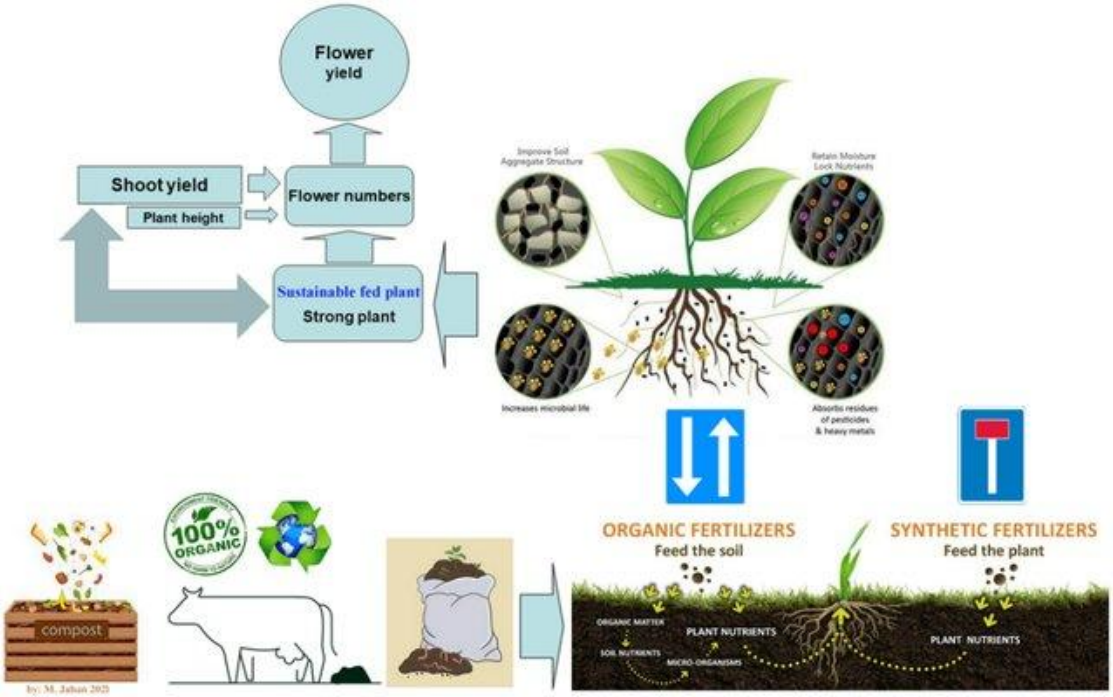

Figure 2. Organic fertilizers versus chemical fertilizers, and the related processes affect the flower yield ofEchium amoenum through the explored causal paths (Amiri *et al.*, 2022).

CONCLUSION

Chemical fertilizers have undeniably transformed crop production, providing numerous advantages in terms of yield and quality. However, their disadvantages, particularly

concerning environmental and health impacts, cannot be overlooked. A balanced approach that incorporates sustainable practices alongside chemical fertilizer use is essential for ensuring long-term agricultural viability. Future research and policy initiatives should focus on promoting sustainable alternatives and optimizing fertilizer use efficiency to mitigate negative consequences while maintaining agricultural productivity.

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