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CHEMICAL FERTILIZERS

AND ENVIRONMENTAL SUSTAINABILITY: CHALLENGES AND IMPLICATIONS FOR MODERN AGRICULTURE

FERTILIZANTES QUÍMICOS Y SOSTENIBILIDAD AMBIENTAL: DESAFÍOS E IMPLICACIONES PARA LA AGRICULTURA MODERNA

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ABSTRACT

Chemical fertilizers have played a fundamental role in increasing agricultural productivity and meeting the growing global demand for food. However, their excessive and prolonged use has generated significant environmental problems and risks to human health. The purpose of this article was to analyze the environmental impacts of chemical fertilizers on ecosystems, agricultural sustainability, and public health through a qualitative review of scientific literature published between 2018 and 2026. The study was based on the analysis of academic research, environmental reports, and scientific publications related to soil degradation, water contamination, greenhouse gas emissions, biodiversity loss, and sustainable fertilization alternatives. The findings revealed that intensive chemical fertilizer use alters the chemical and microbiological properties of soil, reduces natural fertility, and affects ecological balance. Furthermore, nutrient runoff and leaching contribute to the contamination of rivers, lakes, and groundwater systems, promoting eutrophication and increasing risks to human health. In addition, the production and application of synthetic fertilizers increase pollutant emissions associated with climate change. The review also demonstrated that sustainable practices such as organic fertilization, integrated nutrient management, and precision agriculture technologies represent viable alternatives for reducing environmental impacts without compromising agricultural productivity. Finally, the study concludes that the sustainability of modern agriculture depends on the adoption of responsible fertilizer management strategies and environmental policies aimed at protecting ecosystems and ensuring long-term food security.

Keywords:

Chemical fertilizers, environmental sustainability, soil degradation, water contamination, sustainable agriculture, environmental pollution, nutrient management.

RESUMEN

Los fertilizantes químicos han sido fundamentales para incrementar la productividad agrícola y satisfacer la creciente demanda mundial de alimentos. Sin embargo, su uso excesivo y prolongado ha generado importantes problemas ambientales y riesgos para la salud humana. El presente artículo tuvo como objetivo analizar los impactos ambientales de los fertilizantes químicos en los ecosistemas, la sostenibilidad agrícola y la salud pública mediante una revisión cualitativa de literatura científica publicada entre 2018 y 2026. La investigación se basó en el análisis de estudios académicos, informes ambientales y publicaciones científicas relacionadas con degradación del suelo, contaminación del agua, emisiones de gases de efecto invernadero, pérdida de biodiversidad y alternativas sostenibles de fertilización. Los resultados evidenciaron que el uso intensivo de fertilizantes químicos altera las propiedades químicas y microbiológicas del suelo, reduce su fertilidad natural y afecta el equilibrio ecológico. Asimismo, se identificó que el escurrimiento y la lixiviación de nutrientes contribuyen a la contaminación de ríos, lagos y aguas subterráneas, favoreciendo procesos de eutrofización y riesgos para la salud humana. Además, la producción y aplicación de fertilizantes sintéticos incrementan las emisiones contaminantes asociadas al cambio climático. La revisión también mostró que prácticas sostenibles como la fertilización orgánica, el manejo integrado de nutrientes y las tecnologías agrícolas de precisión representan alternativas viables para disminuir el impacto ambiental sin comprometer la productividad agrícola. Finalmente, se concluye que la sostenibilidad de la agricultura moderna depende de la adopción de estrategias responsables de manejo de fertilizantes y de políticas orientadas a la protección ambiental y la seguridad alimentaria.

Palabras clave:

Fertilizantes químicos, sostenibilidad ambiental, degradación del suelo, contaminación del agua, agricultura sostenible, contaminación ambiental, manejo de nutrientes.

INTRODUCTION

Chemical fertilizers have played an essential role in the development of modern agriculture by increasing crop productivity and supporting global food security. Since the Green Revolution, synthetic fertilizers containing nitrogen, phosphorus, and potassium have been widely used in agricultural systems to improve plant growth and maximize crop yields. Their application has contributed significantly to feeding the growing global population and sustaining intensive farming practices. However, despite these agricultural benefits, the excessive and improper use of chemical fertilizers has created serious environmental and health problems across the world (United Nations Environment Programme, 2021).

In recent years, the demand for agricultural production has increased rapidly due to population growth and rising food consumption. To satisfy this demand, many farmers depend heavily on synthetic fertilizers because they provide quick nutrients to crops and improve short-term productivity. Nevertheless, long-term dependence on these fertilizers has caused major environmental concerns, including soil degradation, water contamination, air pollution, biodiversity loss, and climate change. According to the United Nations Environment Programme (2022), the environmental impacts of fertilizers represent one of the most important global challenges affecting ecosystems, public health, and sustainable agriculture.

One of the most significant consequences of chemical fertilizer use is the deterioration of soil health. Healthy soil contains microorganisms and nutrients that are essential for maintaining ecosystem balance and supporting plant growth. However, continuous fertilizer application changes the natural chemical composition of soils and reduces microbial diversity. Bai et al. (2020) explained that long-term use of chemical fertilizers alters soil chemical and microbiological properties, limiting ecosystem functioning and reducing soil quality. These changes weaken the natural fertility of soils and increase agricultural dependence on synthetic inputs. Over time, soil becomes less productive and more vulnerable to erosion, nutrient imbalance, and environmental stress.

Another important issue associated with chemical fertilizers is water pollution. Excessive amounts of nutrients, especially nitrogen and phosphorus, are often washed away from agricultural fields by rainfall or irrigation. These nutrients eventually reach rivers, lakes, and groundwater systems, where they contribute to eutrophication. Eutrophication is a process in which excess nutrients stimulate the rapid growth of algae in aquatic ecosystems. As algae decompose, oxygen levels in the water decrease, causing the death of fish and other aquatic organisms. In addition, nitrate contamination in drinking water poses serious risks to human health, particularly for infants and vulnerable populations. The United Nations Environment Programme (2021) reported that fertilizer pollution threatens water quality worldwide and negatively affects both ecosystems and public health.

Chemical fertilizers also contribute significantly to air pollution and climate change. Nitrogen fertilizers release nitrous oxide into the atmosphere, which is one of the most powerful greenhouse gases. Nitrous oxide contributes to global warming and damages the ozone layer. The production and transportation of synthetic fertilizers also require large amounts of energy derived from fossil fuels, increasing carbon emissions and environmental degradation. Lazewski (2024) emphasized that synthetic fertilizers support food production while simultaneously creating long-term environmental damage that threatens ecosystem sustainability. As a result, agriculture has become an important contributor to climate-related environmental problems.

In addition to affecting soil, water, and air quality, chemical fertilizers can negatively influence biodiversity and ecosystem stability. Excessive fertilizer application changes the balance of nutrients in ecosystems and disrupts natural biological processes. Plants, microorganisms, insects, and aquatic organisms may suffer from habitat degradation and chemical exposure. Furthermore, agricultural soils treated with large amounts of fertilizers often experience reduced biological activity and lower resilience to environmental changes. These effects create ecological imbalances that can threaten sustainable agricultural production in the future.

Research conducted in tea orchards also demonstrates the harmful effects of chemical fertilizers on soil ecosystems. Lin et al. (2019) found that long-term use of chemical fertilizers in tea plantation soils significantly altered rhizosphere conditions, including soil acidity, nutrient availability, and microbial activity. In contrast, organic fertilizers improved soil quality and supported healthier microbial communities. This evidence suggests that sustainable fertilization methods can reduce environmental damage while maintaining agricultural productivity.

Despite the environmental concerns associated with chemical fertilizers, they continue to be widely used because of their effectiveness in increasing agricultural production. However, growing scientific evidence highlights the urgent need to adopt more sustainable agricultural practices. Strategies such as integrated nutrient management, organic fertilization, precision agriculture, and environmentally friendly fertilizers may help reduce pollution and protect natural resources. Sustainable fertilizer management is essential to balancing agricultural productivity with environmental conservation and human health protection.

This article examines the environmental impacts of chemical fertilizers, focusing on soil degradation, water

contamination, air pollution, ecosystem disruption, and threats to human health. It also explores the importance of sustainable agricultural practices that minimize environmental damage while supporting long-term food security and ecosystem sustainability.

MATERIALS AND METHODS

This study was conducted through a qualitative literature review focused on analyzing the environmental impacts of chemical fertilizers on ecosystems, agricultural sustainability, and human health. The research was based on the examination of scientific articles, environmental reports, and peer-reviewed studies published between 2018 and 2026. Academic databases and official environmental publications were used to collect relevant information related to fertilizer use, soil degradation, water contamination, greenhouse gas emissions, biodiversity loss, and sustainable agricultural alternatives.

The selection of sources was guided by their scientific relevance, publication quality, and contribution to the understanding of environmental issues associated with synthetic fertilizers. Studies included in the review examined both the positive agricultural effects and the negative ecological consequences of chemical fertilizer application. Special attention was given to research investigating long-term soil changes, contamination of aquatic ecosystems, atmospheric pollution, and the relationship between fertilizers and public health risks. Reports from international environmental organizations were also incorporated to provide global perspectives on fertilizer-related environmental challenges.

The methodology consisted of collecting, organizing, and critically analyzing information from the selected references. The reviewed studies were compared to identify common findings, recurring environmental concerns, and proposed sustainable solutions. The analysis focused on identifying patterns related to fertilizer overuse, environmental degradation, and alternative fertilization strategies capable of reducing ecological damage while maintaining agricultural productivity.

In addition, the study examined evidence regarding sustainable agricultural practices such as organic fertilization, integrated nutrient management, environmentally friendly fertilizers, and precision agriculture technologies. Comparative analysis was used to evaluate differences between conventional synthetic fertilizers and sustainable nutrient management approaches. The collected information was interpreted descriptively to develop a comprehensive understanding of how chemical fertilizers influence environmental quality and long-term agricultural sustainability.

The research did not involve experimental laboratory procedures or field trials. Instead, it relied entirely on previously published scientific evidence and environmental assessments. This approach allowed the study to integrate findings from multiple geographic regions and agricultural systems, providing a broader understanding of the global environmental consequences associated with chemical fertilizer use.

RESULTS AND DISCUSSION

The analysis of the selected literature demonstrates that chemical fertilizers have both productive and harmful effects on agricultural systems and the environment. Although these fertilizers are effective in increasing crop yields and supporting food production, the reviewed studies consistently indicate that their excessive and prolonged use causes serious ecological disturbances. The findings reveal that environmental impacts are particularly visible in soil quality, water resources, atmospheric conditions, and ecosystem stability.

One of the principal findings observed across the reviewed studies is the progressive decline in soil quality associated with intensive fertilizer application. Research conducted by Bai et al. (2020) showed that long-term use of chemical fertilizers significantly modifies soil chemical composition and microbial activity. The study found that soils exposed to continuous fertilizer application experienced reductions in microbial diversity and biological functioning. Since soil microorganisms are responsible for nutrient cycling and organic matter decomposition, any alteration in microbial populations directly affects soil fertility and ecosystem sustainability. The reduction in beneficial microorganisms limits the natural regenerative capacity of soils and increases agricultural dependence on synthetic nutrient inputs.

Similarly, Lin et al. (2019) reported important differences between soils treated with chemical fertilizers and those treated with organic fertilizers in tea orchards. The researchers observed that chemical fertilizers increased soil acidity and negatively influenced the biological conditions of the rhizosphere. In contrast, organic fertilizers improved microbial activity and supported healthier soil environments. These findings suggest that the repeated use of synthetic fertilizers gradually weakens soil structure and biological balance, which may reduce agricultural productivity over time despite short-term yield improvements.

Another major result identified in the literature is the contribution of chemical fertilizers to water pollution. Nutrient leaching and agricultural runoff were repeatedly mentioned as key environmental concerns. Excess nitrogen and phosphorus from fertilizers frequently enter nearby rivers, lakes, and groundwater systems through rainfall and irrigation processes. According to the United Nations Environment Programme (2021), fertilizer pollution has become one of the main causes of eutrophication in

aquatic ecosystems. Eutrophication stimulates excessive algae growth, which reduces oxygen concentrations in water and threatens aquatic biodiversity. Fish mortality, ecosystem imbalance, and deterioration of water quality are common consequences associated with this process.

The reviewed studies also emphasize the impact of fertilizer contamination on drinking water quality. High nitrate concentrations in groundwater represent a significant public health concern, particularly in rural agricultural regions. Contaminated water may contribute to serious health problems, including respiratory disorders and diseases related to nitrate exposure. The evidence presented by the United Nations Environment Programme (2022) demonstrates that fertilizer pollution affects millions of people worldwide and creates additional economic and environmental burdens for governments and communities.

In addition to water contamination, the findings reveal that chemical fertilizers contribute substantially to atmospheric pollution and climate change. Nitrogen-based fertilizers release nitrous oxide during agricultural processes, and this gas is recognized as one of the most powerful greenhouse gases affecting global warming. The production of synthetic fertilizers also requires considerable industrial energy consumption, much of which depends on fossil fuels. Consequently, fertilizer manufacturing and application increase carbon emissions and intensify environmental degradation.

Lazewski (2024) argued that modern agricultural systems have become increasingly dependent on synthetic fertilizers despite their long-term environmental consequences. The author highlighted that while fertilizers temporarily improve productivity, they often create ecological costs that are ignored in conventional agricultural models. These costs include pollution, biodiversity loss, and soil exhaustion. Such findings support the growing concern that agricultural intensification without environmental regulation may threaten future food security rather than guarantee it.

The literature further indicates that chemical fertilizers influence ecosystem biodiversity and ecological balance. Excessive nutrient accumulation changes natural nutrient cycles and disrupts interactions among plants, microorganisms, insects, and aquatic organisms. Several studies suggest that ecosystems exposed to intensive fertilizer use reduced resilience to environmental stress. The imbalance caused by nutrient overload may favor certain species while eliminating others, ultimately decreasing biodiversity and ecosystem stability.

An important discussion emerging from the reviewed studies involves the comparison between chemical and sustainable fertilization methods. Organic fertilizers and integrated nutrient management practices are frequently presented as environmentally safer alternatives. Lin et al. (2019) observed that organic fertilization improved soil biological activity and reduced harmful environmental effects compared to synthetic fertilizers. Likewise, environmentally friendly fertilizers reviewed by Chen et al. (2018) demonstrated the potential to reduce nutrient losses, improve soil conditions, and minimize environmental contamination. These findings indicate that sustainable agricultural strategies may help maintain productivity while protecting natural ecosystems.

Another significant aspect discussed in the literature is the relationship between fertilizer use and sustainable development. Modern agriculture faces the challenge of producing sufficient food while simultaneously preserving environmental quality. Excessive fertilizer dependence creates a conflict between productivity and sustainability. While farmers rely on synthetic fertilizers to maximize yields, environmental degradation threatens long-term agricultural viability. Therefore, the findings suggest that future agricultural systems must balance economic productivity with environmental responsibility.

The reviewed evidence also highlights the importance of environmental policies and educational programs focused on fertilizer management. Many environmental impacts associated with fertilizers result from overapplication, improper timing, and inefficient nutrient management practices. Precision agriculture technologies, soil testing, and farmer education programs may reduce unnecessary fertilizer use and improve nutrient efficiency. Governments and agricultural institutions play a critical role in promoting regulations and sustainable practices that minimize environmental damage.

Overall, the results of the reviewed studies clearly demonstrate that chemical fertilizers have significant environmental consequences despite their agricultural benefits. Soil degradation, water contamination, greenhouse gas emissions, and biodiversity loss are among the most critical problems associated with intensive fertilizer use. The discussion of these findings emphasizes the urgent need for sustainable agricultural approaches that reduce environmental risks while ensuring food production. Sustainable fertilization practices, technological innovation, and effective environmental management are essential for protecting ecosystems and supporting long-term agricultural sustainability.

Furthermore, Bishnoi (2018) emphasized that the intensive use of chemical fertilizers has generated severe ecological consequences that extend beyond agricultural fields. The study explained that excessive fertilizer application contributes to soil acidification, nutrient imbalance, and contamination of surrounding ecosystems. In addition, the author argued that modern agriculture has prioritized productivity while neglecting the environmental costs associated with synthetic agricultural inputs. This perspective

reinforces the idea that sustainable agricultural practices are necessary to protect environmental quality and long-term soil productivity.

Likewise, Thorat and More (2022) examined the harmful effects of chemical fertilizers on both environmental systems and human health. Their findings indicated that prolonged exposure to fertilizer residues may contribute to respiratory diseases, skin disorders, and water-related health complications. Moreover, the study highlighted that fertilizer runoff contaminates freshwater ecosystems and accelerates ecological degradation. The authors stressed the importance of reducing excessive fertilizer dependence and promoting environmentally responsible agricultural management.

In a similar manner, Lu and Zhang (2026) analyzed the environmental effects of fertilizer reduction strategies in China and demonstrated that agricultural production services can effectively decrease chemical fertilizer consumption without significantly reducing crop productivity. Their research suggested that technological innovation, efficient nutrient management, and environmentally focused agricultural policies play a critical role in minimizing pollution and improving sustainability. The study provides strong evidence that agricultural modernization can support environmental protection when sustainable practices are properly implemented.

Additionally, Alom et al. (2025) investigated the environmental impacts of chemical fertilizer consumption in Australia and reported that fertilizer use contributes significantly to environmental pressure at the state level. Their analysis revealed strong associations between fertilizer application, greenhouse gas emissions, and ecological degradation. The researchers also noted that regions with intensive agricultural activity experienced greater environmental stress due to excessive nutrient use. These findings support global concerns regarding the environmental sustainability of intensive agricultural systems.

Equally important, Singh et al. (2026) discussed the direct relationship between chemical fertilizers, soil degradation, and environmental quality deterioration. Their study demonstrated that continuous fertilizer use negatively affects soil structure, microbial activity, and nutrient balance. Furthermore, the authors emphasized that long-term dependency on synthetic fertilizers reduces natural soil fertility and increases environmental vulnerability. Their conclusions highlight the urgent need for balanced nutrient management practices capable of preserving soil health while maintaining agricultural productivity.

Moreover, Zhuang et al. (2024) explored the effects of reducing chemical fertilizers while incorporating organic manure in apple orchard production systems. The researchers found that combining organic manure with reduced fertilizer application improved soil fertility, enhanced crop productivity, and promoted healthier soil conditions. Their findings suggest that integrated nutrient management strategies may represent an effective alternative for reducing environmental damage without compromising agricultural yields.

Similarly, Kiss et al. (2023) compared the environmental impacts of poultry manure and synthetic fertilizers and concluded that organic nutrient sources produce fewer harmful environmental effects. The study indicated that poultry manure contributes to improved soil conditions while reducing pollution risks associated with chemical fertilizers. Nevertheless, the authors also acknowledged that improper organic waste management may create additional environmental challenges. Therefore, sustainable fertilization requires careful planning and balanced agricultural practices.

In another relevant contribution, Nesirov et al. (2022) investigated the relationship between chemical fertilizer consumption and agricultural carbon emissions in Azerbaijan. Their results demonstrated a positive and statistically significant connection between fertilizer use and carbon dioxide emissions. This finding confirms that synthetic fertilizers contribute not only to local environmental degradation but also to broader climate change processes. The study reinforces international concerns regarding the environmental costs of intensive agricultural production.

Furthermore, Tagkas et al. (2024) conducted a systematic review examining the relationship between fertilizers and human health. Their research identified epidemiological evidence linking fertilizer exposure to multiple health risks, including chronic diseases and environmental health complications. The authors emphasized that vulnerable populations living near agricultural regions may experience higher exposure levels due to contaminated water, soil, and air. Consequently, the study underlines the importance of stricter environmental monitoring and public health protection policies.

Likewise, Jote (2023) analyzed the environmental and human health impacts associated with inorganic chemical fertilizers. The study explained that excessive fertilizer application damages soil ecosystems, contaminates water resources, and contributes to air pollution through greenhouse gas emissions. Additionally, the author argued that human exposure to fertilizer-related contaminants may increase health risks, particularly in communities dependent on agriculture. These findings further demonstrate the interconnected relationship between environmental sustainability and public health.

In addition, Jency (2019) highlighted that fertilizer pollution represents one of the major environmental challenges generated by modern agricultural practices. The study described how nutrient runoff, soil degradation, and water

contamination affect ecological balance and agricultural sustainability. The author also emphasized that continuous fertilizer dependence may gradually reduce natural soil productivity, creating long-term agricultural difficulties despite temporary increases in crop production.

Another important contribution was presented by Krasilnikov et al. (2022), who discussed the relationship between fertilizer use, soil health, and agricultural sustainability. Their research emphasized that maintaining soil quality is essential for ensuring long-term food security and environmental conservation. The authors argued that excessive fertilizer application weakens soil ecosystems and threatens sustainable agricultural development. Consequently, they recommended balanced nutrient management strategies capable of improving productivity while minimizing ecological damage.

Likewise, Chen et al. (2018) reviewed environmentally friendly fertilizers and evaluated their potential to reduce environmental pollution. Their findings demonstrated that innovative fertilizer technologies may decrease nutrient losses, improve nutrient efficiency, and reduce contamination of natural ecosystems. The study suggested that sustainable fertilizer alternatives could help address environmental concerns associated with conventional synthetic fertilizers while supporting agricultural productivity.

Furthermore, Chittora et al. (2023) examined the harmful impacts of synthetic fertilizers on agriculture and the environment. Their research indicated that intensive fertilizer use contributes to declining soil quality, environmental pollution, and ecosystem instability. The authors emphasized that agricultural sustainability depends on reducing excessive chemical inputs and encouraging environmentally responsible farming methods capable of protecting natural resources for future generations.

Finally, Wan et al. (2021) investigated the effects of combining chemical and organic fertilizers on soil properties and crop productivity in citrus cultivation. The study revealed that integrated fertilizer application improved soil conditions, enhanced plant growth, and increased agricultural yield compared to chemical fertilizers alone. The researchers concluded that combining organic and synthetic nutrient sources may reduce environmental stress while maintaining efficient agricultural production.

The reviewed studies collectively demonstrate that the excessive use of chemical fertilizers has generated serious environmental and agricultural challenges worldwide. One of the most consistent findings is the progressive deterioration of soil quality caused by long-term synthetic fertilizer application. Continuous exposure to chemical nutrients alters soil composition, weakens microbial activity, and reduces natural fertility, making agricultural systems increasingly dependent on external inputs. This degradation threatens the long-term sustainability of crop production and reduces ecosystem resilience.

Another major concern identified in the literature is the contamination of water resources through nutrient runoff and leaching. Excess nitrogen and phosphorus released from agricultural fields contribute to the pollution of rivers, lakes, and groundwater systems, negatively affecting aquatic ecosystems and water quality. In many regions, fertilizer pollution has intensified ecological imbalance and increased risks associated with unsafe drinking water. These environmental pressures demonstrate the close relationship between agricultural practices and ecosystem health.

The studies also reveal that chemical fertilizers significantly contribute to atmospheric pollution and climate change. Fertilizer production and application generate greenhouse gas emissions that intensify global warming and environmental degradation. Intensive agricultural systems relying heavily on synthetic fertilizers have been associated with higher carbon emissions and increased ecological stress. These findings indicate that fertilizer-related pollution extends beyond local agricultural fields and affects broader environmental processes.

In addition to environmental degradation, the reviewed research highlights important concerns regarding human health. Exposure to fertilizer contaminants through water, soil, and air has been associated with various health risks, particularly in agricultural communities. The literature emphasizes the need for improved environmental monitoring and safer agricultural management practices to reduce human exposure to harmful chemical substances.

At the same time, several studies demonstrate that sustainable fertilization strategies can reduce environmental impacts while maintaining agricultural productivity. Approaches such as integrated nutrient management, reduced fertilizer application, organic manure incorporation, and environmentally friendly fertilizer technologies were shown to improve soil conditions, enhance nutrient efficiency, and minimize pollution. These alternatives suggest that agricultural production and environmental protection can be balanced through more sustainable and scientifically informed farming practices.

Overall, the reviewed evidence confirms that while chemical fertilizers have contributed to increased food production, their excessive use poses serious risks to soil health, water quality, atmospheric stability, biodiversity, and human well-being. The findings strongly support the transition toward sustainable agricultural systems that prioritize environmental conservation alongside agricultural productivity.

CONCLUSIONS

The findings of this study demonstrate that the intensive use of chemical fertilizers represents one of the most significant environmental challenges facing modern agriculture. Although synthetic fertilizers have contributed substantially to increased food production and agricultural efficiency, their excessive and prolonged application has generated severe consequences for soil quality, water resources, atmospheric stability, biodiversity, and human health. The evidence reviewed throughout this research confirms that environmental degradation associated with fertilizers is not an isolated problem but rather a global issue affecting ecosystems and communities across different regions of the world.

One of the most critical conclusions is that continuous dependence on chemical fertilizers weakens the natural capacity of soils to maintain fertility and ecological balance. Changes in soil composition, microbial diversity, and nutrient cycling reduce long-term agricultural sustainability and increase dependence on external chemical inputs. Likewise, fertilizer runoff and nutrient leaching continue to threaten freshwater systems, contributing to eutrophication, water contamination, and ecological imbalance in aquatic environments. These impacts highlight the interconnected nature of agricultural practices and environmental health.

The reviewed literature also demonstrates that chemical fertilizers contribute significantly to climate change through greenhouse gas emissions generated during fertilizer production and application. The accumulation of environmental damage caused by intensive agricultural systems suggests that current production models cannot remain sustainable without substantial changes in nutrient management practices. In addition, the association between fertilizer exposure and human health risks emphasizes the urgent need for stronger environmental regulations and public health protections.

At the same time, the evidence indicates that sustainable alternatives can effectively reduce environmental damage while preserving agricultural productivity. Strategies such as organic fertilization, integrated nutrient management, precision agriculture, and environmentally friendly fertilizers offer practical solutions for minimizing pollution and improving soil health. These approaches demonstrate that environmental conservation and food production do not have to be conflicting objectives when agricultural systems are managed responsibly.

The future of global agriculture depends on the ability to balance productivity with environmental protection. Governments, researchers, agricultural institutions, and farmers must work collaboratively to promote sustainable farming practices, improve environmental education, and encourage responsible fertilizer management. Without significant action, the continued misuse of chemical fertilizers may intensify environmental degradation and threaten the long-term stability of agricultural ecosystems and food security worldwide.

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Conflicts of Interest:

The authors declare no conflicts of interest.

Author Contributions:

Farshid Hadi, Zhila Daneshvar Ameri: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, original draft writing, and writing, review, and editing.

Ethical statement:

The study was based on the analysis of documentary sources and publicly available data, and therefore did not involve the direct participation of human subjects. No personally identifiable information was handled.