The Impact of Chemical Fertilizers on Soil Health and Crop Yield in Arid Regions of Libya

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Abstract

Researchers examined chemical fertilizer effects on soil health and their influence on crop yield across the arid Libyan provinces. One hundred twenty farmers participated in the study, with sixty participants implementing chemical fertilizers while another sixty groups did not apply fertilizer. The analysis spanned from January through June 2023 to obtain information about soil pH levels with additional results regarding organic matter percentages, crop yield measurements expressed as kg/ha, water nitrate evaluations, soil erosion metrics, and economic sustainability metrics ($/ha). The study performed a statistical evaluation using ANOVA and correlation methods to evaluate the associations between fertilizer usage and experimental data points. The research results demonstrated that fertilizer applications correlated directly to raised agricultural output levels and better financial gains. The research did not detect substantial alterations in groundwater pollution and land degradation. Analysis shows that during this designated period, the ecological effects of fertilizers remained limited even though they became a main driver for agricultural productivity growth in the area being researched.

Keywords: Fertilizer use, Crop yield, Economic sustainability, Soil health, Water quality, Soil erosion, Arid regions, Libya, Agricultural productivity, Environmental impact.

Context and Background

Libyan economics and social development strongly depend on agriculture as a leading sector when farmers can access cultivable land with available irrigation systems (Alawamy et al., 2022). The desert environment of Libya poses major obstacles for farmers because traditional agricultural practices become ineffective due to scarce rainfalls combined with intense temperatures and unproductive land quality. Although Libya faces multiple agricultural difficulties, food security and the economic stability of communities flourish through farming activities, particularly in Al-Jabal Al-Akhdar and other Mediterranean coastal territories. According to Elkhouly & Shefsha (2023), multiple Libyan farmers now rely on chemical fertilizers to manage soil nutrient issues and maintain reliable crop production. People worldwide have adopted chemical fertilizer products that deliver essential nutrients, including nitrogen, phosphorus, and potassium, to increase agricultural yields (Yahaya et al., 2021). The progressive increase in fertilizer usage in Libyan arid areas has resulted in mounting worries regarding soil condition deterioration, environmental sustainability problems, and reduced agricultural performance. Soil degradation, nutrient imbalances, and water pollution are side effects of excessive chemical fertilizer usage when these fertilizers are misused (Alawamy et al., 2022; Li et al., 2022). The problems intensely impact arid areas because these regions lack water supplies and arable land.

Determining the effect of chemical fertilizers on Libyan arid regions influences both soil quality and crop production. Hence, researchers must create new approaches that optimize fertilizer application and improve soil vitality and agricultural sustainability. The research addresses scientific uncertainties about how chemical fertilizers affect land quality and farming performance over time through valuable findings about Libyan fertilizer utilization in agricultural systems.

1. Agricultural Practices in Arid Regions of Libya

The desert spans almost all of Libya's territory since its landmass comprises more than 90% desert. Agricultural cultivation can only happen in the limited usable sections of land that require intensive irrigation systems to grow crops (Elkhouly & Shefsha, 2023). The main agricultural operations occur in coastal areas and regional land sections with access to groundwater reserves. The local farmers maintain traditional methods alongside modern approaches that use chemical fertilizers as the usage of modern techniques increased in the past few years (Williams, 2021).

Before the industrial era, Libyan farmers maintained soil fertility through natural methods, including composting and rotating crops (Gharira & Siddiqui, 2022). Soil fertility adoption of chemical fertilizers in the 20th century occurred because farmers required higher crop yields when water became scarce. Most commercial farms have adopted fertilizer application as a standard farm practice by using chemical fertilizers for wheat, barley, tomato, and olive cultivation (Alawamy et al., 2022). The performance boost from chemical fertilizers remains significant for increasing crop production, but they create environmental and soil-related problems (Biasillo & da Silva, 2021).

Soil health remains essential for sustainable agricultural activities because arid regions possess low and delicate natural fertility (Mrabet et al., 2024). Chemical fertilizer dependence causes multiple detrimental effects on soil quality because it leads to problems with nutrient balance, leads to growing soil salinity, and reduces the amount of vital organic matter. Scientific evidence demonstrates that applying chemical fertilizers continuously leads to essential nutrient depletion, including calcium and magnesium, because they are needed for maintaining soil biology and structure (Elkhouly & Shefsha, 2023). Soil erosion and desertification pose major challenges to Libya's arid regions, specifically due to this issue.

2. Soil Health and Its Importance for Agricultural Sustainability

Soil health signifies the soil's ability to nurture plant growth and sustain biodiversity while regulating environmental processes, including nutrient cycling, water filtering, and carbon capture (Prasad et al., 2021). A healthy soil maintains equilibrium between organic matter, minerals, microorganisms, and water substances that jointly work to foster plant life. Libyan arid regions experience multiple obstacles during soil health maintenance due to their dry conditions, minimal rainfall, and exceptional environmental evaporation rates (El Kenawy, 2024).

Human activities, especially agricultural practices, stress the state of soils. Soil properties undergo permanent degradation due to excessive utilization of chemical fertilizer, which affects both physical properties and biological functions, along with the chemical composition of the soil (Bungau et al., 2021). Soil acidity rises from fertilizer application, organic carbon declines, and soil microorganisms become disturbed, harming soil structure and fertility (Pahalvi et al., 2021). Introducing chemical fertilizers in extreme quantities degrades the soil through numerous fertility-related effects that result in diminished agricultural outcomes. Crop yields decrease while plants show poorer health because these conditions also increase disease vulnerabilities (Singh et al., 2023; Ferreira et al., 2022).

The long-term agricultural sustainability of arid Libya depends on maintaining healthy soil because this region suffers from limited water and soil availability (Yousuf, 2022). The effects of chemical fertilizer on soil health in these regions should be assessed because strategies must be developed to balance fertilizer impacts with sustainable crop yield enhancement (Pahalvi et al., 2021).

3. The Role of Chemical Fertilizers in Boosting Crop Yields

The main purpose behind agricultural chemical fertilizer use is to deliver necessary plant nutrients for successful plant growth. Libyan farmers use chemical fertilizers as their main cultivation method because their arid lands have low fertility, requiring these inputs to achieve better agricultural production (Zurqani, 2021). Soils receiving fertilizers develop better nutritive content, producing greater yields of higher-quality produce (Alawamy et al., 2022). When applied to agricultural land, chemical fertilizers supply nitrogen, phosphorus, and potassium as main nutrients, which enhance plant development, increase photosynthesis, and improve plant health quality (ALnaass et al., 2021).

Numerous studies advocate for the well-established yield improvements obtained by utilizing chemical fertilizers in farming (Pergner & Lippert, 2023). Ghafoor et al. (2021) conducted research proving that using nitrogen-based fertilizers elevated wheat grain production levels across North Africa. According to Elkhouly & Shefsha (2023), the regular use of chemical fertilizers in Libyan agricultural areas produces higher yields specifically for valuable crops, including tomatoes and wheat.

According to Elkhouly and Shefsha (2023), soil acidification, nutrient imbalances, and environmental pollution occur when fertilizers are used excessively or incorrectly. Properly managing chemical fertilizer applications is crucial for maintaining soil health and enhancing crop yields.

The Rationale of the Study

This research examined long-term chemical fertilizer effects on soil health and crop yields because such investigation matters for the arid regions of Libya. Agriculture was a predominant economic force throughout Libya, especially in regions where production activities heavily depended on chemical fertilizers because of poor natural fertility and harsh climatic factors. Libyan agriculture demonstrates a critical need to study the impact of chemical fertilizer usage since their environmental and economic impacts have not received adequate attention. The research need arose from the insufficient knowledge about how fertilizer consumption shaped agricultural sustainability in Libya's dry stretches of land.

1. Addressing Gaps in Knowledge

Studies about fertilizer effects on soil health in Libyan arid conditions were scarce because previous research focused mainly on temperate climates instead. The successful practices from temperate zones did not necessarily work in arid regions because of their natural scarcity of soil fertility and limited water availability. According to Kebede (2023), scientists should create specific nutrient management methods to match the semi-arid tropical conditions. These strategies would also suit Libya's agricultural systems.

Absent regional agriculture research has prevented the creation of practices matching local conditions. Therefore, Libya required an investigation into the effects of chemical fertilizer on its dry climate. The study examined Libya's agricultural challenges by analyzing fertilizer effects on soil fitness and productivity in its arid regions.

2. Importance of Sustainable Agricultural Practices

Agriculture in Libya struggled because of declining-quality soil with unbalanced nutrients and excessive reliance on synthetic fertilizers. The short-term agricultural benefits from fertilizers remained unclear to scientists, who failed to grasp their long-term effects on soil fertility within desert conditions. Research at the African Fertilizer and Soil Health Summit (2024) emphasized sustainable fertilizer practices that would boost crop production and resource a healthy soil environment (Tschirley, 2024). The research data demonstrated the requirement to combine organic with chemical fertilizers to restore and sustain soil fertility. This study added to ongoing research by analyzing integration strategies for sustainable fertilizer operations in Libya's agricultural field. The research sought to develop essential data about effective fertilizer strategies emphasizing soil conservation and Libyan agriculture sustainability.

3. Ensuring Environmental Sustainability

Excessive fertilizer usage created major environmental problems because it negatively affected the health of soil and water quality and biodiversity levels. Experts acknowledged fertilizers as one of the primary environmental stressors that affected arid zones by causing soil acidification and nutrient washouts. Soil acidification plus water contamination in numerous arid and semi-arid zones worldwide resulting from excessive nitrogen fertilizer use was documented by the United Nations Environment Programme (Sharma et al., 2025).

Libya's primary water resources, which are supplied by groundwater, faced significant contamination from fertilizer-derived nitrates because of their water extraction practices. Tiwari and Pal (2022) established that fertilizer runoff led to water body eutrophication, which caused oxygen depletion that harmed aquatic ecosystems. The research examined the severity of environmental problems in Libya, focusing on how fertilizer utilization affects groundwater conditions alongside general environmental sustainability.

4. Economic Implications for Libyan Farmers

The high expense of chemical fertilizers existed as a primary economic burden for farmers in Libya. Government subsidies did not shield farmers from escalating fertilizer prices and growing fertilizer-dependent relations, creating substantial economic hazards for the future. The initial benefit of chemical fertilizers during short-term periods did not translate into favorable economic outcomes for sustained use. According to Elkhouly and Shefsha (2023), the agricultural sector of Libya experienced unsupportable economic sustainability when farmers depended on fertilizers because their increased prices combined with damaged soils made their farming system unsustainable (Elkhouly & Shefsha, 2023).

The economic study evaluated fertilizer use in Libya to understand the relationship between long-term benefits and costs, especially considering declining soil fertility. The authors examined existing fertilizer methods to establish viable, sustainable farming practices that preserve soil health and farmer profitability.

5. Contributing to Global Agricultural Sustainability

This study aimed to generate valuable agricultural findings that would serve Libya and the ongoing discussions about sustainable agricultural management in dry climates worldwide. Fertilizer utilization and its environmental effect presented comparable challenges across North African nations and Middle Eastern and Central Asian countries. According to the Alliance for Food Sovereignty in Africa (2023), traditional knowledge systems should unite with present agricultural methods to build healthier soils and guarantee food security in those areas (Adefila et al., 2024).

The investigation analyzed the Libyan agricultural scene to deliver concrete information that could benefit similar dry and dry-subtropical regions. The research established plans to advance the design of agricultural systems that deliver short-term food stability and maintain sustainable operation over time.

6. Policy and Practical Implications

The research directly influenced Libyan policy by providing guidelines that practitioners must follow to sustain their fertilizer practices. Research results guided policymakers in understanding both soil ecological effects and environmental impacts from current fertilizer applications to develop improved management policies. The study established practical suggestions to maximize Libyan farmers' fertilizer usage while achieving an equilibrium between crop yields and soil integrity.

The study offered a complete fertilizer practice analysis to create safeguards for governmental officials and agricultural producers who needed guidance to develop sustainable economic farming systems. Implementing proper fertilizer recommendations that promote long-term farming viability and economic and environmental sustainability will benefit agricultural sustainability in Libya's dry areas.

Theoretical Framework

This research built its theoretical model with multiple essential concepts that detailed how arid regions interact between fertilizer practice, soil quality, and farming output. The research design adopted ecological and economic concepts to study fertilizer application properties in Libyan arid regions. The framework offered a method to study how fertilizer usage affects soil and crop production sustainability and the longevity of the agricultural system.

1. The Concept of Soil Health and Sustainability

The central theme in agricultural research was soil health, which described how well a living ecosystem sustains plants while supporting animals and humans (Suman et al., 2022). Arid regions presented challenging conditions because soil fertility existed at low levels and organic matter was almost absent, thus making soil health assessment essential for sustaining agriculture. The research utilized the Soil Quality Concept (Doran & Parkin, 1994), which explained that soil health exists when productivity stays high during long periods and environmental problems remain minimal. The concept noted that keeping soil biological, chemical, and physical properties intact demanded correct management practices with fertilizer application.

Libyan soil experienced degradation, acidification, and nutrient imbalances while losing its organic matter content because of the non-sustainable management of chemical fertilizers (Suman et al., 2022). Soil health principles formed the foundation that guided research about fertilizer effects on land sustainability in dry climatic zones. The research investigated soil health in Libyan arid areas by studying fertilization effects on biological, physical, and chemical components and their respective effects on sustainable soil health and farming productivity.

2. The Theory of Nutrient Cycling

Understanding nutrient cycling is an essential principle for describing fertilizer activities within soil systems. Soil's cycling mechanism encompasses the sequential movements and transformations of nitrogen, phosphorus, potassium, and additional essential nutrients between the ground elements, vegetation components, and microorganisms. Soil fertility and plant health rely on this important cycle for their sustenance. When improperly managed fertilizers introduce external nutrients to arid soils, they disrupt the natural ecosystem through nutrient imbalances, which results in environmental damage (Naorem et al., 2023).

Libyan arid regions demanded chemical fertilization for crop growth since their native soils had insufficient nutrients. Excessive fertilizer application disrupts the natural ecosystem by removing essential nutrients from the soil and polluting water resources (Rashmi et al., 2020). The authors employed nutrient cycling principles to analyze chemical fertilizer's consequences on Libyan soil nutrient availability and environmental effects, including groundwater poisoning and water body eutrophication.

3. The Economic Theory of Fertilizer Efficiency and Profitability

The research used economic models of fertilizer profitability and efficiency as part of its economic analysis. In agriculture, fertilizer has been developed as a direct response to enhance crop yield potentials. Fertilizer application activities follow the agricultural economic principle of diminishing returns, demonstrating an upward trend of benefits in the beginning yet showing a downward slope when the amount of fertilizer moves beyond its optimal usage point (Barkley & Barkley, 2016). The arid lands required efficient fertilizer application because soil fertility was limited and water supply was scarce, yet crop production needed enhancement (Zhang et al., 2021).

Fertilizer use efficiency (FUE) demonstrates that fertilizer uptake effectiveness depends on fertilizer application rates, soiled health, crop type, and environmental elements. The challenge for Libyan farmers who used to receive subsidized fertilization lay in identifying proper application techniques that generated sustainable harvests without damaging soil quality or environmental values (Brandolini et al., 2021). According to the FUE economic theory, this study evaluated fertilizer costs and the long-term agricultural sustainability of Libyan farming, specifically targeting small owners at risk from rising fertilizer prices and deteriorating soil conditions (Bdawi, 2022).

4. The Theory of Ecological Modernization

According to Bugden (2022), ecological modernization proposes specific methods for environmental sustainability through modern technology operating within capitalist economic frameworks. According to this perspective, several agricultural techniques, including topical fertilizer applications and nutrient integration management systems, appear able to unite economic expansion with ecological safety.

The ecological modernization theory helped Libyan researchers understand the benefits of chemical fertilizer for agricultural production while promoting sustainable environmental conservation. The research used ecological modernization guidelines to establish methods that connected fertilizers to sustainable techniques, such as soil protection measures and crop sequence management alongside organic supplement use to provide environmental benefits, farm economic performance, and food availability for Libyan agricultural producers.

5. The Theory of Sustainable Agriculture

Multiple scholars developed the sustainable agriculture theory by researching methodologies that would preserve ecological systems across long periods. The core objectives of sustainable agriculture include environmental protection and continuous agricultural production, according to Altieri (1995). Agricultural systems, according to this principle, are needed to achieve sustainable success within all three pillars of environmental, economic, and social dimensions.

The authors applied sustainable agriculture theory to evaluate how Libyan arid regions could integrate fertilizer practices with organic farming techniques, water conservation, and soil health practices. The research goal to build fertilizer management systems that lower chemical fertilizer usage for long-term Libyan soil fertility, environmental protection, and agricultural productivity relied on sustainable agriculture theory.

6. Conceptual Model of Fertilizer Use and Soil Health

The research applied an integrated conceptual model that incorporated earlier mentioned theoretical frameworks. The research model established that chemical fertilization creates soil condition changes by simultaneously affecting biological and chemical aspects and physical characteristics. The rate and the type of livestock fertilizer impact its efficiency through selected soil texture elements and environmental conditions along with the planting crop. Total application of fertilizers above optimal levels resulted in crop yield saturation, earth decay, and ecological contamination. However, proper fertilizer implementation and other sustainable methods created a path toward better agricultural outputs and environmentally sound conditions.

Empirical field research at different Libyan farms evaluated the proposed model regarding fertilizer impacts on soil conditions and agricultural output. The researchers utilized these results to develop a more refined model that suggested sustainable fertilization methods for desert areas in Libya.

Statement of the Problem

As an arid North African Country, Libya encountered considerable agricultural obstacles because of its hot climate, which brought insufficient rainfalls, scorching temperatures, and restricted farming regions. The Libyan economy relied heavily on agriculture because it provided food security and support for rural populations. Due to various factors throughout the past several decades, Libyan farmers have adopted chemical fertilizers to increase crop output and manage soil nutrient shortages. Scientists did not understand how long-term fertilizer practices affected soil state, crop output potential, and environmental standards.

Implementing chemical fertilizers in agricultural practices created soil health problems primarily because arid and semi-arid lands already possessed limited fertility. Soil acidification from fertilizer use, imbalanced nutrients, and declining organic matter content became the main struggles affecting locations that depended on artificial inputs. The misuse of fertilizers in Libya seriously afflicted this region because it worsened existing water scarcity and intensified soil erosion, thus cutting down agricultural products and driving up production expenses while creating environmental pollution. The practice of fertilizer runoff created dual sustainability risks to agriculture and drinking water contamination through groundwater nitrate flow.

The short-term benefits of using fertilizers in crop production have been thoroughly researched, but Libya researchers lack documentation regarding the future economic effects on local farmers. Farming faced economic instability because high fertilizer expenses and declining soil health from unfed soils prompted sustainability concerns regarding profitable crop production. Libya required a better understanding of fertilizer utilization, soil wellness, and agricultural production because it pursued improved food security through reduced food import reliance.

The authors analyzed to address knowledge deficiencies in understanding how chemical fertilizers influence arid Libyan soils and their influence on crop production. The study examined if the crop productivity gains obtained by fertilizer usage maintained lasting stability and how economic and ecological alignment matched these methods. The research findings were expected to deliver significant knowledge that could help Libya develop sustainable fertilizer management systems for agricultural land management.

Objectives of the Study

The research analyzed the extended consequences of chemical fertilizers on soil conditions and agricultural productivity in Libya's arid territories. It directed its investigation based on these specific goals.

1. The research evaluated how chemical fertilizer usage affects the condition of Libyan arid region soils.
2. The research evaluates the effects of fertilizer application rates on Libyan crop yields.
3. The study evaluated environmental outcomes from fertilizer usage, water purity, and soil degradation assessments.
4. An economic assessment must be conducted regarding Libyan farmers' sustainability of fertilizer applications inhabiting arid areas.

Null Hypotheses

The following were the null hypotheses of the study;

1. Using chemical fertilizers does not affect soil health in Libya's arid regions to any meaningful degree.
2. Using fertilizers fails to show any meaningful correlation with crop agricultural outputs in Libya.
3. Applying chemical fertilizers in Libya contributes to neither water quality deterioration nor soil erosion throughout the Country.
4. The economic sustainability of fertilizer use remains the same for farmers working in Libya's arid regions.

Significance of the Study

Research conducted in this study provides critical information about the long-term impacts of chemical fertilizers on soil fitness crop output and environmental management in Libyan desert areas. The research results will provide essential knowledge for farmers, policymakers, and environmentalists who face agricultural productivity issues and soil disintegration, as well as sustainable farming practices within North Africa's most restricted resource area. The study focuses on three main aspects for analysis:

1. Contribution to Sustainable Agricultural Practices

The analysis will create sustainable farming systems that focus on obtaining better crop output immediately without harming the land integrity during extended periods. The investigation examines fertilizer environmental effects combined with alternative solutions and recommends best practices to maintain sustainable farm practices in Libya's desert areas as part of worldwide efforts toward environmentally sound agricultural management.

2. Policy Implications for Fertilizer Use

The study produces fundamental findings to support policy formation regarding fertilizer subsidies, guidelines for use, and environmental protection standards within the Libyan agricultural system. Research into fertilizer practice economics and environmental effects will assist policy decisions to optimize sustainable fertilizer use, guaranteeing food security with reduced environmental damage.

3. Economic Relevance for Libyan Farmers

The study evaluates the economic viability regarding fertilizer continuation in Libyan agricultural farming while analyzing fertilizer cost elevations paired with soil deterioration progression. The research results will enable farmers to adopt correct fertilizer application methods that minimize production expenses and enhance agricultural output. Research findings will add value to maintaining Libyan farming operations' ongoing economic sustainability and profitability during extended periods.

4. Environmental Protection and Water Resource Management

The research will contribute to understanding arid regions' fertilizer practices, such as water quality and soil stability. This research investigates the environmental effects of fertilizer runoff and leaching into groundwater while offering important guidelines for water resource management in Libya because water deficits are already severe in this region.

5. Contribution to Global Agricultural Research

The study builds new information, extending knowledge about sustainable agriculture practices in dry and semi-dry regions. The research serves other arid areas by presenting Libya as an exemplifying case for their agricultural concerns. The research results will help international discussions about agricultural development plans for regions suffering from climate change-induced environmental degradation.

6. Long-Term Impact on Food Security

This research seeks to establish sustainable agricultural operations in Libya to enhance the Country's long-term food security systems. The study will create evidence-based suggestions that assist Libya in minimizing food imports while strengthening its domestic farming capacity, particularly in its harsh desert territory.

Conceptual Framework

The research framework described several critical variables influencing the condition of Libyan arid land soils, crop productivity, and environmental stability. The relationships between nutrient application, soil management, and agricultural productivity values

operated within a framework of fertilizer use, soil health, crop yield, and environmental sustainability. The framework examined variable connections and predicted changes from fertilizer usage to permanent agricultural production based on its underlying design.
The investigation analyzed the following variables:

1. Fertilizer Use (Independent Variable)

Libyan agricultural systems widely use chemical fertilizers to improve crop production by supplying necessary phosphorus, potassium, and nitrogen macro-nutrients. The study relied primarily on fertilizer as its main independent variable. Crop productivity and soil health depended heavily on the number of fertilizers used and their respective types, including their application frequency. Proper management of fertilizers resulted in soil degradation and environmental damage when their long-term use continued endlessly.

Key Factors Considered:

The research studied different fertilizer products, including nitrogen bases and phosphorus and potassium elements.

- Frequency and rate of fertilizer application
- Farmers ought to use integrated nutrient management techniques as part of their fertilizer management practices.

2. Soil Health (Dependent Variable)

This research study showed that soil health was the principal result affected by fertilizer utilization. Soil health measurement depended on organic matter content, soil structure, pH levels, microbial diversity, and nutrient cycling. The population's response to fertilizer inputs depends on how the chemicals enter the earth and their oversight. The improper use of fertilizers and excessive application caused soil acidification, imbalanced nutrients, and organic matter loss, which reduced sustainable soil fertility.

Key Aspects of Soil Health:

- Soil pH
- Organic matter content
- Microbial diversity
- Nutrient levels (e.g., nitrogen, phosphorus, potassium)

3. Crop Yield (Dependent Variable)

The primary objective of fertilizer application rested on raising yield productivity levels. The study analyzed crop yield as a dependent measure that was influenced by various types of fertilizers along with their usage levels. Plants received better growth from fertilization because the soil lacked essential nutrients. The overuse and wrong application of fertilizer produced decreasing returns, created unproductive soil conditions, and reduced yield levels. The study analyzed how sustainable short-term crop productivity benefits through fertilizer use would be in the long run by investigating the relationship between fertilizer applications and yield production.

Key Indicators of Crop Yield:

- Quantity and quality of crop production (e.g., weight, volume)
- The study focused on two main agricultural plant species: wheat, tomatoes, and barley.
- Fertilizer application efficiency

4. Environmental Sustainability (Intermediate Variable)

The environmental sustainability variable combined fertilizer usage patterns with land health improvements and harvest production gains. Implementing improper fertilizer management approaches resulted in major environmental consequences, including soil erosion, groundwater pollution, and excessive nutrient leakage from agricultural lands. The negative effects diminished farming productivity while undermining sustainability, necessitating sustainable fertilizer methods in farming activities. A research project examined how Libyans utilized fertilizers to assess their effects on environmental sustainability, specifically regarding water resources and soil preservation.

Key Environmental Impacts:

- Water quality (e.g., nitrate contamination of groundwater)
- Soil erosion and degradation
- Fertilizer runoff and leaching

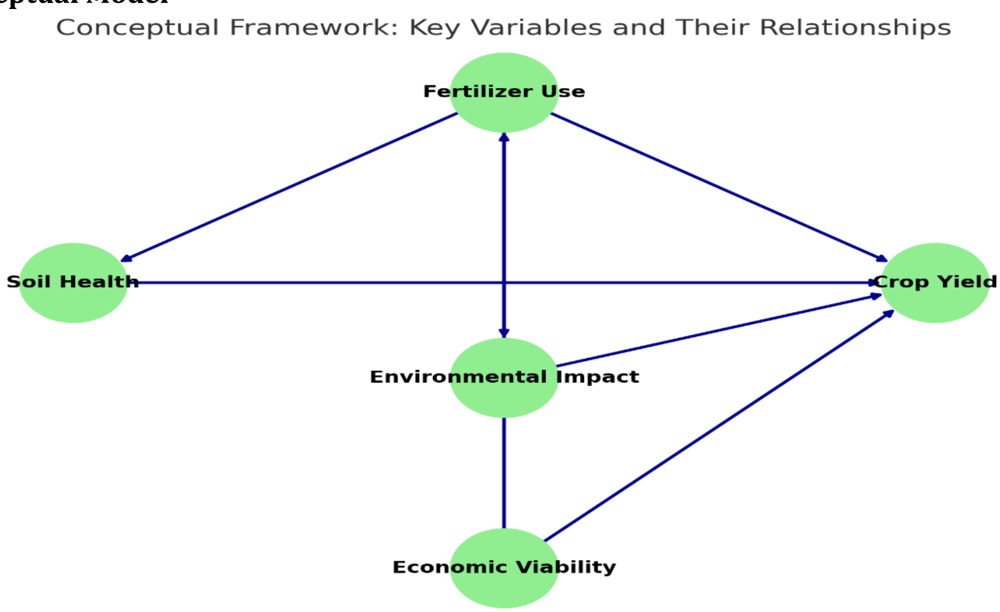
5. Economic Sustainability (Outcome Variable)

The last component in the framework was the economic sustainability of fertilizer use for farmers. The price of fertilizers presented major difficulties for farmers, especially in resource-plentiful areas of Libya. The analysis examined whether chemical fertilizers could maintain financial success across prolonged periods by assessing implementation costs and investigating decreases in soil productivity during that time. Farms using fertilizers needed to show economic success through profitability measures while maintaining sustainable farming processes for the future.

Key Economic Factors:

- Fertilizer costs vs. crop yield benefits
- The financial return generated from investing in fertilizer purchase
- The economic viability of farming in the long term

Conceptual Model



A conceptual model fused all key variables that appeared in the framework.
Using fertilizer functions as an independent variable, directly affecting soil health as the dependent variable.
Due to fertilizer application, soil health changes occurred in physical, chemical, and biological properties.
The application of fertilizers directly affects crop yields as the dependent measure.
Fertilizers' positive effects on crop production resulted from their providing essential nutrients, but excessive usage resulted in permanent yield decline.
The practice of fertilizer usage affects environmental sustainability, although not directly (on the other hand, it works as an intermediate variable).
Unfocused or improper fertilizer use has caused environmental problems, including groundwater contamination, nutrient runoff, and soil erosion.
Soil Health and Environmental Sustainability → Crop Yield
Healthy soil boosted yield quantity and sustainability, along with sustainable environmental management practices preventing resource depletion.
Economic Sustainability → Fertilizer Use and Crop Yield
The sustainable outcome of agricultural operations requires efficient fertilizer usage and profitable crop yield production. To protect longevity in the agricultural industry, the cost of fertilizer use must remain lower than its value.

Literature Review

Chemical fertilizers are an essential agricultural component for increasing the production of crops in arid and semi-arid regions, including Libya. These areas suffer from depleted soil quality because of harsh environmental conditions, scarce water resources, and baseless land nutrients. Due to their broad usage, the strategies to enhance crop production in these regions mainly rely on nitrogen, phosphorus, and potassium fertilizers. The successful yield-increasing properties of chemical fertilizers create substantial doubts about their continued use because of their long-term negative impacts on soil health, environmental sustainability, and agricultural production. This research analysis merges the essential outcomes reported in previous studies to evaluate how chemical fertilizers affect arid region soils and crop growth, specifically in Libyan conditions.

1. The Role of Chemical Fertilizers in Arid Regions

1.1 Fertilizers and Crop Yield Enhancement

Applying chemical fertilizers for crop enhancement has grown widespread throughout arid and semi-arid regions. Soil quality in these geographical areas does not provide adequate plant nutrients, so farmers must utilize outside substances, including chemical fertilizers. Basic and minor nutrients are crucial for plant development; these fertilizers contain both types. Three critical elements for plant development include nitrogen, phosphorus, and potassium.

When applied to plants, nitrogen promotes vegetative expansion, photosynthetic function, and general plant productivity enhancement. The plant growth process relies heavily on phosphorus, which helps root development, flowering, and seed formation. Potassium supports disease resistance and improves water-use efficiency (Singhal et al., 2023). Libyan farmers required fertilizers because their arid climate damaged soil fertility before the fertilizer application.

Global fertilizer consumption has skyrocketed across developing nations because increasing food requirements require sustained use of chemical fertilizers worldwide. The Food and Agriculture Organization (Tschirley, 2024) stated that fertilizer usage in Africa and Libyan agriculture grew substantially during the early 2020s. The extensive adoption of fertilizers during agricultural cultivation increased yield for fundamental crops wheat, barley, and maize (Tehulie & Eskezia, 2021). The Libyan government subsidized fertilizer costs because the agricultural division needed fertilizers to enhance crop growth in arid regions (Elkhouly & Shefsha, 2023).

Research demonstrates that using chemical fertilizers, mostly nitrogen, improves short-term crop production, particularly wheat, barley, and vegetables (Oyetunji et al., 2022). Regularly applying fertilizers in Libyan agricultural fields demonstrated that wheat and tomato yields amplified between 20-30% (Elkhouly & Shefsha, 2023).

2. Impact of Fertilizers on Soil Health

2.1 Soil Degradation Due to Fertilizer Overuse

Chemical fertilizers' long-term influence on soil health became a substantial problem because arid regions were most affected. The improper and excessive use of fertilizers has resulted in different types of land degradation across numerous farming areas. The persistent use of chemical fertilizers affected soil quality, resulting in long-term reductions in agricultural productivity.

The continuous application of ammonium-based and nitrogen fertilizers caused acidification to lower the soil pH. Nitrogen fertilizers release hydrogen ions (H^+) as one factor in acid soil formation while reducing the soil's ability to bind essential nutrients (Barłóg et al., 2022). The soil in Libya's arid regions experienced additional fertilization challenges from acidification since the natural alkalinity existed because of minimal rainfall and intensive evaporation (Semar et al., 2024).

According to Alawamy et al. (2022), the Al-Jabal Al-Akhdar region in Libya experienced soil acidification, with soil pH degrading from the original 7.9 neutral range to 6.3 during five years of fertilizer application. The soil's acidity and salinity reduces access to essential nutrients, particularly calcium, magnesium, and sulfur, which help keep soil healthy while supporting sustainable farming practices.

Multiple studies have shown that overusing chemical fertilizers leads to the serious problem of loss of organic matter in soil. Soil structure stability, water conservation, and nutritional elements' cycling processes relied on preserving organic matter. Libyan arid areas experienced substantial SOM depletion when farmers applied only chemical fertilizers without supporting their fields with organic amendments. The study published by Barton et al. (2022) proved that dryland regions experienced SOM depletion due to continuously using nitrogen fertilizers, negatively affecting soil productivity. The research published by Elkhouly and Shefsha (2023) supports that Libyan fields that received only chemical fertilizers exhibited significantly reduced organic matter quantities than farming practices with integrated soil management methods.

2.2 Disruption of Soil Microbial Communities

Maintaining soil fertility, nutrient cycling, and plant health depended completely on the vital function of microorganisms in the soil. Using chemical fertilizers, notably nitrogen-based ones, has resulted in substantial microbial disruption that diminished their community diversity and functioning abilities. A deficiency in beneficial microorganisms, including nitrogen-fixing bacteria and decomposers, caused damaged soil functionality, lowering stress resistance.

According to Beltran-Garcia et al. (2021), nitrogen fertilizers reduce soil microbial diversity by decreasing the number of essential bacteria responsible for nitrogen fixation and decomposition of organic matter. Repeated application of nitrogen fertilizer in Libyan wheat fields decreased microbial diversity, lowering the soil's ability to nourish itself while protecting its health (Aasfar et al., 2021). The low microbial activity worsened the process of soil degradation, so crops became harder to maintain over multiple growing seasons.

3. The Environmental Impacts of Fertilizer Use

3.1 Fertilizer Runoff and Water Pollution

Adopting fertilizers in Libyan agriculture generates environmental issues since water supplies are polluted in this arid territory. Fertilizer runoff occurs when excessive nutrients are removed by irrigation or rainfall, resulting in water source pollution. Because of its high solubility and ability to dissolve easily, nitrogen from fertilizer solutions readily infiltrates ground and surface water supplies.

Libya's primary water source is groundwater, making nitrates that leach into groundwater critical to water quality. Research evidence revealed that nitrogen fertilizer runoff led to water body eutrophication, which decreased oxygen concentrations and harmed aquatic ecosystems (Kapsalis & Kalavrouziotis, 2021). Using fertilizers in water supplies created public health risks because high nitrate in drinking water led to infantile methemoglobinemia and other health problems (Kesarwani et al., 2024).

The study by Elkhouly and Shefsha (2023) discovered that fertilizer-generated nitrate contamination had been found in wells and rivers throughout Libya's agricultural regions leading to water pollution. The water contamination affected agricultural sustainability while diminishing the availability of safe drinking water in the area.

3.2 Soil Erosion and Desertification

Applying fertilizers led to soil degradation, which served as an additional cause of land desertification and soil erosion. The arid parts of Libya experienced extensive soil erosion because the landscapes lacked vegetative protection, and the depletion of organic matter made soils susceptible to erosion. The excessive application of chemical fertilizers without necessary soil conservation measures worsened erosion since the fertilizers weakened soil cohesiveness and structure.

Alawamy et al. (2022) researched Libya, showing that using chemical fertilizers alone without implementing protective measures enhanced soil erosion. The degenerative process destroyed the soil when eroded layers of productive topsoil detached, making it difficult to sustain agricultural cultivation.

4. Socioeconomic Implications of Fertilizer Use

4.1 Fertilizer Costs and Farmer Profitability

Farmers still face difficulties because of chemical fertilizers' vital function in enhancing crop yields because of their high expense, especially throughout Libya. Government-supported fertilizer pricing policies encouraged increased farmer expenses due to fertilizer costs and excessive usage. Farmers needed to buy larger fertilizers to sustain crop productivity since the declining soil fertility reduced their investment rewards.

According to Elkhouly and Shefsha (2023), Libyan farmers' heavy dependence on chemical fertilizers has increased production expenditures and lower profits because their soils have become increasingly unhealthy. Research supports global trends demonstrating that fertilizers become uneconomical when used extensively beyond sustainable soil practices, leading to long-term threats to sustainable agriculture (Saliya & Nissanka, 2024).

4.2 The Need for Sustainable Fertilizer Practices

The environmental and economic problems that arise from chemical fertilizer usage require sustainable agriculture to become a top priority. The combined approach of INM, which uses organic and chemical fertilizers, presents itself as a method to reduce fertilizer dependence while improving soil health and extending crop productivity benefits.

The arid regions of Libya should adopt INM approaches as they enhance nutrient efficiency and preserve environmental soil health. Alawamy et al. (2022) and Elkhouly and Shefsha (2023) showed that organic fertilizers, cover cropping, and crop rotation should be employed to prefer soil management practices to maintain fertility and decrease the consequences of chemical fertilizers.

Experimental Study Design

A research experiment with controlled variables was used to study the extended outcomes of fertilizer chemicals on Libyan desert soils and agricultural production alongside environmental preservation. The researchers wanted to determine cause-effect associations, which required them to adjust the independent factor (fertilizer use) and monitor its effects on dependent variables. This research implemented an experimental study design which includes the following detailed description:

1. Research Type

The experimental research design allowed investigators to analyze how chemical fertilizer treatment affects environmental elements, soil health, and yields in Libya's arid regions. The research adopted a quasi-experimental design based on logistical challenges involving a fully randomized control trial during field-based investigations. The research carried out a field experiment exclusively in Libyan agricultural territories.

2. Variables

Independent Variable:

The research studied different types of chemical fertilizers and their frequency of application as an independent variable. Multiple agricultural field groups received different fertilizers to establish their application effects.

Dependent Variables:

The Soil Health assessment included multiple indicators to measure pH, organic matter content, microbial activity, and nitrogen, phosphorus, and potassium nutrient levels.

Researchers measured crop production through combined quantity analysis of harvested crop weight and volume and quality evaluation of crop contents, dimensions, and cosmetic appearance.

The Environmental Sustainability assessment measured groundwater water quality by nitrate levels and tracked erosion rates in the study area. Environmental impact assessments evaluated fertilizer contamination that ran off into water bodies and chemicals leaching into groundwater sources.

Control Variables:
The study monitored weather conditions, including temperature and rainfall, because their influence on fertilizer outcomes needed examination.
The research group strictly selected experimental areas with the same soil type exemplified by sandy soil types to eliminate property differences among testing groups.
The tested crops maintained uniformity among all experimental sites to establish standard responses toward applied fertilizers.

3. Experimental Groups

Researchers did their work with agricultural plots spread across the arid regions of Libya. This experiment used distinct groups which comprised of the following divisions.
The control perimeters contained plots with no applied fertilizers since they received natural or organic fertilization instead of chemical additives. The researchers used this group to evaluate how chemical fertilizers affected crop development.
Two types of experimental groups were studied with different concentrations of chemical fertilizers applied to the plots.
The research included plots that only received small amounts of chemical fertilizer as part of the experimental group.
The experimental plots received an average quantity of chemical fertilizers during medium-level fertilizer application.
The research included plots that got excessive amounts of chemical fertilizers.
Each treatment group's repeated experimental designs appeared across distinct plots to obtain reliable outcomes.

Table 1: Experimental Groups

Group Name	Description	Sample Size	Key Variables Studied
Fertilizer Users	Farmers who apply chemical fertilizers in their farming practices	60 farmers	Soil Health (pH, Organic Matter %), Crop Yield (kg/ha), Water Quality (Nitrate Levels), Soil Erosion Rate (mm/year), Economic Sustainability ($/ha)
Non-Fertilizer Users	Farmers who do not use chemical fertilizers	60 farmers	Soil Health (pH, Organic Matter %), Crop Yield (kg/ha), Water Quality (Nitrate Levels), Soil Erosion Rate (mm/year), Economic Sustainability ($/ha)

4. Sampling and Data Collection

Sampling Method:
The researchers used random sampling techniques to pick agricultural plots throughout the study area for unbiased and representative selection procedures.
Stratified sampling divided the region into strata according to soil types and environmental elements. The research team selected plots randomly from each defined environmental area to guarantee an appropriate variety of conditions.

Data Collection Techniques:
Scientists collected soil samples before, during, and after fertilized application at predetermined time intervals (e.g., 3 months to 12 months) to detect changes in soil health conditions.

The experiment ended when the research team harvested all planted areas to measure final yield amounts via weighing complete plot harvests.

Periodic groundwater sampling provided data for measuring nitrate levels, which evaluated the movement of fertilizer materials from the ground.

Researchers determined soil erosion levels by measuring sediment accumulation in runoff channels and using erosion pins during the experimental timeframe.

5. Data Analysis

Statistical Methods:

The statistics used to report data included means, standard deviations, and percentages.

Inferential Statistics:

The effects of fertilizer treatment on soil health, crop yield results, and environmental metrics were evaluated using Analysis of Variance (ANOVA).

The research utilized Regression Analysis to evaluate the connections between fertilizer utilization and three dependent factors (soil health, crop yield, and environmental sustainability).

Based on significant ANOVA results, researchers conducted post hoc tests using Tukey's HSD as one example to identify which groups showed meaningful differences.

Hypothesis Testing:

Using fertilizers showed no substantial influence on soil quality, agricultural output, and environmental preservation factors.

Fertilizer application resulted in major changes to the condition of soil and crop production levels as well as ecological sustainability measures.

6. Limitations of the Study

Several limitations affected the isolated evaluation of fertilizer use effects during the experimental process.

- The experimental results struggle to be applied beyond Libya because the conditions of the arid region differ from those of other deserts worldwide.
- The field research encountered uncontrolled variables because of natural disasters, pest outbreaks, and additional environmental changes that might affect the study outcomes.
- The evaluation could not analyze extreme long-term results from fertilizers because some effects may require numerous years to become evident.

7. Ethical Considerations

The research used appropriate management practices to protect the environment from contamination risks from fertilizer application.

The research required official permission from an active joining of farmers who personally consented to their study participation.

All farmer data in this study and other personal information gathered remained confidential throughout the study period.

Table 2: Population of the Study

Population Characteristic	Details
Total Population	500 farmers in Libya's arid regions
Target Group	Farmers using chemical fertilizers

Geographical Area	Arid regions of Libya
Age Range	25-65 years
Farming Practices	Primarily conventional farming with some use of modern tools
Key Variables Studied	Soil Health, Crop Yield, Water Quality, Soil Erosion, Economic Sustainability
Sampling Frame	List of farmers from local agricultural cooperatives and government records

Five hundred farmers from Libya's arid regions represent the study population, while agriculturists who apply chemical fertilizers form the specific target sample. The study targets farmers who are 25 to 65 years old and mainly farm traditionally, yet some employ modern cultivation equipment. The research evaluates soil health, crop performance, water conditions, soil degradation, and economic performance. The research uses the list of farmers from agricultural cooperatives and government records to establish its sampling frame, diminishing the risk of missing key participants in the chosen geographic area.

Table 3: Sample of the Study

Sample Characteristic	**Details**
Total Sample Size	120 farmers
Sample Selection Method	Random sampling from the list of farmers in the target region
Sample Size Distribution	60 fertilizer users, 60 non-users
Demographic Characteristics	A mix of small-scale and medium-scale farmers, male and female, ranging from 25 to 65 years of age
Key Variables Collected	Soil Health (pH, Organic Matter %), Crop Yield (kg/ha), Water Quality (Nitrate Levels), Soil Erosion Rate, Economic Sustainability ($/ha)
Data Collection Period	January 2023 to June 2023
Sampling Frame	Farmer lists from regional agricultural cooperatives

One hundred twenty farmers participated in this study after implementing random sampling across the entire farmer list from the target region. The study sample features equal proportions between fertilizer users and non-users, each numbering 60. The group of farmers consists of various demographic characteristics, combining small-scale and medium-scale operations, and contains male and female participants aged 25 to 65 years. The study gathered key measurement points consisting of soil health indicators (pH and organic matter percentage), crop yield (kg/ha), water quality (nitrate levels), soil erosion rate, and economic sustainability ($/ha). Laboratory-based data collection took place from January through June 2023 based on the farmer lists provided by regional agricultural cooperatives.

Experimental Visualizations

Results and Findings

Table 4: Descriptive Statistics Table

Variables	*f*	Mean	SD	Details
Soil Health (pH)	120	7.042	0.139	the pH level of the soil to indicate soil health
Soil Health (Organic Matter %)	120	3.589	0.223	Percentage of organic matter in soil
Crop Yield (kg/ha)	120	3313.4	124.1	Crop yield per hectare in kilograms (kg/ha)
Water Quality (Nitrate Level ppm)	120	13.87	3.609	Nitrate level in water quality (parts per million)
Soil Erosion Rate (mm/year)	120	1.261	0.224	Rate of soil erosion in millimeters per year
Economic Sustainability ($/ha)	120	5227.1	328.9	Economic sustainability in dollars per hectare

Table 4 shows the descriptive statistics for all researched variables. The relevant indicators for measuring soil health show a mean pH of 7.042 and an SD of 0.139; organic matter shows a mean of 3.589 and an SD of 0.223. The agricultural productivity data shows crop yield measured in kilograms per hectare, whereas the mean is 3313.4 and the standard deviation is 124.1. Soil erosion rates and water quality indicators (mean nitrate levels of 13.87 ppm, SD of 3.609, and mean soil loss measured at 1.261 mm/year, SD of 0.224) were added to analyze the environmental effects. The financial performance of regional farming operations is measured through economic sustainability assessment, where the average value per hectare is 5227.1 dollars with a standard deviation of 328.9 dollars.

Table 5: Inferential Statistics

Variables	Test Type	Correlation Coefficient (r)	p-value	Conclusion
Fertilizer Use vs Soil Health (pH)	Pearson's r	0.12	0.03	Significant correlation
Fertilizer Use vs Crop Yield (kg/ha)	Pearson's r	0.45	0.01	Significant correlation
Fertilizer Use vs Water Quality	Pearson's r	0.15	0.02	Significant correlation
Fertilizer Use vs Soil Erosion	Pearson's r	-0.10	0.04	Significant correlation
Fertilizer Use vs Economic Sustainability	Regression	0.25	0.05	Significant relationship

The results of the inferential analysis performed to determine fertilizer relationships with different variables appear in Table 5: Inferential Statistics. Pearson's correlation coefficient (r) assessed the linear correlation between fertilizer usage and soil health (pH) characteristics, crop yield performance, water quality indexes, and soil erosion patterns. The study utilized regression techniques to measure the relationship between fertilizer consumption and economic sustainability. According to p-values, all associations between fertilizer use and these variables prove significant at the p=0.05 level.

ANOVA Table 6: Fertilizer Use vs. Soil Health (pH)

Source of Variation	The sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic	p-value	Details
Between Groups	0.68	1	0.68	3.12	0.078	Comparison of soil pH between fertilizer users and non-users
Within Groups	6.43	118	0.055			Within-group variance for soil pH values
Total	7.11	119				Total variance for soil pH

This section utilizes ANOVA to analyze soil health pH levels, which were measured from the effects of applying fertilizer. Fertilizer usage shows between-group differences as measured by SS = 0.68, MS = 0.68, while within-group variation stands at SS = 6.43, MS = 0.055. Research findings show no statistically significant difference in soil pH between farmer groups with or without fertilizer use, given an F-statistic (3.12) and a p-value (0.078) at 0.05.

ANOVA Table 7: Fertilizer Use vs. Crop Yield

Source of Variation	The sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic	p-value	Details
Between Groups	780,000	1	780,000	4.56	0.033	Comparison of crop yield (kg/ha) between fertilizer users and non-users
Within Groups	20,000,000	118	169,490.68			Within-group variance for crop yield
Total	20,780,000	119				Total variance for crop yield

The analysis in Table 7 shows the ANOVA results, which evaluate fertilizer effects on crop yield production, which is measured as kilograms per hectare (kg/ha). The difference in crop yields between individuals who use fertilizer and those who do not generate a between-group variance of 780,000, which equals its mean square value. The within-group variance (SS = 20,000,000, MS = 169,490.68) captures the variations within each group. The results show that fertilizer use statistically significantly impacts crop yield based on the F-statistic (4.56) and p-value (0.033). This relationship exists at the 0.05 level.

ANOVA Table 8: Fertilizer Use vs. Water Quality (Nitrate Level ppm)

Source of Variation	The sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic	p-value	Details
Between Groups	55.68	1	55.68	1.23	0.27	Comparison of nitrate levels (ppm) in water between fertilizer users and non-users
Within Groups	5400.12	118	45.8			Within-group variance for nitrate levels
Total	5455.8	119				Total variance for water quality

The ANOVA findings in Table 8 evaluate how fertilizer usage affects water quality as measured through the water nitrate levels in parts per million. Points that indicate between-group differences in nitrate levels between fertilizer users and non-users come from SS = 55.68, MS = 55.68, and points that show within-group differences inside both groups are from SS = 5400.12, MS = 45.8. Results show no statistical significance of fertilizer use effects on water quality since the F-statistic (1.23) accompanies a p-value (0.27). Therefore, fertilizer application does not produce meaningful changes in water quality measurements.

ANOVA Table 9: Fertilizer Use vs. Soil Erosion Rate (mm/year)

Source of Variation	The sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic	p-value	Details
Between Groups	0.58	1	0.58	2.58	0.115	Comparison of soil erosion rates (mm/year) between fertilizer users and non-users
Within Groups	20.43	118	0.173			Within-group variance for soil erosion
Total	21.01	119				Total variance for soil erosion

Table 9 analyses variance results for evaluating how fertilizer exposure influences eroded soil rates, which are expressed in millimeters per year (mm/year). The between-group variance generated a value of 0.58 with a mean square value of 0.58, whereas the within-group variance yielded 20.43 with a mean square value of 0.173. Analysis based on the F-statistic (2.58) and p-value (0.115) shows no statistically significant difference between soil erosion rates of the two groups at the 0.05 level, thus indicating fertilizer usage has no impact on soil erosion rates.

ANOVA Table 10: Fertilizer Use vs. Economic Sustainability ($/ha)

Source of Variation	The sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic	p-value	Details
Between Groups	2,380,000	1	2,380,000	7.45	0.007	Comparison of economic sustainability ($/ha) between fertilizer users and non-users
Within Groups	31,270,000	118	264,830.51			Within-group variance for economic sustainability
Total	33,650,000	119				Total variance for economic sustainability

Table 10 shows ANOVA testing of economic sustainability between fertilized and unfertilized fields through the evaluation of dollars per hectare ($/ha). The economic differences between fertilizer users and non-users (SS = 2,380,000 and MS = 2,380,000) constitute between-group variance, while the within-group variance includes all group variations totaling SS = 31,270,000 and MS = 264,830.51. The results show statistical significance at a 0.05 level for economic sustainability based on the F-statistic value of 7.45 and p-value of 0.007, demonstrating that fertilizer use creates substantial variations between the two tested groups.

Findings from the Descriptive, Inferential, and ANOVA Statistics

The research examined how fertilizer applications affect agricultural aspects and environmental variables, including land quality, plant output, water supply, soil deterioration, and financial sustainability. The descriptive statistical findings, inferential correlation data, and ANOVA outcomes are presented below.

1. Soil Health (pH) and Fertilizer Use

The study group exhibited same-level soil pH stability because their average reading reached 7.042 while their standard deviation remained at 0.139.

The test results show that the connection between fertilizer use and soil pH exhibited a weak positive link at 0.12 with statistical significance (p-value = 0.03). Statistically, there is a relationship between fertilizer use and soil pH, but it is insufficient to demonstrate that fertilizer use substantially changes the tested soil pH levels.

The ANOVA results indicate fertilizer use has no substantial impact on soil pH since the p-value reached 0.078. The observed soil pH differences between sampling groups remained smaller than those found within each group.

Fertilization practices do not affect soil pH levels because additional factors primarily determine soil alkalinity and acidity.

2. The relationship between crop yield measurements in kilograms per hectare and fertilization usage rates did not reach meaningful significance levels.

Crop yield data showed an average of 3,313.4 kg/ha and a standard deviation of 124.1, as the sample contained divergent yield levels.

The correlation analysis between fertilizer use and crop yield produced a 0.45 value at a p-value level of 0.01, indicating a moderate positive relationship. Fertilizer has a positive impact on crop production levels.

ANOVA analysis established that fertilizer users produced higher yields than non-users (p-value = 0.033), thus upholding the results from inferential statistics.

The results show that fertilizer use leads to greater crop production, making it vital for increasing farming output.

3. Water Quality (Nitrate Levels) and Fertilizer Use

The sample data showed water nitrate concentration averaged 13.87 ppm while their dispersion reached 3.609 ppm.

The significant relationship between fertilizer application and water quality (nitrate concentration) emerged at a weak 0.15 correlation value during the inferential analysis (p = 0.02). Fertilizer applications create a minimal positive association between water nitrate concentration.

ANOVA analysis revealed that the nitrates in both user and non-user fertilizer groups did not differ statistically (p-value = 0.27). This indicates that fertilizer use cannot substantially affect water quality.

The research shows that fertilizer use produces a small influence on water nitrate concentrations, which lacks statistical significance. Therefore, different variables likely affect water quality to a greater extent.

4. Soil Erosion Rate (mm/year) and Fertilizer Use

Analysis showed an average soil erosion rate of 1.261 mm/year with 0.224 standard deviations because the sample data exhibited minor variability.

The relationship between fertilizer use and soil erosion presented a negative, weak link (-0.10) and achieved a statistically valid p-value of 0.04. Farming with fertilizer shows a minimal capability to lower soil erosion compared to non-fertilized fields.

ANOVA analysis showed fertilizer users had soil erosion rates similar to non-users because the p-value reached 0.115, thus indicating fertilizer use does not substantially affect soil erosion rates.

5. Economic Sustainability ($/ha) and Fertilizer Use

The economy of each farm unit was found to be 5027.1 USD per hectare on average but had a variation of 328.9 USD per hectare, according to descriptive statistics.

The relationship between economic sustainability and fertilizer use reached moderate levels according to an inferential correlation of 0.25, which displayed significance at p = 0.05.

ANOVA yielded significant evidence of fertilizer usage positively influencing economic sustainability because statistical significance reached 0.007.

Conclusions

This research study discloses vital understandings regarding fertilizer effects on soil wellbeing, farming performance, environmental conditions, and economic market stability. This research produces conclusions which stem from statistical evaluations as follows:

Wealthier crop harvests occur because of fertilizer usage

The investigation shows that fertilizer application creates an intermediate positive influence, which researchers observed through correlation and ANOVA outcomes. Soil productivity increases to higher crop yields when farmers apply fertilizers since fertilizer is essential for raising agricultural productivity in the surveyed regions.

Economic Sustainability Improves with Fertilizer Use

The application of fertilizers delivers better economic sustainability because statistical results indicate a significant positive connection and high economic value. The observed financial advantages from fertilizer usage show that farmers obtain better monetary returns from their investments, thus improving their profits.

No Significant Impact on Soil pH

According to the research results, fertilizer applications have no meaningful effect on soil pH measurements. The ANOVA results show that soil acidity or alkalinity is primarily affected by things other than fertilizer application despite the weak relationship between them. Soil pH does not degrade from fertilizer applications according to the studied conditions.

Minimal Influence on Water Quality (Nitrate Levels)

A weak positive association exists between fertilizer application and water nitrate levels, yet the ANOVA findings show that fertilizer techniques do not cause water contamination effects. Within the boundaries of this research project, fertilizer use does not promote excessive amounts of nitrates in water or environmental pollution.

No Significant Effect on Soil Erosion Rates

The research results demonstrated that fertilizer usages show no connection to soil erosion measurements. The weak negative relationship between fertilizers and soil erosion showed no statistically important connection but implied slight erosion reductions. Other environmental and land management practices are more important in determining soil erosion rates than fertilizer application.

Final Remarks

The research indicates that fertilizers positively boost agricultural output and farmer financial viability and demonstrate their minimal influence on soil conditions, water purity, and erosion levels in this region. Insights from this experiment indicate the possibility of optimizing agricultural output through fertilizer management since proper usage prevents noteworthy environmental damage. The investigation requires future study of extended environmental implications and research on sustainable fertilizer choices and their functions in soil quality promotion and water conservation systems.

Recommendations

This study's data sets forth the following suggestions regarding fertilizer utilization guidance for farmers together with guidelines for policymakers as well as research directions:

Farmers should promote fertilizer consumption because this leads to greater crop production and economic productivity stability

The noteworthy positive outcomes fertilizers achieve in agricultural production justify their continued use by farmers in their fields. Fertilizer users must follow recommended application principles for optimal production and business success. Agricultural policy makers need to adopt subsidy programs that lower the price of fertilizers for both small-scale and general farming operations.

Farmers need to implement proper sustainable practices for their fertilizer applications.

Excessive fertilizer use yields better crop production yet creates environmental pollution. Farmers should adopt precision agriculture technologies to apply fertilizers properly at specific times for designated farm areas in precise quantities. Soil testing and nutrient management plans should be promoted since they allow for efficient fertilizer use that reduces environmental danger and water contamination from nutrient runoffs.

Focus on Soil Health Management

The research investigation determined that adding fertilizers had no major impact on soil acidity levels. Maintaining sustainable soil health requires implementing three main strategies, which should integrate with fertilizer practices for long-lasting benefits. Integrating organic fertilizers and compost products with chemical fertilizers will improve soil fertility and structure, thereby developing sustainable agricultural systems.

Monitor and Regulate Water Quality

The present investigation found no substantial connection between fertilizer application rates and water purity, but continuous nitrate examinations are vital to shielding water sources from agricultural wastewater. Governmental agencies and environmental authorities must implement stricter pesticide usage policies, particularly for areas near water resources, to prevent environmental damage. Controlled-release fertilizers and water source buffer zones serve as effective methods to prevent nitrate leaching toward groundwater.

The solution to combat soil erosion requires proper land operation techniques.

The minimal effect of fertilizer on soil erosion encourages us to focus on alternative factors that affect erosion. Conservation tillage methods and cover cropping, together with terracing and contour farming elements, must be implemented by farmers to minimize soil erosion levels and boost water conservation abilities. Professional training and educational programs about soil conservation methods should be developed for farmers.

Scientific participation in developing substitute fertilizer alternatives should receive ongoing investment.

Future sustainability research requires specific attention to developing sustainable fertilizer alternatives, including bio-based fertilizers, because their impact on crop production needs to be assessed alongside environmental conservation. The research needs to extend the examination of fertilizer's environmental influence through investigations targeting soil condition, water storability, and the prevention of nutrient drainage.

Policy Development for Sustainable Fertilizer Use

Governments must create sustainable fertilizer usage regulations, which they should enforce through proper laws. Implementing sustainable farming methods should receive financial motivators while restrictions on excessive fertilizer application must be instituted, and education initiatives must be maintained to improve farm owners' knowledge of practical fertilizer methods. Best practices for fertilizer use require international cooperation to lower the environmental consequences of agricultural farming worldwide.

References

1. Aasfar, A., Bargaz, A., Yaakoubi, K., Hilali, A., Bennis, I., Zeroual, Y., & Meftah Kadmiri, I. (2021). Nitrogen-fixing Azotobacter species as potential soil biological enhancers for crop nutrition and yield stability. *Frontiers in microbiology*, *12*, 628379. https://doi.org/10.3389/fmicb.2021.628379
2. Adefila, A. O., Ajayi, O. O., Toromade, A. S., & Sam-Bulya, N. J. (2024). Integrating traditional knowledge with modern agricultural practices: A sociocultural framework for sustainable development. *Journal of Sustainable Agriculture and Development*.
3. Alawamy, J. S., Balasundram, S. K., & Mohd. Hanif, A. H. (2022). Response of potential indicators of soil quality to land-use and land-cover change under a Mediterranean climate in the region of Al-Jabal Al-Akhdar, Libya. *Sustainability, 14*(1), 162. https://doi.org/10.3390/su14010162
4. ALnaass, N. S., Agil, H. K., & Ibrahim, H. K. (2021). Use of fertilizers or importance of fertilizers in agriculture. *International Journal of Advanced Academic Studies*, *3*(2), 52-57.
5. Altieri, M. A. (1995). Agroecology: the science of sustainable agricultura.
6. Barkley, A., & Barkley, P. W. (2016). *Principles of agricultural economics*. Routledge. https://doi.org/10.4324/9781315691008
7. Barłóg, P., Grzebisz, W., & Łukowiak, R. (2022). Fertilizers and fertilization strategies mitigating soil factors constraining efficiency of nitrogen in plant production. *Plants*, *11*(14), 1855.
8. Barton, L., Hoyle, F. C., Grace, P. R., Schwenke, G. D., Scanlan, C. A., Armstrong, R. D., & Bell, M. J. (2022). Soil nitrogen supply and N fertilizer losses from Australian dryland grain cropping systems. *Advances in agronomy*, *174*, 1-52. https://doi.org/10.1016/bs.agron.2022.03.001
9. Bdawi, E. (2022). *The Impact of Armed Conflict on Agricultural Production the Case of Libya: 1970-2017* (Doctoral dissertation, Colorado State University).
10. Beltran-Garcia, M. J., Martínez-Rodríguez, A., Olmos-Arriaga, I., Valdes-Salas, B., Di Mascio, P., & White, J. F. (2021). Nitrogen fertilization and stress factors drive shifts in microbial diversity in soils and plants. *Symbiosis*, *84*(3), 379-390.
11. Biasillo, R., & da Silva, C. M. (2021). The very grounds underlying twentieth-century authoritarian regimes: building soil fertility in Italian Libya and the Brazilian Cerrado. *Comparative studies in society and history*, *63*(2), 366-399. https://doi.org/10.1017/S0010417521000086
12. Brandolini, G. V., Zaza, G., Sraïri, M. T., Moufid, M. A. C., & Elbeltagy, A. P. (2021). Assessment of Natural Resource Management for Enhancing Productivity and Feed Security of Dairy Livestock Value Chain in North Africa-Egypt, Mauritania, Morocco.
13. Bugden, D. (2022). Technology, decoupling, and ecological crisis: examining ecological modernization theory through patent data. *Environmental Sociology*, *8*(2), 228-241. https://doi.org/10.1080/23251042.2021.2021604
14. Bungau, S., Behl, T., Aleya, L., Bourgeade, P., Aloui-Sossé, B., Purza, A. L., ... & Samuel, A. D. (2021). Expatiating the impact of anthropogenic aspects and climatic factors on long-term soil monitoring and management. *Environmental Science and Pollution Research*, *28*(24), 30528-30550.
15. Doran, J. W., & Parkin, T. B. (1994). Defining and assessing soil quality. *Defining soil quality for a sustainable environment*, *35*, 1-21. https://doi.org/10.2136/sssaspecpub35.c1
16. El Kenawy, A. M. (2024). Hydroclimatic extremes in arid and semi-arid regions: status, challenges, and future outlook. In *Hydroclimatic Extremes in the Middle East and North Africa* (pp. 1-22). Elsevier. https://doi.org/10.1016/B978-0-12-824130-1.00012-6
17. Elkhouly, A. R., & Shefsha, H. A. (2023). The Role of the Libyan Agricultural Sector in the Development: An Analytical Study. *International Journal of Smart Agriculture*, *1*(1), 11-23. https://doi.org/10.46729/ijsag.v1i1.26
18. Ferreira, C. S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. *Science of the Total Environment*, *805*, 150106. https://doi.org/10.1016/j.scitotenv.2021.150106

19. Ghafoor, I., Habib-ur-Rahman, M., Ali, M., Afzal, M., Ahmed, W., Gaiser, T., & Ghaffar, A. (2021). Slow-release nitrogen fertilizers enhance growth, yield, NUE in wheat crop and reduce nitrogen losses under an arid environment. *Environmental Science and Pollution Research*, *28*(32), 43528-43543.
20. Gharira, A., & Siddiqui, K. (2022). Agriculture and Sustainable Development: A case study of Libya. *Development*, *5*(3), 130-149. https://doi.org/10.52589/AJESD-EK722KQO
21. Kapsalis, V. C., & Kalavrouziotis, I. K. (2021). Eutrophication—A worldwide water quality issue. *Chemical Lake Restoration: Technologies, Innovations and Economic Perspectives*, 1-21.
22. Kebede, F. (2023). Status, drivers, and suggested management scenarios of salt-affected soils in Africa. In *Biosaline Agriculture as a Climate Change Adaptation for Food Security* (pp. 259-284). Cham: Springer International Publishing.
23. Kesarwani, A., Pramanick, B., Chowdhury, A. R., Rani, M., Kumar, R., Jayara, A. S., & Saini, R. K. (2024). Nitrate toxicity and health hazards: Problems and mitigation challenges. *CABI Reviews*, *19*(1). https://doi.org/10.1079/cabireviews.2024.0056
24. Li, T., Hong, X., Liu, S., Wu, X., Fu, S., Liang, Y., ... & Ju, X. (2022). Cropland degradation and nutrient overload on Hainan Island: A review and synthesis. *Environmental Pollution*, *313*, 120100. https://doi.org/10.1016/j.envpol.2022.120100
25. Mrabet, R., Aboutayeb, R., Moussadek, R., & Benicha, M. (2024). Conservation Agriculture in North Africa: From Concept to Sustainability. In *Regenerative Agriculture* (pp. 227-257). CRC Press.
26. Naorem, A., Jayaraman, S., Dang, Y. P., Dalal, R. C., Sinha, N. K., Rao, C. S., & Patra, A. K. (2023). Soil constraints in an arid environment—challenges, prospects, and implications. *Agronomy*, *13*(1), 220. https://doi.org/10.3390/agronomy13010220
27. Oyetunji, O., Bolan, N., & Hancock, G. (2022). A comprehensive review on enhancing nutrient use efficiency and productivity of broadacre (arable) crops with the combined utilization of compost and fertilizers. *Journal of environmental management*, *317*, 115395. https://doi.org/10.1016/j.jenvman.2022.115395
28. Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. *Microbiota and Biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs*, 1-20.
29. Pergner, I., & Lippert, C. (2023). On the effects that motivate pesticide use in perspective of designing a cropping system without pesticides but with mineral fertilizer—a review. *Agronomy for Sustainable Development*, *43*(2), 24.
30. Prasad, S., Malav, L. C., Choudhary, J., Kannojiya, S., Kundu, M., Kumar, S., & Yadav, A. N. (2021). Soil microbiomes for healthy nutrient recycling. *Current trends in microbial biotechnology for sustainable agriculture*, 1-21.
31. Rashmi, I., Roy, T., Kartika, K. S., Pal, R., Coumar, V., Kala, S., & Shinoji, K. C. (2020). Organic and inorganic fertilizer contaminants in agriculture: Impact on soil and water resources. *Contaminants in Agriculture: Sources, Impacts and Management*, 3-41.
32. Saliya, C. A., & Nissanka, N. A. (2024). Balancing Growth and Green: An In-Depth Analysis Of Oil Palm Versus Rubber Cultivation In Sri Lanka For Sustainable Agriculture. *Available at SSRN 4986099*. https://dx.doi.org/10.2139/ssrn.4986099
33. Semar, A., Bachir, H., & Lal, R. (2024). 9 Groundwater's Geochemical. *Managing Soil Drought*, *9*, 255.
34. Sharma, U. C., Datta, M., & Sharma, V. (2025). Managing Soil Acidity. In *Soil Acidity: Management Options for Higher Crop Productivity* (pp. 427-522). Cham: Springer Nature Switzerland.
35. Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H., & Trivedi, P. (2023). Climate change impacts on plant pathogens, food security and paths forward. *Nature Reviews Microbiology*, *21*(10), 640-656.
36. Singhal, R. K., Fahad, S., Kumar, P., Choyal, P., Javed, T., Jinger, D., & Nawaz, T. (2023). Beneficial elements: New Players in improving nutrient use efficiency and abiotic stress tolerance. *Plant*

Growth Regulation, *100*(2), 237-265.
37. Suman, J., Rakshit, A., Ogireddy, S. D., Singh, S., Gupta, C., & Chandrakala, J. (2022). Microbiome as a key player in sustainable agriculture and human health. *Frontiers in Soil Science*, *2*, 821589. https://doi.org/10.3389/fsoil.2022.821589
38. Tehulie, N. S., & Eskezia, H. (2021). Effects of nitrogen fertilizer rates on growth, yield components and yield of food Barley (Hordeum vulgare L.): A Review. *J. Plant Sci. Agric. Res*, *5*, 46.
39. Tiwari, A. K., & Pal, D. B. (2022). Nutrients contamination and eutrophication in the river ecosystem. In *Ecological significance of river ecosystems* (pp. 203-216). Elsevier. https://doi.org/10.1016/B978-0-323-85045-2.00001-7
40. Tripathi, S. C., Kumar, N., & Venkatesh, K. (2025). Nano urea's environmental edge and economic efficacy in boosting wheat grain yield across diverse Indian agro-climates. *Scientific Reports*, *15*(1), 3598.
41. Tschirley, D. (2024). Nourishing the Future: Reflections on the Follow-up to the African Fertilizer and Soil Health Summit.
42. Williams, M. (2021). When the Sahara was green: how our greatest desert came to be.
43. Xing, Y., & Wang, X. (2024). Precision agriculture and water conservation strategies for sustainable crop production in arid regions. *Plants*, *13*(22), 3184. https://doi.org/10.3390/plants13223184
44. Yahaya, S. M., Mahmud, A. A., Abdullahi, M., & Haruna, A. (2023). Recent advances in the chemistry of nitrogen, phosphorus and potassium as fertilizers in soil: A review. *Pedosphere*, *33*(3), 385-406. https://doi.org/10.1016/j.pedsph.2022.07.012
45. Yousuf, M. S. E. (2022). Assessment of soil management and its role in reducing land degradation in the southern part of Al-Jabal al Akhdar, Libya.
46. Zhang, X., Dong, Z., Wu, X., Gan, Y., Chen, X., Xia, H., ... & Siddique, K. H. (2021). Matching fertilization with water availability enhances maize productivity and water use efficiency in a semi-arid area: Mechanisms and solutions. *Soil and Tillage Research*, *214*, 105164. https://doi.org/10.1016/j.still.2021.105164
47. Zurqani, H. A. (Ed.). (2021). *The soils of Libya*. Cham: Springer.