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Review on the Role of Integrated Organic and Inorganic Fertilizer Application on Yield and Climate-Smart Agriculture: Challenges and Opportunities in Ethiopia

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Abstract: This review paper explores at the effects of organic and inorganic fertilizer use on climate-smart agriculture (CSA) in Ethiopia, evaluating problems and opportunities. Regarding the growing climate-related challenges to agriculture, understanding the efficacy of fertilizer application methods is crucial for long-term agricultural development. According to the studies analyzed, using both organic and inorganic fertilizers increases grain crop output in Ethiopia. Furthermore, the data highlight the advantages of this integrated strategy for cereal crop yield and soil fertility growth in the country. This study reviews the influence of integrated organic and inorganic fertilizers on crop resilience, soil health and climate change adaptation in Ethiopian agriculture by reviewing the current literature. The review also examines limitations such as access to inputs. This paper also analyzes constraints such as access to inputs and knowledge gaps, as well as the potential to promote CSA practices through government support and capacity-building efforts. Finally, the comparison analysis demonstrates that Ethiopia must use both organic and inorganic fertilizers to improve crop output and soil health. Further research and outreach initiatives are required in order to encourage the adoption of integrated fertilization systems and address present challenges for sustainable agricultural development.

Key words: Climate Change · Sustainable Agriculture · Soil Improvement · Yield Improvement

INTRODUCTION

Low productivity and climate change impacts require climate-smart agriculture (CSA), through improving food security by sustainably increasing crop productivity, enhancing the resilience of agricultural systems or adaptive capacity and offsetting greenhouse gas emissions [1, 2]. The integrated soil fertility management framework could play an important role in achieving sustainable intensification in sub Saharan Africa [2]. It targets to increase crop productivity by maximizing the agronomic efficiency of fertilizer inputs through the combined application of mineral and organic fertilizers, improved germplasm and good agronomic practices [3-5]. Climate change poses significant challenges to Ethiopia's agricultural sector, including unpredictable rainfall patterns, temperature fluctuations and increased pest and disease pressure. Climate-smart agriculture (CSA) offers a framework for addressing these challenges by promoting sustainable practices that enhance resilience, adaptation and mitigation [6, 7]. Fertilizer application, particularly the integration of organic and inorganic sources, plays a crucial role in supporting CSA objectives. With the increasing pressure on land and resources, optimizing fertilization practices becomes imperative for sustainable agriculture [8]. Integrated fertilization systems, combining organic and inorganic inputs, have gained attention for their potential to enhance yields while improving soil health [9]. However, several challenges hinder the widespread adoption of integrated fertilization practices in Ethiopia. This paper observes the effects of organic and inorganic fertilizer application on CSA and discusses the challenges and opportunities associated with its implementation.

Objective of the Review:

- To review the role of integrated organic and inorganic fertilizer application on soil health improvement and crop productivity for agricultural sustainability.

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- To review the role of integrated organic and inorganic fertilizer application on climate change.

A comprehensive literature search was directed to gather relevant studies on the topic. Studies focusing on the impact of integrated fertilizer application on cereal crops such as maize, teff, wheat and barley in Ethiopia were included. Data regarding crop yield, nutrient uptake, soil fertility and economic implications were extracted and analyzed.

Integrated fertilizer practices have been related with:

- Increased crop yields: from different Studies have consistently reported yield improvements across various cereal crops, including maize, teff, wheat and barley, following integrated fertilizer application.
- Soil fertility enhancement: Integrated fertilization leads to improvements in soil organic matter content, nutrient availability, pH levels and soil structure, thereby enhancing soil fertility and productivity.
- Nutrient uptake efficiency: Integrated fertilizer management improves crop quality and resilience to environmental impacts by optimizing nutrient uptake efficiency.

Integrated Organic and Inorganic Fertilizer Application on Yield and Soil Improvement: The synergistic effects of combining organic and inorganic fertilizers contribute to sustainable agricultural intensification in Ethiopia. By combination the complementary benefits of both fertilizer sources, farmers can achieve higher yields while maintaining soil health and fertility. Integrated fertilizer practices not only improve crop productivity but also offer environmental and economic benefits, including reduced environmental pollution, cost savings and enhanced market access for sustainably produced crops.

Yield Improvement: The study conducted by Tadesse *et al.* [9] provides valuable awareness into the comparative evaluation of integrated organic and inorganic fertilizers on cereal crop production in Ethiopia. Yield data analysis revealed significant improvements in crop yields when integrated fertilization systems were employed compared to conventional methods. Abegaz *et al.* [10] reported a significant increase in maize yield from 4.2 tons per hectare to 5.5 tons per hectare compared to chemical fertilizer alone.

Worku and Mamo [13] observed a substantial enhancement in teff grain yield, increasing from 0.8 tons per hectare to 1.2 tons per hectare. Gebremedhin *et al.* [11] found improved wheat yields, with an increase from 2.5 tons per hectare to 3.2 tons per hectare. Lemma *et al.* [12] noted increased barley biomass production, with yields rising from 1.6 tons per hectare to 2.0 tons per hectare.

Yield and Soil Improvement: According to Table (1, 2 and 3) the study, the integration of organic and inorganic fertilizers resulted in a 15-25% increase in grain yield compared to sole application of either organic or inorganic fertilizers. This suggests a synergistic effect between organic and inorganic inputs, enhancing nutrient availability and uptake by cereal crops. Girma Chala *et al.* [5], Tadesse *et al.* [9] and Abegaz *et al.* [10], observed increases in soil organic matter content, indicating improved soil fertility.

Additionally, Worku and Mamo [13] reported an increase in soil pH, which is crucial for nutrient availability and crop growth. Smith *et al.* [14], reported an increase in soil nitrogen content, which is essential for plant growth and productivity. Worku and Mamo [12] observed a reduction in soil acidity, contributing to improved soil health and nutrient uptake by crops.

Furthermore, soil improvement was evident in fields where integrated fertilization practices were adopted. Increased levels of organic matter, improved soil structure and enhanced water retention capacity were observed, indicating the long-term sustainability of integrated fertilization systems. The data presented in the Table (3, 4) supports the findings from the study conducted by Tadesse *et al.* [9]. Integrated fertilization resulted in the highest grain yield of 3500 kg/ha compared to organic (2800 kg/ha) and inorganic (3000 kg/ha) fertilizers alone. This indicates a significant increase in yield when organic and inorganic inputs are combined. Moreover, soil improvement was evident in fields where integrated fertilization practices were adopted. Integrated fertilizer application led to higher levels of soil organic matter (3.5%) compared to organic (2.8%) and inorganic (2.9%) fertilizers alone. Additionally, soil structure improved in fields treated with integrated fertilizers, contributing to enhanced water retention capacity. Furthermore, soil improvement was evident in fields where integrated fertilization practices were adopted.

Soil Health: Both organic and inorganic fertilizers can influence soil health, but organic fertilizers typically have a more positive impact in the long term. Organic fertilizers improve soil structure, water retention capacity and microbial activity, which can enhance soil resilience to climate variability.

Table 1: Impact of integrated organic and inorganic fertilizer application on crop production

Cereal Crop	Integrated Fertilizer Effects	Source
Maize	Increased grain yield by 30% compared to chemical fertilizer	[10]
Teff	Enhanced soil organic matter and improved teff grain quality	[9]
Wheat	Improved nutrient uptake efficiency and higher wheat yields	[11]
Barley	Reduced soil acidity and increased barley biomass production	[12]

Table 2: Impact of integrated organic and inorganic fertilizer application on crop production

Cereal Crop	Integrated Fertilizer Effects	Source
Maize	Increased grain yield by 30% compared to chemical fertilizer	[10]
Teff	Enhanced soil organic matter and improved teff grain quality	[9]
Wheat	Improved nutrient uptake efficiency and higher wheat yields	[11]
Barley	Reduced soil acidity and increased barley biomass production	[12]

Table 3: Impact of integrated organic and inorganic fertilizer on Yield and soil improvement

Cereal Crop	Integrated Fertilizer Effects	Yield Improvement	Soil Improvement	Source
Maize	Increased grain yield by 30% compared to chemical fertilizer	4.2 tons/ha to 5.5 tons/ha	Improved soil organic matter content by 20%	[10]
Teff	Enhanced soil organic matter and improved teff grain quality	0.8 tons/ha to 1.2 tons/ha	Increase in soil pH from 5.5 to 6.2	[9]
Wheat	Improved nutrient uptake efficiency and higher wheat yields	2.5 tons/ha to 3.2 tons/ha	Increase in soil nitrogen content by 25%	[11]
Barley	Reduced soil acidity and increased barley biomass production	1.6 tons/ha to 2.0 tons/ha	Decrease in soil pH from 5.8 to 5.4	[12]

Table 4: Comparative Evaluation of Integrated Organic and Inorganic Fertilizers on yield and soil improvement

Treatment Group	Grain Yield (kg/ha)	Soil Organic Matter (%)	Soil Structure	Water Retention Capacity
Integrated Fertilizer	3500	3.5	Improved	Enhanced
Organic Fertilizer	2800	2.8	Unchanged	Unchanged
Inorganic Fertilizer	3000	2.9	Unchanged	Unchanged

Source: [9].

Table 5: Comparison of soil health indicators between organic and inorganic fertilizer

Component	Organic Fertilizers	Inorganic Fertilizers	Source
Soil Structure	Improved	May degrade over time	[15], [16]
Microbial Activity	Enhanced	Reduced	

Organic fertilizers promote soil health by improving soil structure and microbial activity [14]. This enhances nutrient cycling and soil fertility over time. In contrast, continuous use of inorganic fertilizers may lead to soil degradation due to nutrient imbalances and reduced microbial diversity [15].

While each study focuses on different cereal crops, the findings collectively emphasize the effectiveness of integrated organic and inorganic fertilizer application in enhancing both crop yields and soil fertility. Additionally, the studies demonstrate the adaptability of integrated fertilization across various cereal crops, emphasizing its potential for widespread adoption in Ethiopian agriculture. These decisions emphasize the synergistic effects of combining organic and inorganic fertilizers, leading to improved nutrient availability, enhanced crop yields and sustainable soil management practices.

Effects of Organic and Inorganic Fertilizer Application on Disease Control: Organic fertilizers contribute to disease control by enhancing soil microbial diversity and suppressing soil-borne pathogens [16]. This can reduce the incidence of certain plant diseases and improve crop health. However, inorganic fertilizers have limited impact on disease control and may even increase susceptibility to certain diseases due to nutrient imbalances and alterations in soil microbial communities [17]. The study conducted by Smith *et al.* [18] examined the impacts of organic and inorganic fertilizer applications on climate-smart agriculture and disease control in Ethiopia.

Impact of Organic and Inorganic Fertilizer on Climate-Smart Agriculture Practices

Carbon Sequestration: Organic fertilizers contribute to carbon sequestration by enhancing soil organic carbon content [20]. This helps mitigate climate change by removing carbon dioxide from the atmosphere and storing it in the soil. In contrast, inorganic fertilizers have a limited contribution to soil carbon sequestration [21]. Organic fertilizers, such as compost and manure, contribute to soil organic carbon content, which helps sequester carbon dioxide from the atmosphere. This can mitigate climate change by reducing greenhouse gas emissions.

Table 6: Comparison of disease control measures between organic and inorganic fertilizer

Aspect/perspective	Organic Fertilizers	Inorganic Fertilizers	Source
Soil Microbial Diversity	Increased	Limited	[16, 17]
Pathogen Suppression	Effective	Limited	

Table 7: Effects of Organic and Inorganic Fertilizer Application on agriculture practice

Components	Organic Fertilizers	Inorganic Fertilizers
Soil Health	Improve soil structure, microbial activity	May lead to soil degradation over time
Disease Control	Enhance soil microbial diversity, suppress soil-borne pathogens	Limited impact on disease control, may increase susceptibility to certain diseases
Carbon Sequestration	Enhance soil organic carbon content	Limited contribution to soil carbon sequestration
Water Conservation	Improve water retention capacity	Limited improvement in water conservation
Resilience to Climate Variability	Enhance soil resilience to climate variability	May exacerbate soil degradation during extreme weather events
Nutrient Management	Promote balanced nutrient uptake by crops	Risk of nutrient imbalances, leaching and runoff

Source: [18, 19]

Table 8: Comparison of soil organic carbon content between organic and inorganic fertilizer

Components	Organic Fertilizers	Inorganic Fertilizers	Source
Soil Organic Carbon Content	Increased	Limited	[18, 21]

Table 9: Comparison of resilience to climate variability between organic and inorganic fertilizer

Aspect	Organic Fertilizers	Inorganic Fertilizers	Source
Resilience to Climate Events	Improved	Reduced	[15, 14]

Table 10: Comparison of water retention capacity between organic and inorganic fertilizer

Aspect	Organic Fertilizers	Inorganic Fertilizers	Source
Water Retention Capacity	Enhanced	Limited	[14, 19]

Table 11: Comparison of nutrient uptake between organic and inorganic fertilizer

Aspect	Organic Fertilizers	Inorganic Fertilizers	Source
Nutrient Uptake	Balanced	Risk of Imbalances	[13, 19]

Table 12: Impact of organic and inorganic fertilizer on Climate-Smart Agriculture Practices

Aspect	Organic Fertilizers	Inorganic Fertilizers
Nitrogen Management	Lower risk of nitrous oxide emissions	Risk of nitrous oxide emissions due to excess nitrogen application
Ecosystem Services	Support biodiversity and ecosystem functions	Potential negative impacts on non-target organisms and ecosystem services
Energy Use	Low energy requirements for production and application	Higher energy requirements for production and application

Source: [20, 21]

Resilience to Climate Variability: Organic fertilizers enhance soil resilience to climate variability, helping crops withstand drought and other extreme weather events [15]. This is achieved through improved soil structure, water retention capacity and nutrient availability. In contrast, over-reliance on inorganic fertilizers may exacerbate soil degradation during extreme weather events, leading to reduced resilience of agricultural systems [14].

Role of Integrated Organic and Inorganic Fertilizer Application on Nutrient and Moisture Management

Water Conservation: Organic fertilizers improve water retention capacity in soils, thereby promoting water conservation in agricultural systems [19]. This is particularly important in regions prone to drought or experiencing changes in precipitation patterns due to climate change. In contrast, inorganic fertilizers may provide limited improvements in water conservation compared to organic equivalents [13].

Nutrient Management: Organic fertilizers promote balanced nutrient uptake by crops, reducing the risk of nutrient imbalances and associated issues such as leaching and runoff [19]. In contrast, inorganic fertilizers may pose risks of nutrient imbalances and environmental pollution if not managed properly [13].

Generally, the outcomes underline the importance of adopting climate-smart agricultural practices, including the judicious use of organic fertilizers, to promote soil health, disease control and resilience to climate variability in Ethiopia.

The Role of Integrated Organic and Inorganic Fertilizer Application on Economic and Environmental Benefit: The synergistic effects of combining organic and inorganic fertilizers contribute to sustainable agricultural intensification in Ethiopia. By harnessing the complementary benefits of both fertilizer sources, farmers can achieve higher yields while maintaining soil health and fertility. Integrated fertilizer practices not only improve crop productivity but also offer environmental and economic benefits, including reduced environmental pollution, cost savings and enhanced market access for sustainably produced crops.

Integrated fertilizer application has been found to enhance soil fertility by improving nutrient availability and soil structure. This, in turn, has led to increased crop yields and improved crop quality. Additionally, integrated fertilizer management has been associated with better nutrient uptake efficiency and reduced environmental pollution compared to sole reliance on chemical fertilizers. Economically, farmers adopting integrated fertilizer practices have reported increased profits due to higher yields and reduced input costs over time.

Economic Benefit: In addition to the agronomic benefits, it's essential to consider the economic feasibility of adopting integrated organic and inorganic fertilizer practices in Ethiopian agriculture. While the initial investment in organic inputs may be higher compared to conventional chemical fertilizers, the long-term economic benefits often balance the costs. Economically, farmers adopting integrated fertilizer practices have reported increased profits due to higher yields and reduced input costs over time [21].

Cost Savings: This review had shown that integrated fertilizer management can lead to reduced input costs over time. For instance, Abegaz *et al.* [10] reported that despite the initial investment in organic fertilizers, the overall cost of production for maize decreased due to lower dependency on expensive chemical fertilizers. Similarly, Lemma *et al.* [12] noted cost savings associated with reduced soil acidity, which minimizes the need for costly soil amendments.

Yield Increase: The significant improvement in crop yields resulting from integrated fertilizer application contributes to increased farm income. Gebremedhin *et al.* [11] observed a substantial increase in wheat yields, transforming to higher profits for farmers. Similarly, Tadesse *et al.* [9] reported enhanced teff grain quality, which can realize higher prices in the market, thereby improving farmers' economic returns.

Market Access: With growing consumer demand for sustainably produced food, farmers adopting integrated fertilization practices may have better access to quality markets and price rewards for organic or sustainably grown crops. This can further enhance the economic viability of integrated fertilizer management systems.

Energy Use: Organic fertilizers often require less energy for production and application compared to inorganic fertilizers, leading to lower carbon ways associated with their use [23].

Environmental Benefits: Integrated fertilization practices also offer environmental benefits, such as reduced soil erosion and pollution. By enhancing soil health and fertility, farmers can maintain sustainable production systems while minimizing environmental degradation. This, in turn, can lead to long-term economic gains by preserving natural resources and reducing the need for costly interventions to mitigate environmental damage.

Ecosystem Services: Organic fertilizers support biodiversity and ecosystem services by promoting beneficial soil organisms and reducing the reliance on synthetic chemicals, which can have negative impacts on non-target organisms and ecosystem functions [24].

Nitrogen Management: Inorganic fertilizers, particularly nitrogen-based ones, can contribute to nitrous oxide emissions, a potent greenhouse gas. Improper application of nitrogen fertilizers can also lead to nitrate leaching, contributing to water pollution and ecosystem degradation [25, 26].

Challenges and Opportunities on the Integrated Use of Fertilizer Application: The challenges and opportunities associated with integrated organic and inorganic fertilizer application in Ethiopian agriculture emphasize the need for comprehensive strategies to promote climate-smart agriculture. Addressing challenges such as limited access to inputs and knowledge gaps requires collaborative efforts from policymakers, researchers and extension services. By leveraging policy support, capacity-building initiatives and research investments, Ethiopia can overcome barriers to adoption and connect the potential of integrated fertilization practices to build a more resilient and sustainable agricultural sector.

Challenges: Limited Access to Inputs: Smallholder farmers in Ethiopia often face challenges accessing quality organic inputs, such as compost and manure, due to availability and affordability issues [27-30].

Knowledge Gaps: There is a lack of awareness and technical knowledge among farmers regarding the benefits and proper use of integrated fertilization practices [31].

Policy Constraints: Inadequate policy support and incentives for promoting integrated fertilization practices hinder adoption and investment in CSA [32-34].

Opportunities

Policy Support: Government policies that incentivize the use of organic fertilizers and promote sustainable agricultural practices can encourage adoption among farmers [35]

Capacity Building: Training programs and extension services can improve farmers' knowledge and skills in implementing integrated fertilization practices.

Research and Innovation: Continued research and innovation in fertilizer technology and agronomic practices can lead to the development of more effective and affordable organic inputs [36, 37]. However, challenges such as limited access to organic inputs and concerns regarding environmental pollution from inorganic fertilizers were also emphasized. To fully realize these benefits, it is essential to address the challenges hindering the adoption of integrated fertilizer management and implement supportive policies and programs.

CONCLUSION

Considering an extensive review of the literature, several main conclusions emerge about the influence of combined organic and inorganic fertilizer application on the productivity and sustainability of agriculture in Ethiopia:

- Integrated organic and inorganic fertilizer treatment has the potential to considerably boost production and yield components across a variety of crops. This research emphasizes the need of using integrated fertilization strategies to increase agricultural productivity.
- Integrated organic and inorganic fertilizer application can enhance crop resilience, improve soil health and contribute to climate adaptation in Ethiopian agriculture
- This review emphasizes the importance of integrated fertilizer management as a viable strategy for sustainable cereal crop production in Ethiopia, contributing to food security, economic growth and environmental sustainability.
- Finally from this review, the use of both organic and inorganic fertilizers has the potential to promote crop resilience, soil health and climate adaption in Ethiopian agriculture. This shows that integrated fertilization strategies can play an important role in increasing agricultural resilience to climate change impacts, while ensuring food security and livelihoods.

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