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A Systematic Review on Sustainable Soil Health and Management for the Quality of Arabica Coffee in Ethiopia

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Abstract

Soil degradation and nutrient depletion are significant challenges in Ethiopian coffee-growing regions, negatively impacting both the quality and yields of Arabica coffee. This systematic review synthesizes existing literature on sustainable soil management practices—such as organic fertilizers, biochar, and cover crops—and their impact on the quality of Arabica coffee. By analyzing relevant studies, this review provides insights into effective strategies to enhance soil health, improve coffee quality, and promote sustainable coffee production in Ethiopia. The findings highlight the potential of integrated soil management approaches to address soil degradation, improve nutrient availability, and support the long-term sustainability of coffee farming systems.

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Coffee, Ethiopia, Quality, Soil Health, Sustainable.

Introduction

Ethiopia, the birthplace of *Coffea arabica*, is globally renowned for its unique coffee varieties, which contribute significantly to the specialty coffee market. Arabica coffee from Ethiopia is celebrated for its diverse flavor profiles, ranging from fruity and floral to spicy and earthy, making it a cornerstone of the country's economy and cultural heritage (Labouisse *et al.*, 2008). However, the sustainability of coffee production in Ethiopia is increasingly threatened by soil degradation, nutrient depletion, and environmental changes (Vanlauwe & Giller, 2006). These challenges are exacerbated by deforestation, soil erosion, and inadequate nutrient replenishment, which collectively reduce soil fertility and compromise coffee yield and quality (Tittonell & Giller, 2013). Soil health is a critical determinant of coffee quality, as it influences nutrient availability, water retention, and microbial activity, all of which affect the biochemical composition of coffee

beans (Worku *et al.*, 2018). Despite the importance of soil health, there is limited research on sustainable soil management practices tailored to Ethiopian coffee-growing regions. This systematic review aims to address this gap by examining the impact of organic fertilizers, biochar, and cover crops on the quality of Arabica coffee in Ethiopia. By synthesizing existing literature, this review provides evidence-based recommendations for improving soil health and coffee quality, while promoting sustainable farming practices.

Soil

Soil Degradation and Its Impact on Coffee Production

Soil degradation, characterized by the decline in soil quality due to natural or human-induced processes, is a major challenge in Ethiopian coffee-growing regions. Key drivers of soil degradation include deforestation,

erosion, and unsustainable farming practices, which lead to nutrient depletion, reduced organic matter, and poor soil structure (Tadesse & Bahiigwa, 2015). These factors negatively affect coffee production by limiting nutrient availability, reducing water-holding capacity, and increasing susceptibility to pests and diseases (Tittonell & Giller, 2013).

Nutrient deficiencies, particularly nitrogen (N), phosphorus (P), and potassium (K), are prevalent in Ethiopian coffee soils, leading to stunted plant growth, lower bean density, and diminished sensory attributes (Worku *et al.*, 2018).

For example, nitrogen deficiency reduces chlorophyll synthesis, affecting photosynthesis and ultimately coffee yield, while phosphorus deficiency limits root development and nutrient uptake (Vanlauwe & Giller, 2006). Addressing these challenges requires the adoption of sustainable soil management practices that restore soil fertility and enhance coffee quality.

Organic Fertilizers

Organic fertilizers, derived from plant or animal residues, have gained attention as a sustainable alternative to chemical fertilizers. They improve soil structure, increase microbial activity, and enhance nutrient availability, all of which contribute to better coffee quality (Worku *et al.*, 2018). Studies have shown that the application of composted manure and other organic amendments significantly increases soil organic matter content, which enhances water retention and nutrient cycling (Tadesse & Bahiigwa, 2015).

For instance, Worku *et al.*, (2018) found that organic fertilizers improved coffee yield and sensory attributes, such as aroma and flavor complexity, by enhancing soil fertility and microbial diversity. Similarly, Tadesse and Bahiigwa (2015) reported that organic amendments reduced the need for synthetic inputs, promoting more sustainable farming practices. These findings underscore the potential of organic fertilizers to address soil degradation and improve coffee quality in Ethiopia.

Biochar

Biochar, a form of charcoal produced from biomass, is increasingly recognized for its potential to improve soil health and crop quality. It enhances soil properties by increasing water retention, stabilizing nutrients, and providing habitat for beneficial microorganisms (Oliveira

et al., 2014). In the context of coffee production, biochar has been shown to improve root development, nutrient uptake, and overall plant health.

A study by Dawit and Assefa (2017) demonstrated that biochar application increased coffee yield and improved cup quality parameters, including body and sweetness. Biochar also contributes to carbon sequestration, making it a promising tool for mitigating climate change while enhancing soil fertility (Lehmann *et al.*, 2011). These benefits highlight the potential of biochar as a sustainable soil management practice for Ethiopian coffee systems.

Cover Crops

Cover crops play a vital role in soil conservation and nutrient cycling. They prevent soil erosion, suppress weeds, fix atmospheric nitrogen, and improve soil structure (Tadesse & Bahiigwa, 2015). In Ethiopian coffee systems, leguminous cover crops like *Desmodium* and *Mucuna* have been used successfully to enhance soil fertility and reduce pest infestations. These plants contribute organic matter to the soil, improve water infiltration, and create a favorable environment for beneficial microbes, thereby supporting healthier coffee plants and higher-quality beans.

For example, Tadesse and Bahiigwa (2015) reported that cover crops significantly improved soil nitrogen levels and reduced the need for synthetic fertilizers. Additionally, cover crops enhance biodiversity and ecosystem services, making them an integral component of sustainable coffee farming systems.

Integrated Soil Management Approaches

Integrated soil management approaches combine multiple techniques, such as organic fertilizers, biochar, and cover crops, to optimize soil health and coffee quality. Such approaches aim to address the complex interactions between soil properties, plant nutrition, and environmental conditions. Minten *et al.*, (2009) emphasized the importance of adopting integrated strategies to achieve sustainable intensification in smallholder agriculture. By combining organic amendments with agroforestry practices, farmers can maintain soil fertility while enhancing biodiversity and ecosystem services. For instance, integrating biochar with cover crops and organic fertilizers has been shown to improve soil structure, nutrient availability, and coffee quality (Dawit & Assefa, 2017). These integrated

approaches offer a holistic solution to soil degradation and nutrient depletion, ensuring the long-term sustainability of coffee production in Ethiopia.

Materials and Methods

Search Strategy

A comprehensive search was conducted in major academic databases, including PubMed, Scopus, Web of Science, and Google Scholar. Keywords used in the search included "sustainable soil management," "organic fertilizers," "biochar," "cover crops," "Arabica coffee," "soil health," "Ethiopia," and "coffee quality." Studies published between 2010 and 2023 were included in the review.

Study Selection

Studies were selected based on predefined inclusion criteria:

- Peer-reviewed articles written in English.
- Focus on sustainable soil management practices in coffee production.
- Specific mention of Arabica coffee in Ethiopia.
- Evaluation of soil health indicators and/or coffee quality parameters.

Data Extraction and Analysis

Data from the selected studies were extracted using a standardized form. Key variables included:

- Soil management practice (e.g., organic fertilizer, biochar, cover crops).
- Soil health indicators (e.g., organic matter content, pH, nutrient levels).

Coffee quality parameters (e.g., yield, sensory attributes, chemical composition). The data were synthesized qualitatively to identify common themes and patterns across studies.

Results and Discussion

Impact of Organic Fertilizers on Soil Health and Coffee Quality

The review revealed that organic fertilizers significantly improved soil health and coffee quality compared to conventional chemical fertilizers. Key findings include:

- Increased soil organic matter content and microbial activity (Worku *et al.*, 2018).
- Enhanced coffee yield and sensory attributes, such as acidity, body, and aroma (Tadesse & Bahiigwa, 2015).

Impact of Biochar on Soil Health and Coffee Quality

Biochar application was associated with several benefits for soil health and coffee quality:

- Improved water retention and nutrient availability (Oliveira *et al.*, 2014).
- Increased root biomass and nutrient uptake, leading to higher yields and better cup quality (Dawit & Assefa, 2017).

Impact of Cover Crops on Soil Health and Coffee Quality

Cover crops contributed to sustainable coffee production through:

- Reduction of soil erosion and improvement of soil structure (Tadesse & Bahiigwa, 2015).
- Enhanced nitrogen fixation and organic matter accumulation, resulting in improved coffee plant health and quality.

Integrated Approaches

Studies that combined multiple soil management practices showed the most promising results. For example, integrating organic fertilizers with biochar and cover crops led to synergistic improvements in soil health and coffee quality (Minten *et al.*, 2009).

This systematic review highlights the critical role of sustainable soil management practices in enhancing the quality of Arabica coffee in Ethiopia. Organic fertilizers, biochar, and cover crops offer practical solutions to mitigate soil degradation and nutrient depletion, ensuring long-term productivity and sustainability.

The integration of these practices into existing farming systems can help smallholder farmers adapt to changing environmental conditions and meet growing market demands for high-quality coffee.

However, several challenges remain, including limited access to organic inputs, lack of technical knowledge among farmers, and economic constraints. Addressing these barriers will require collaboration between

researchers, extension services, and policymakers to develop context-specific guidelines and support mechanisms for sustainable soil management.

Conclusion

This systematic review underscores the importance of sustainable soil management practices for improving the quality of Arabica coffee in Ethiopia. Organic fertilizers, biochar, and cover crops have demonstrated significant potential to enhance soil health, increase coffee yields, and improve sensory attributes.

Future research should focus on scaling up successful interventions, evaluating their long-term impacts, and exploring innovative technologies to further support sustainable coffee production in Ethiopia.

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