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A REVIEW OF THE ROLE OF COVER CROPS IN MITIGATING SOIL HEALTH DEGRADATION AND OTHER CHALLENGES ASSOCIATED WITH MAIZE MONOCULTURE

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ABSTRACT

Maize (Zea mays L.) is a staple crop widely cultivated in sub-Saharan Africa, particularly Nigeria. However, its predominant cultivation through monoculture systems has contributed significantly to soil health degradation, reduced biodiversity, increased erosion, and heightened pest and disease pressures. These challenges threaten long-term agricultural sustainability and food security. As a response, the integration of cover crops into maize cropping systems has emerged as a promising sustainable agricultural practice. This review examines the role of cover crops in mitigating the negative impacts of maize monoculture, with a focus on improving soil physical, chemical, and biological properties. The paper discusses how different cover crop types—leguminous, non-leguminous, grasses, and brassicas contribute to improved soil structure, enhanced nutrient cycling, increased microbial diversity, and better water retention. The interaction between cover crops and maize is explored, highlighting benefits such as nitrogen fixation and organic matter enrichment, alongside potential challenges like resource competition if not properly managed. Historical and regional perspectives on the use of cover crops in Nigeria and globally are provided, emphasizing traditional practices and modern innovations. The review also identifies research gaps, including the need for long-term studies and better understanding of context-specific responses of cover crops across varying agro-ecological zones. Ultimately, the paper highlights that integrating cover crops into maize production systems can enhance soil health, reduce dependency on chemical inputs, and build resilience against climate variability. The insights provided serve as a valuable resource for policymakers, researchers, and farmers aiming to adopt sustainable and ecologically sound farming practices.

Key words: Cover crops, Maize, Monoculture, Soil health, Soil fertility

INTRODUCTION

Maize (Zea mays L.) is one of the most widespread cereal crops to be cultivated across the globe and one of the staple cereals in most of sub-Saharan Africa, including Nigeria. Its high demand for food, feed, and industry has made it a crop produced perpetually, with numerous cases of monoculture production. Maize monoculture, while common in many agricultural regions, has led to extensive soil degradation, decreased crop productivity, and threats to food security (Acevedo-Siaca and Goldsmith, 2020). The continuous cropping of maize has resulted in soil fertility loss, erosion, and reduced biodiversity, exacerbating environmental problems and climate change impacts (Francaviglia et al., 2023). These issues threaten the productivity and sustainability of maize-based agricultural systems, especially where access to inputs is low and smallholder farmers dominate agricultural production (Lal, 2015; Ademiluyi and Omotoso, 2021). In response to these challenges, sustainable agricultural practices, including the use of cover crops, have emerged as cost-effective solutions to address land degradation, enhance food security, and contribute to climate change mitigation and adaptation (Francaviglia et al., 2023; Zou et al., 2024).

Cover crops have emerged as a sustainable and viable agronomic strategy aimed at reversing the detrimental effects of monoculture. Cover crops, also grown primarily to enilfe and cover the soil as opposed to harvest, play a major role in soil health preservation and enhancement (Schipanski et al., 2014). They strengthen the structure of the soil, enhance nutrient cycling, inhibit weed growth, reduce soil erosion, and stimulate microbial activity and thereby restore depleted soils resulting from continued cultivation of the maize (Blanco-Canqui et al., 2015). In addition, cover crops that are legumes have a capacity to fix atmospheric nitrogen, decreasing the use of artificial fertilizers and increasing nutrient content for subsequent maize crops (Dube et al., 2012).

Soil health is a foundational element in sustainable agricultural systems, serving as the bedrock for plant growth, water regulation, and ecosystem stability. Understanding and maintaining soil health is crucial for ensuring long-term agricultural productivity and environmental quality (De Corato et al., 2024). In the context of maize cropping systems, soil health influences everything from nutrient availability to crop resilience against diseases and environmental stresses (Yang et al., 2020). Cover crops, as an integral component of agricultural management, play a significant role in enhancing soil health by improving soil structure, increasing organic matter content, and fostering a diverse microbial ecosystem (Van Eerd et al., 2023).

Cover crops, when integrated into crop rotations or used during fallow periods, offer numerous ecological benefits. They improve soil structure, promote nutrient cycling, enhance soil fertility and microbial activity, control soil erosion, and inhibit weed growth, pests, and diseases (Muhammad et al., 2022). By introducing cover crops, farmers can reduce their reliance on synthetic fertilizers, minimize greenhouse gas emissions, and improve overall soil health (Omer et al., 2024; Xing and Wang, 2024). This review aims to synthesize current knowledge on the role of cover crops in addressing the challenges associated with maize monoculture, providing insights for researchers, farmers, and policymakers to effectively integrate these practices into sustainable farming systems.

Definition and Importance of Soil Health

Soil health is a broad concept that encompasses the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. It is often defined as the ability of soil to support agricultural productivity, maintain environmental quality, and promote plant and animal health (Doran and Zeiss, 2000). Healthy soil is fundamental to agricultural sustainability because it supports plant growth, regulates water, sustains biodiversity, and sequesters carbon, thereby mitigating climate change (Lehmann et al., 2020). The importance of soil health extends beyond agriculture; it is critical for ecosystem services, including water filtration, nutrient cycling, and the provision of habitats for diverse organisms (Kibblewhite et al., 2008).

Key Indicators of Soil Health

The assessment of soil health is often based on various indicators that reflect its physical, chemical, and biological properties. Some of the key indicators include:

Soil Organic Matter (SOM): SOM is a critical indicator of soil health, influencing nutrient availability, soil structure, and water retention capacity. It serves as a reservoir of nutrients and plays a key role in the carbon cycle (Gregorich et al., 1994). High SOM levels are generally associated with improved soil fertility and resilience to environmental stresses.

Soil Structure: Soil structure refers to the arrangement of soil particles into aggregates. Good soil structure enhances root penetration, water infiltration, and air exchange, all of which are essential for healthy plant growth. It also reduces the risk of erosion and compaction (Bronick and Lal, 2005).

Soil Fertility: Soil fertility involves the presence and availability of essential nutrients required for plant growth, such as nitrogen, phosphorus, and potassium. Fertile soil supports high crop yields and is crucial for sustainable agriculture (Johnston and Bruulsema, 2014).

Microbial Activity: Soil microbes, including bacteria, fungi, and protozoa, play a vital role in decomposing organic matter, cycling nutrients, and promoting plant health through symbiotic relationships (Nannipieri et al., 2003). High microbial activity is often an indicator of a well-functioning and healthy soil ecosystem.

Factors Affecting Soil Health in Agricultural Systems

Several factors influence soil health, particularly within agricultural systems, some of these factors include:

Land Management Practices: Practices such as crop rotation, tillage, and the use of cover crops significantly impact soil health. Cover crops, for example, can enhance SOM, improve soil structure, and reduce erosion, thereby improving overall soil health (Blanco-Canqui et al., 2015). Conversely, intensive tillage can degrade soil structure, reduce organic matter, and lead to compaction.

Soil Erosion: Erosion removes the nutrient-rich topsoil, leading to a decline in soil fertility and structure. It is a major threat to soil health, particularly in regions with poor vegetation cover or improper land management (Lal, 2003).

Chemical Inputs: The excessive use of chemical fertilizers and pesticides can harm soil health by disrupting microbial communities, altering nutrient cycling, and leading to the accumulation of toxic residues (Tilman et al., 2002). Sustainable practices that minimize chemical inputs while maintaining productivity are essential for long-term soil health.

Climate Change: Changes in temperature and precipitation patterns can directly affect soil health by altering moisture levels, increasing the risk of erosion, and affecting microbial activity and SOM decomposition rates (Davidson and Janssens, 2006). Adaptive land management strategies are crucial to maintaining soil health under changing climatic conditions.

In summary, soil health is a multidimensional concept essential for sustainable agriculture and ecosystem services. The use of cover crops in maize cropping systems can play a significant role in maintaining and improving soil health by influencing key indicators and mitigating the adverse effects of various factors.

Definition and Types of Cover Crops

Cover crops are plant species cultivated primarily to cover the soil rather than for the purpose of being harvested. They are a key component of sustainable agriculture, serving multiple functions that benefit both the soil and the cropping system. Cover crops are typically grown during the off-season when main crops are not in the field, providing ground cover that protects the soil from erosion and helps maintain soil health (Snapp et al., 2005). There are various types of cover crops, broadly categorized based on their functional attributes and botanical families:

Leguminous Cover Crops: These include species such as clover (Trifolium spp.), vetch (Vicia spp.), and peas (Pisum sativum). Legumes are valued for their ability to fix atmospheric nitrogen through symbiosis with rhizobia bacteria, thus enriching the soil with nitrogen and reducing the need for synthetic fertilizers (Drinkwater et al., 1998).

Non-Leguminous Cover Crops: Examples include cereal rye (Secale cereale), oats (Avena sativa), and radishes (Raphanus sativus). These cover crops are primarily used for their ability to improve soil structure, suppress weeds, and scavenge residual nutrients, particularly nitrogen, preventing leaching into water bodies (SARE, 2007).

Grass Cover Crops: These include species like ryegrass (Lolium multiflorum) and barley (Hordeum vulgare). Grass cover crops are known for their dense root systems, which help in reducing soil erosion and improving soil organic matter (dos Santos Cordeiro et al., 2021).

Brassica Cover Crops: These include species like mustard (Brassica juncea) and radish. Brassicas are often used for their deep rooting system, which helps in breaking up compacted soils and enhancing water infiltration (Wiggins et al., 2015).

Role and Benefits of Cover Crops in Agricultural Systems

Cover crops offer numerous benefits to agricultural systems, making them an integral component of sustainable farming practices. Some of the key roles and benefits include:

Soil Health Improvement: Cover crops contribute to soil health by increasing soil organic matter, enhancing soil structure, and promoting microbial diversity. The addition of organic matter from decomposed cover crops helps to improve soil fertility, water-holding capacity, and cation exchange capacity (Stagnari et al., 2017).

Nutrient Management: Cover crops play a crucial role in nutrient cycling within the soil. Leguminous cover crops, in particular, fix atmospheric nitrogen, reducing the need for chemical fertilizers and enhancing the nutrient content of the soil (Fageria et al., 2005). Non-leguminous cover crops can absorb excess nutrients, such as nitrogen, from the soil, preventing nutrient leaching and promoting more efficient nutrient use by subsequent crops.

Erosion Control: By providing ground cover, cover crops protect the soil surface from the impact of raindrops and reduce surface runoff, thereby minimizing soil erosion. This is particularly important in regions with heavy rainfall or on sloped lands (Hartwig and Ammon, 2002).

Weed Suppression: Cover crops can suppress weed growth through both physical coverage of the soil and allelopathic effects, where certain cover crops release chemicals that inhibit weed germination and growth (Teasdale, 1996). This reduces the need for herbicides and promotes more sustainable weed management.

Pest and Disease Management: Some cover crops, such as brassicas, produce biofumigant compounds that can suppress soil-borne pests and diseases, thereby reducing the reliance on chemical pesticides (Björkman et al., 2011). Additionally, cover crops can create a more diverse agroecosystem that supports natural pest predators.

Historical Perspective on the Use of Cover Crops in Different Cropping Systems

The use of cover crops has been an integral part of traditional agricultural practices, especially among smallholder farmers who have long relied on diverse cropping systems to maintain soil fertility and ensure food security. The history of cover cropping in Nigeria is closely tied to the indigenous knowledge systems that have been passed down through generations, with farmers using various cover crops to enhance soil health, manage pests, and improve crop yields in different agro-ecological zones.

Historically, Nigerian farmers have used legumes, such as cowpeas (Vigna unguiculata) and groundnuts (Arachis hypogaea), as cover crops in mixed cropping systems. These legumes were often intercropped with staple crops like maize, sorghum, and millet, particularly in the northern and middle belt regions of Nigeria. The nitrogen-fixing ability of these legumes played a crucial role in enriching the soil, reducing the need for external inputs, and sustaining crop productivity over time. This practice was particularly important in regions with poor soils, where maintaining soil fertility through organic means was essential for agricultural sustainability (Ogunwole et al., 2010).

In the southeastern and southwestern parts of Nigeria, traditional farming systems also included the use of cover crops such as pigeon peas (Cajanus cajan) and velvet beans (Mucuna pruriens). These cover crops were utilized in fallow periods to restore soil fertility and control weeds. The use of Mucuna, in particular, became widespread due to its ability to suppress the growth of noxious weeds like speargrass (Imperata cylindrica), which posed a significant challenge to farmers in these regions. This practice demonstrated an early understanding of the ecological benefits of cover crops in weed management and soil restoration (Manyong et al., 1996).

During the colonial period, the introduction of cash crops such as cocoa, groundnuts, and cotton led to changes in traditional farming practices, including the use of cover crops. The focus shifted towards monoculture and the cultivation of export-oriented crops, often leading to soil degradation and the decline of traditional cover cropping practices. However, smallholder farmers continued to employ cover crops in subsistence farming systems, particularly in less commercialized areas where the benefits of these practices were well understood (Idowu et al., 2011). In the post-independence era, the Nigerian government and various agricultural research institutes began to recognize the importance of cover crops in improving soil health and promoting sustainable agriculture. Research conducted by institutions such as the International Institute of Tropical Agriculture (IITA) in Ibadan highlighted the role of cover crops in enhancing soil fertility, particularly in degraded lands. The promotion of cover crops like Mucuna and lablab (Lablab purpureus) gained momentum as part of soil fertility management programs aimed at improving the productivity of smallholder farms across the country (Sanginga and Woomer, 2009).

In recent years, there has been a renewed interest in cover cropping in Nigeria, driven by the challenges of soil degradation, climate change, and the need for sustainable agricultural practices. The Nigerian government, through various initiatives, has encouraged the adoption of cover crops as part of integrated soil fertility management strategies. Programs such as the Agricultural Transformation Agenda (ATA) and the Green Alternative have emphasized the role of cover crops in enhancing soil health, reducing dependency on chemical fertilizers, and improving the resilience of farming systems to climate variability (FMARD, 2016).

In maize cropping systems, cover crops are increasingly being recognized for their potential to improve soil structure, increase organic matter, and enhance soil nutrient availability. Farmers in the maize belts of Nigeria, particularly in the northern regions, are adopting cover crops like cowpeas and lablab to manage soil fertility and boost maize yields. This modern application of traditional practices underscores the enduring relevance of cover crops in Nigerian agriculture and their critical role in promoting sustainable farming systems in the face of contemporary challenges.

Maize Cropping System

The maize cropping system is a cornerstone of agriculture in many parts of the world, including Nigeria, where maize (Zea mays) is a staple crop and a primary source of food, income, and livestock feed. This section explores the maize cropping system in detail, discussing its overall structure, the significance of maize as a staple crop, and the challenges associated with maize monoculture, particularly in the context of soil health.

Overview of the Maize Cropping System

The maize cropping system refers to the agricultural practices and management strategies involved in the cultivation of maize, which is a major cereal crop grown worldwide. Maize can be cultivated in various cropping systems, including monoculture, intercropping, and rotational cropping. In monoculture systems, maize is grown continuously on the same piece of land, while in intercropping systems, it is cultivated alongside other crops such as legumes. Rotational cropping involves alternating maize with other crops in successive seasons to improve soil fertility and reduce pest and disease pressures (Fisher et al., 2015).

In Nigeria, maize is predominantly grown in the northern and central regions, where the agro-ecological conditions characterized by adequate rainfall, suitable temperatures, and fertile soils are favourable for its production. The cropping calendar for maize typically follows the rainy season, with planting occurring at the onset of the rains and harvesting towards the end of the wet season. In some regions, particularly where irrigation is available, maize can be grown twice a year, further underscoring its importance in the agricultural landscape (Nwafor et al., 2014). The maize cropping system is often integrated with other farming practices, such as the use of cover crops, organic and inorganic fertilizers, and various tillage methods, to enhance soil fertility and manage pests. These practices are essential for maintaining the productivity of maize, especially in areas where soil degradation and nutrient depletion are prevalent due to continuous cultivation.

Importance of Maize as a Staple Crop

Maize is one of the most important staple crops in Nigeria and many other parts of the world. It serves as a critical source of carbohydrates, vitamins, and minerals for millions of people. In Nigeria, maize is a versatile crop used in various forms, including as food (e.g., cornmeal, maize flour, and porridge), animal feed, and industrial raw materials for the production of products like starch and ethanol (IITA, 2019). The significance of maize in Nigerian agriculture extends beyond its role as a food crop. Economically, maize is a major cash crop that supports the livelihoods of smallholder farmers, contributing to household income and national food security. The crop's adaptability to different climatic conditions and soil types has made it a preferred choice for farmers across various regions of the country, from the semi-arid zones of the north to the more humid areas in the south (FAO, 2020).

Furthermore, maize is a vital component of the livestock industry, where it is used as feed for poultry, cattle, and other animals. This dual role of maize in both human and animal nutrition amplifies its importance in the agricultural value chain, making it a key driver of rural development and economic growth.

Challenges Associated with Maize Monoculture

While maize monoculture-growing maize continuously on the same land year after year can be economically attractive due to its simplicity and the potential for high yields, it poses significant challenges to soil health and overall agricultural sustainability. One of the primary issues with maize monoculture is soil degradation. Continuous maize cultivation without adequate soil management practices leads to the depletion of essential nutrients, particularly nitrogen and phosphorus, which are critical for plant growth (Lemaire et al., 2014). Over time, this nutrient depletion results in reduced soil fertility, necessitating the increased use of chemical fertilizers to maintain yields, which can further harm soil structure and biodiversity.

Another major challenge associated with maize monoculture is the increased pressure from pests and diseases. Pests such as the maize weevil (Sitophilus zeamais) and diseases like maize streak virus thrive in monoculture systems due to the continuous availability of their host crop. This persistence leads to greater reliance on chemical pesticides, which can have negative environmental and health impacts, as well as contribute to the development of pesticide-resistant pest populations (Meissle et al., 2010).

Moreover, maize monoculture contributes to soil erosion, particularly in regions with sloped terrains or heavy rainfall. The lack of crop diversity and ground cover between planting seasons leaves the soil exposed to erosion, leading to the loss of topsoil, which is rich in organic matter and nutrients. This erosion not only reduces soil fertility but also negatively impacts water quality in nearby water bodies due to sedimentation and runoff (Pimentel and Burgess, 2013).

To mitigate these challenges, integrated soil management practices, including the use of cover crops, crop rotation, and conservation tillage, are essential. These practices help maintain soil fertility, reduce pest and disease pressures, and minimize the environmental impact of maize cultivation. Incorporating cover crops into maize cropping systems, in particular, offers a sustainable solution to improving soil health by enhancing soil organic matter, preventing erosion, and fostering a more balanced ecosystem.

Impact of Cover Crops on Soil Physical Properties

Cover crops are essential in sustainable agricultural practices due to their significant impact on soil physical properties. The inclusion of cover crops in a maize cropping system can lead to various benefits that enhance soil health and improve crop productivity. This section explores the influence of cover crops on soil structure and compaction, soil moisture retention, and their role in reducing soil erosion.

Influence on Soil Structure and Compaction

Cover crops play a vital role in improving soil structure by enhancing the formation of soil aggregates, which are clusters of soil particles that bind together. The root systems of cover crops exude organic compounds that act as a glue, binding soil particles together and forming stable aggregates. These aggregates increase soil porosity, allowing better air and water movement within the soil profile (Blanco-Canqui et al., 2015). As a result, the soil becomes less compacted, which is critical in maintaining a healthy root environment for subsequent crops like maize. Moreover, cover crops like legumes and grasses have deep root systems that penetrate compacted soil layers, breaking up hardpans and alleviating soil compaction (Shaheb et al., 2021). This root activity not only loosens the soil but also creates channels that facilitate deeper root growth for maize plants, enhancing their access to nutrients and water. Reduced compaction leads to better root proliferation and more efficient nutrient uptake, ultimately improving maize crop yields.

Effects Cover Crops on Soil Moisture Retention

One of the significant benefits of cover crops is their ability to improve soil moisture retention. Cover crops reduce surface evaporation by providing a protective cover that shields the soil from direct sunlight and wind (Unger and Vigil, 1998). Additionally, their root systems increase soil organic matter content, which enhances the soil's ability to retain moisture. Organic matter acts like a sponge, holding water in the soil and making it available to plants during dry periods (Basche and DeLonge, 2019). In a maize cropping system, maintaining adequate soil moisture is critical, particularly during key growth stages like tasseling and grain filling. The improved soil moisture retention due to cover cropping can lead to more consistent crop growth and higher yields, especially in regions prone to drought or irregular rainfall patterns (Fageria et al., 2005).

Role in Reducing Soil Erosion

Soil erosion is a major concern in agriculture, leading to the loss of topsoil and essential nutrients, which are critical for crop production. Cover crops play a crucial role in reducing soil erosion by providing ground cover that protects the soil surface from the impact of raindrops and wind (Dabney et al., 2001). The roots of cover crops help to bind the soil, reducing the detachment and transport of soil particles. In maize cropping systems, cover crops such as rye or clover are particularly effective in minimizing erosion, especially during periods when the maize crop is not present to protect the soil. The presence of a cover crop reduces the velocity of surface runoff, allowing more water to infiltrate the soil rather than washing away valuable topsoil (Kaspar et al., 2001). This protection is especially important in sloped fields where erosion risks are higher.

Impact of Cover Crops on Soil Chemical Properties

Cover crops have become a key component of sustainable agricultural practices due to their profound influence on soil health. This section explores how cover crops impact soil chemical properties, focusing on soil pH and nutrient availability, organic matter accumulation and nutrient cycling, and soil carbon sequestration. These factors are crucial for understanding the overall improvement of soil health under maize cropping systems.

Influence on Soil pH and Nutrient Availability (Nitrogen, Phosphorus, Potassium)

Cover crops can significantly influence soil pH and the availability of essential nutrients, such as nitrogen (N), phosphorus (P), and potassium (K). The impact of cover crops on soil pH is generally variable and depends on the type of cover crop used and the soil conditions. For instance, legumes such as clover (Trifolium spp.) and vetch (Vicia spp.) can help neutralize soil acidity through their nitrogen fixation processes and root exudates, which can improve soil pH and make nutrients more available for subsequent crops (Hassink, 2003). In terms of nutrient availability, cover crops play a vital role in enhancing the levels of nitrogen, phosphorus, and potassium in the soil. Leguminous cover crops are particularly beneficial for nitrogen cycling. They fix atmospheric nitrogen through symbiotic relationships with soil bacteria, which enriches the soil with this crucial nutrient. When incorporated into the soil, the biomass of leguminous cover crops decomposes and releases nitrogen, increasing its availability for maize crops (Drinkwater et al., 1998).

Non-leguminous cover crops, such as cereals and grasses, primarily contribute to phosphorus and potassium dynamics. These crops can scavenge residual nutrients from the soil, reducing nutrient leaching and making them available for subsequent crops. Additionally, cover crops can help reduce nutrient runoff by improving soil structure and increasing organic matter, which enhances nutrient retention (Blanco-Canqui et al., 2015).

Role in Organic Matter Accumulation and Nutrient Cycling

Cover crops are essential for organic matter accumulation and nutrient cycling within soil systems. The organic matter added to the soil from decomposed cover crop residues improves soil structure, increases soil water holding capacity, and enhances microbial activity. This organic matter also serves as a reservoir of nutrients, contributing to a more balanced nutrient supply for crops. The decomposition of cover crop residues contributes to the formation of soil organic matter (SOM), which is a critical component of soil health. SOM improves soil fertility by providing a slow-release source of nutrients and by forming stable aggregates that enhance soil structure. The cycling of nutrients through the cover crop biomass also aids in replenishing soil nutrients, thus reducing the dependency on synthetic fertilizers (Abdulkadir et al., 2024a; Lal, 2004; Noma and Sani 2008).

Cover crops such as rye (Secale cereale) and radish (Raphanus sativus) can also influence nutrient cycling by promoting microbial activity. The root exudates from these crops stimulate the growth of beneficial microorganisms that assist in breaking down organic matter and making nutrients more accessible to plants (Abdulkadir et al., 2024; Hargrove, 1986). This microbial activity enhances the overall nutrient cycling process, supporting sustainable agricultural practices.

Impact on Soil Carbon Sequestration

Soil carbon sequestration is another significant benefit of incorporating cover crops into maize cropping systems. Cover crops contribute to soil carbon sequestration by increasing the amount of organic carbon stored in the soil. This occurs through the addition of root biomass and crop residues, which decompose and contribute to the formation of soil organic carbon (SOC). Research has shown that cover crops can substantially increase soil carbon stocks compared to conventional cropping systems. For instance, a study by Adesoji et al. (2025) demonstrated that cover cropping practices led to an increase in SOC, particularly in the topsoil layers. This increase in SOC is beneficial for enhancing soil fertility, improving soil structure, and mitigating climate change through the reduction of atmospheric CO_2 levels.

The impact of cover crops on soil carbon sequestration is influenced by several factors, including the type of cover crop, the duration of cover cropping, and the management practices employed. Leguminous cover crops and deep-rooted species generally contribute more to soil carbon sequestration compared to shallow-rooted or non-leguminous cover crops (Koudahe et al., 2022). Furthermore, the integration of cover crops into a long-term management system can lead to cumulative increases in soil carbon stocks, promoting long-term sustainability in maize cropping systems (Adesoji et al., 2025).

Impact of Cover Crops on Soil Biological Properties

Cover crops are instrumental in enhancing soil health by positively impacting soil biological properties. These impacts are particularly significant in the context of a maize cropping system, where maintaining a healthy and biologically active soil is critical for sustainable production. This section examines how cover crops influence soil microbial diversity and activity, affect soil fauna, and contribute to disease suppression and pest management.

Effect Cover Crops on Soil Microbial Diversity and Activity

Cover crops have a profound effect on soil microbial diversity and activity, which are key indicators of soil health. The root exudates of cover crops provide a continuous supply of organic substrates that support a diverse community of soil microorganisms (Finney et al., 2017). These microorganisms play crucial roles in nutrient cycling, organic matter decomposition, and the formation of stable soil aggregates. The presence of cover crops increases microbial biomass and promotes the activity of beneficial microorganisms such as bacteria, fungi, and mycorrhizae (Tiemann et al., 2015). For instance, legumes as cover crops can enhance the population of nitrogen-fixing bacteria, leading to increased nitrogen availability for subsequent maize crops (Drinkwater and Snapp, 2007). This enhanced microbial activity not only improves soil fertility but also contributes to the suppression of soil-borne pathogens by outcompeting them for resources.

Influence Cover Crops on Soil Fauna (e.g., Earthworms, Nematodes)

Soil fauna, including earthworms and nematodes, are integral components of the soil ecosystem, and their presence is influenced by cover crops. Earthworms, often referred to as ecosystem engineers, benefit significantly from the organic matter provided by cover crops. The residue from cover crops serves as a food source for earthworms, which in turn enhances soil aeration, water infiltration, and nutrient availability through their burrowing and casting activities (Dawaki et al.,; Blouin et al., 2013). Nematodes, which include both beneficial and harmful species, are also affected by cover crops. The use of cover crops can alter the nematode community structure by increasing the populations of beneficial nematodes that prey on soil pests, while reducing populations of plant-parasitic nematodes through the production of bioactive compounds by certain cover crops (Wang et al., 2002). This balance between beneficial and harmful nematodes is crucial for maintaining a healthy soil ecosystem under a maize cropping system.

Role of Cover Crops in Disease Suppression and Pest Management

One of the key benefits of cover crops is their ability to suppress soil-borne diseases and manage pest populations, which is essential for maintaining healthy maize crops. Certain cover crops, such as brassicas, release biofumigant compounds like glucosinolates when decomposed, which have been shown to suppress pathogens and reduce the incidence of diseases like root rot and damping-off in maize (Kirkegaard et al., 1993). Additionally, cover crops can disrupt the life cycles of pests by providing alternative habitats for natural predators or by acting as trap crops that reduce pest pressure on maize (Lu et al., 2000). For example, the use of cover crops can decrease the prevalence of root-knot nematodes and other soil pests that typically affect maize, leading to healthier plants and improved yields.

Interaction Between Cover Crops and Maize

The integration of cover crops into a maize cropping system involves complex interactions that can significantly influence the performance and productivity of maize. Understanding these interactions is crucial for optimizing cover crop use to enhance soil health without compromising maize yield. This section discusses the influence of different types of cover crops on maize yield and growth, the timing of cover crop termination and its effects on maize performance, and the potential competition between cover crops and maize for essential resources such as water and nutrients.

Influence of Different Types of Cover Crops on Maize Yield and Growth

The type of cover crop used in a maize cropping system can have varying impacts on maize yield and growth. Leguminous cover crops like clover and vetch are known for their ability to fix atmospheric nitrogen, which can be subsequently used by maize, potentially reducing the need for synthetic nitrogen fertilizers (Mamman et al., 2025; Scharf et al., 2002). This nitrogen contribution often results in improved maize growth and higher yields, especially in systems where nitrogen availability is a limiting factor (Kaspar and Singer, 2011). On the other hand, non-leguminous cover crops such as rye or radish contribute to soil health by enhancing soil structure and organic matter content, which indirectly benefits maize growth (Blanco-Canqui et al., 2015). However, the choice of cover crop must be carefully considered, as some species can lead to allelopathic effects or harbor pests that may negatively impact maize. For instance, certain brassica species release bioactive compounds that can inhibit maize seed germination if not managed properly (Boydston and Hang, 1995).

Timing of Cover Crop Termination and Its Effects on Maize Performance

The timing of cover crop termination is a critical factor that affects the success of maize following cover crops. Early termination of cover crops, typically two to three weeks before maize planting, allows sufficient time for the decomposition of cover crop residues, reducing the risk of nutrient immobilization and ensuring that nutrients are readily available for the maize crop (Haramoto and Gallandt, 2005). Early termination also minimizes the competition for water and light, which is essential during the early stages of maize growth. Conversely, delaying cover crop termination closer to maize planting can maximize the biomass production of cover crops, leading to greater soil cover and organic matter input. However, this practice can also lead to increased competition for resources and potential negative effects on maize germination and early growth (Reeves, 1994). Therefore, the timing of cover crop termination must be carefully managed to balance the benefits of cover cropping with the needs of the maize crop.

Potential Competition Between Cover Crops and Maize for Resources (Water, Nutrients)

While cover crops offer numerous benefits, they can also compete with maize for essential resources, particularly water and nutrients. This competition is most pronounced when cover crops are not terminated in a timely manner or when moisture availability is limited. For example, cover crops with extensive root systems, such as cereal rye, can deplete soil moisture, making it less available for the subsequent maize crop, especially in regions prone to drought (Clark, 2007). Nutrient competition is another concern, particularly for nitrogen. While leguminous cover crops can provide nitrogen through fixation, non-leguminous cover crops may compete with maize for available nitrogen in the soil. This competition can be exacerbated if the cover crops are terminated too late, as the immobilization of nitrogen during the decomposition of high-carbon residues can reduce nitrogen availability to the maize crop, leading to potential yield reductions (Thorup-Kristensen, 2006).

Sustainability and Environmental Benefits

The integration of cover crops into a maize cropping system offers substantial sustainability and environmental benefits. Cover crops play a pivotal role in promoting sustainable agricultural practices, reducing reliance on chemical inputs, and enhancing biodiversity and ecosystem services. This section explores these contributions and their relevance to the overall soil health and productivity within a maize cropping system.

Contribution to Sustainable Agricultural Practices

Cover crops contribute significantly to the sustainability of agricultural systems by enhancing soil health, improving resource use efficiency, and reducing environmental degradation. By maintaining continuous vegetative cover on the soil surface, cover crops help prevent soil erosion, maintain soil structure, and promote water infiltration and retention, all of which are essential for sustainable farming (Fageria et al., 2005). In a maize cropping system, the use of cover crops can break the cycle of monoculture, reducing the risks associated with soil degradation and nutrient depletion. This diversification of crop rotations improves soil fertility and resilience, ensuring long-term productivity. Additionally, cover crops contribute to carbon sequestration by increasing soil organic matter content, which mitigates climate change by reducing atmospheric carbon dioxide levels (Poeplau and Don, 2015). This practice aligns with the principles of sustainable agriculture, which seek to balance productivity with environmental stewardship.

Role in Reducing Reliance on Chemical Inputs (Fertilizers, Pesticides)

One of the key environmental benefits of cover crops is their ability to reduce the reliance on chemical inputs such as synthetic fertilizers and pesticides. Leguminous cover crops, such as clover and vetch, fix atmospheric nitrogen and enrich the soil with this essential nutrient, thereby reducing the need for synthetic nitrogen fertilizers in subsequent maize crops (Drinkwater et al., 1998). This natural nitrogen contribution not only lowers input costs for farmers but also reduces the risk of nitrogen leaching into water bodies, which can cause eutrophication and other environmental problems (Tonitto et al., 2006). Moreover, cover crops can suppress weed growth, reduce pest populations, and control soil-borne diseases, thereby decreasing the need for chemical herbicides and pesticides (Hartwig and Ammon, 2002). For instance, cover crops like rye produce allelopathic compounds that inhibit weed germination, while others, such as mustard, release biofumigants that suppress nematodes and soil pathogens. These natural pests and weed management strategies reduce the environmental and health risks associated with chemical inputs, contributing to a more sustainable agricultural system.

Impact on Biodiversity and Ecosystem Services

Cover crops enhance biodiversity and provide a range of ecosystem services that are critical for the health and stability of agroecosystems. By creating diverse habitats and food sources, cover crops support a wide range of beneficial organisms, including pollinators, natural predators of pests, and soil microorganisms (Bugg and Waddington, 1994). This biodiversity not only helps in pest control but also improves the resilience of the cropping system to environmental stresses. In addition to supporting above-ground biodiversity, cover crops also enhance below-ground biodiversity by promoting a healthy and diverse soil microbial community (Cappelli et al., 2022). This increased microbial activity is crucial for nutrient cycling, soil structure formation, and disease suppression, all of which contribute to the overall health of the maize cropping system (Marzouk et al., 2024).

Furthermore, the ecosystem services provided by cover crops, such as soil erosion control, water purification, and carbon sequestration, have far-reaching environmental benefits. These services contribute to the sustainability of agricultural landscapes and help mitigate the negative impacts of intensive farming practices on the environment (Tilman et al., 2002). By fostering a more diverse and resilient ecosystem, cover crops play a vital role in maintaining the long-term sustainability of maize production systems.

Case Studies and Research Findings

The application of cover crops in maize cropping systems has been the subject of numerous studies and case analyses worldwide. This section reviews specific studies, analyzes the effects of cover crops across different climatic and soil conditions, and discusses success stories and challenges associated with implementing cover crops in maize farming systems.

Review of Specific Studies on Cover Crops in Maize Cropping Systems

Several studies have documented the positive impacts of cover crops on soil health within maize cropping systems. A study by Blanco-Canqui et al. (2015) in the U.S. Corn Belt demonstrated that cover crops such as cereal rye and hairy vetch significantly improved soil structure, organic matter content, and microbial activity, leading to better soil health and increased maize yields. Similarly, Wortman et al. (2012) observed that leguminous cover crops, including clover and peas, provided substantial nitrogen to the subsequent maize crop, reducing the need for synthetic fertilizers and enhancing overall crop performance.

In South America, research by Da Silva et al. (2014) in Brazil highlighted the benefits of cover crops like black oats and oilseed radish in no-till maize systems. These cover crops improved soil moisture retention, reduced soil compaction, and enhanced root development in maize, ultimately increasing maize yields and sustainability.

These studies underscore the versatility and effectiveness of cover crops in various maize cropping systems, particularly in enhancing soil health and crop productivity.

Comparative Analysis of Cover Crops' Effects in Different Climatic and Soil Conditions

The impact of cover crops can vary significantly depending on climatic and soil conditions. In temperate regions, like the U.S. Midwest, cover crops such as rye and clover have been shown to perform well in improving soil health and maize yields. For instance, research by Marcillo and Miguez (2017) revealed that winter cover crops in this region effectively reduced soil erosion and enhanced nitrogen availability, resulting in better maize performance.

Conversely, in tropical and subtropical regions, such as parts of Africa and South America, the effects of cover crops can be influenced by factors like temperature, rainfall, and soil type. In a study conducted in sub-Saharan Africa, Mupangwa et al. (2016) found that cover crops such as cowpea and pigeon pea were particularly effective in sandy soils with low fertility, where they helped to retain soil moisture and improve nutrient cycling, leading to better maize growth. However, in arid and semi-arid regions, the effectiveness of cover crops can be limited by water availability. Research by Abdul-Baki et al. (2001) in the Middle East demonstrated that while cover crops could improve soil organic matter, their water usage sometimes competed with the main maize crop, particularly in drought-prone areas, necessitating careful management and selection of cover crop species.

These comparative analyses highlight the importance of tailoring cover crop practices to specific environmental conditions to maximize their benefits in maize cropping systems.

Success Stories and Challenges in Implementing Cover Crops in Maize Farming

The successful implementation of cover crops in maize farming has been documented in various regions, but it also comes with challenges. In the United States, the Sustainable Agriculture Research and Education (SARE) program has promoted numerous success stories where farmers have integrated cover crops into their maize systems, resulting in improved soil health, reduced input costs, and enhanced resilience to weather extremes (CTIC, 2017). For example, in Illinois, a farmer managed to reduce soil erosion and improve maize yield by adopting a cereal rye cover crop, which also helped in weed suppression and moisture retention.

However, challenges remain, particularly in regions where farmers lack access to appropriate knowledge, resources, or suitable cover crop varieties. In some areas of sub-Saharan Africa, the adoption of cover crops in maize systems has been slow due to limited access to seeds, lack of awareness, and the initial costs associated with cover crop establishment (Ngwira et al., 2014). Additionally, there are challenges related to the timing of cover crop termination, as premature or delayed termination can either result in insufficient biomass or competition with the maize crop for water and nutrients.

In Latin America, efforts to implement cover crops in maize farming have faced issues related to land tenure and the need for immediate returns on investment, which can discourage farmers from adopting long-term soil health practices like cover cropping (Ogieriakhi and Woodward 2022). Nevertheless, where adoption has been successful, such as in parts of Brazil and Argentina, cover crops have contributed to more sustainable and productive maize farming systems.

Gaps in the Literature

While research on the influence of cover crops on soil health under maize cropping systems has been extensive, several gaps remain in the literature. The paper highlights several gaps in the literature regarding the role of cover crops in mitigating soil health degradation and challenges associated with maize monoculture. While existing studies emphasize on the potential benefits of cover crops, such as improved soil organic carbon levels, microbial biomass, and enzyme activities, several areas remain underexplored. Most studies focus on short-term impacts, leaving a need for long-term assessments of how cover crops influence soil health and maize yields over extended periods. There is limited research comparing different mixtures of cover crops versus monocultures, which could help identify the best combinations for enhancing soil health in maize systems. Research tends to be region-specific, with few studies examining the impact of cover crops across diverse climatic and soil conditions, which is crucial for broader applicability. The underlying mechanisms by which cover crops improve or alter soil health, particularly regarding biogeochemical processes, are not fully understood, pointing to a need for deeper investigations. There's a scarcity of literature on socio-economic factors affecting the adoption of cover crops in maize monoculture, highlighting the need to understand these barriers to devise effective policies and educational programs (Decker et al., 2022; Wang et al., 2023; Ablimit et al., 2022; Chavarría et al., 2016). Addressing these gaps would significantly enhance the understanding and optimization of cover crop use in maize monoculture, ultimately supporting sustainable agricultural practices.

Areas Where More Research is Needed

One significant gap in the literature is the need for more long-term studies on the cumulative effects of cover crops on soil health in maize cropping systems. Most existing studies focus on short-term benefits, such as immediate improvements in soil structure or nutrient availability (Blanco-Canqui et al., 2015). However, the long-term sustainability and potential trade-offs associated with continuous cover cropping, especially in diverse climatic conditions, remain underexplored. For instance, how different cover crop species contribute to soil carbon sequestration over decades or their long-term impact on soil microbial communities needs further investigation (Poeplau and Don, 2015). Another area where more research is needed is the interaction between cover crops and maize under varying water availability conditions. While some studies have highlighted the benefits of cover crops for soil moisture retention, the effects in water-limited environments, such as semi-arid or arid regions, are less understood (Mupangwa et al., 2016). There is a need for research that evaluates how cover crops can be optimized to balance water usage between themselves and the main maize crop, particularly in regions prone to drought.

Additionally, research on the economic viability and adoption of cover crops by smallholder farmers in developing countries is limited. Most studies have been conducted in developed regions like North America and Europe, where resources and technologies differ significantly from those in developing countries (Ngwira et al., 2014). Understanding the socio-economic barriers and incentives for cover crop adoption in low-income regions, particularly in maize-based systems, is crucial for promoting sustainable agricultural practices globally.

Contradictions or Debates in Existing Research Findings

There are several contradictions and debates within the existing literature regarding the impact of cover crops on maize yields. Some studies report positive effects, citing enhanced soil health and nutrient availability as key drivers of increased maize productivity (Wortman et al., 2012). However, other research suggests that cover crops can sometimes compete with maize for water and nutrients, particularly if not managed properly, leading to reduced yields (Abdul-Baki et al., 2001). These conflicting findings highlight the complexity of cover crop-maize interactions and the need for more nuanced research that considers factors such as cover crop species, timing of termination, and environmental conditions.

Another debate centers around the impact of cover crops on soil microbial communities. While it is generally accepted that cover crops enhance microbial diversity and activity, the specific effects on different microbial groups and their functional roles in soil processes are still unclear. Some studies suggest that cover crops primarily promote beneficial microbes, which contribute to soil health and plant growth (Blanco-Canqui et al., 2015). However, other research indicates that certain cover crops may also harbor pathogens or negatively impact beneficial soil organisms, leading to potential trade-offs (Brennan and Acosta-Martínez, 2017).

These contradictions indicate a need for more targeted research that can clarify under what conditions cover crops are most beneficial or potentially detrimental to maize systems.

Potential Implications for Future Research Directions

The gaps and contradictions identified in the literature have important implications for future research directions. There is a clear need for more long-term and context-specific studies that can provide a comprehensive understanding of the role of cover crops in maize cropping systems. Future research should prioritize:

Longitudinal studies that monitor the impact of cover crops on soil health and maize productivity over multiple growing seasons and under varying environmental conditions. This would help in understanding the sustainability of cover cropping practices in the long run.

Region-specific studies that explore the use of cover crops in diverse agro-ecological zones, particularly in under-researched areas such as sub-Saharan Africa and Southeast Asia. This research should consider local environmental conditions, available resources, and socio-economic factors influencing adoption.

Interdisciplinary approaches that combine agronomy, ecology, economics, and social sciences to address the multi-faceted challenges of implementing cover crops in maize systems. This could involve exploring the role of policy incentives, extension services, and farmer education in promoting cover crop adoption.

Research on specific interactions between cover crops and soil microbial communities, focusing on the identification of beneficial microbes and the development of cover crop management practices that enhance their activity while minimizing potential negative impacts.

By addressing these research gaps, future studies can contribute to a more comprehensive and practical understanding of the role of cover crops in sustainable maize farming systems.

Summary

This review comprehensively explores the use of cover crops as a sustainable strategy to address soil health degradation associated with maize monoculture, particularly in Nigeria. It begins by highlighting the importance of maize in food and economic security, as well as the negative consequences of continuous monoculture practices, including nutrient depletion, erosion, pest build-up, and overall decline in soil quality. The review defines soil health as a multi-dimensional concept encompassing the physical, chemical, and biological functionality of soil, and identifies key indicators such as soil organic matter, structure, fertility, and microbial activity. Cover crops are presented as a cost-effective and environmentally friendly solution to these challenges. The paper categorizes cover crops into leguminous (e.g., clover, vetch), non-leguminous (e.g., rye, radish), grasses, and brassicas, each providing distinct benefits. These include nitrogen fixation, organic matter addition, erosion control, nutrient recycling, pest suppression, and enhancement of biodiversity. The biological roles of cover crops, particularly in stimulating soil microbial and faunal activity, are emphasized as essential to restoring soil ecosystem functions. The interactions between maize and cover crops are analyzed, noting benefits like improved yields and challenges such as competition for water and nutrients when termination is mistimed. Historical and contemporary use of cover crops in Nigerian agriculture is examined, along with global case studies that demonstrate their efficacy across diverse agro-climatic zones. Gaps in existing literature are acknowledged, particularly regarding long-term effects, regional adaptability, and socioeconomic barriers to adoption. Cover crops hold great promise for reversing the negative effects of maize monoculture. The review advocates for their broader implementation and calls for policy support, farmer education, and further interdisciplinary research to enhance their adoption and effectiveness in promoting sustainable maize production.

Conclusion

The integration of cover crops into maize cropping systems offers a multifaceted solution to the pressing challenges of soil degradation, nutrient loss, pest infestations, and declining agricultural sustainability associated with monoculture practices. This review has synthesized existing knowledge on how cover crops improve soil health by enhancing its physical structure, chemical composition, and biological activity. Leguminous cover crops contribute to nitrogen fixation, while non-leguminous and brassica species support organic matter accumulation, erosion control, and pest management. These combined benefits position cover crops as a vital component of sustainable farming practices, particularly in regions like sub-Saharan Africa where maize dominates and input access is limited. The interaction between maize and cover crops can yield significant agronomic and ecological benefits, but also presents challenges if not properly managed—especially regarding timing, water availability, and resource competition. As demonstrated by case studies from diverse regions, successful implementation depends on choosing appropriate cover crop species, adapting practices to local environmental conditions, and equipping farmers with necessary knowledge and resources. Despite growing evidence of their effectiveness, several gaps remain, particularly regarding the long-term and region-specific impacts of cover cropping in maize systems. Future research should focus on evaluating economic viability, understanding microbial interactions, and promoting adoption among smallholder farmers through policy incentives and extension services.

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