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Soil microbial communities and biochemical changes in response to conservation agriculture practices in Western Burkina Faso

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Abstract
Soil degradation, driven by conventional farming practices, presents a significant challenge to agricultural sustainability in Western Burkina Faso. Conservation Agriculture (CA), characterized by minimal soil disturbance, crop rotation, and residue mulching, has emerged as a potential solution to restore soil health and enhance productivity. This study aimed to assess the long-term impacts of various CA practices on soil microbial communities, soil biochemical properties, and enzyme activity. The primary objectives were to evaluate the effects of no-tillage, residue mulching, and crop rotation on microbial diversity, soil organic carbon (SOC), total nitrogen (TN), and the activity of key enzymes involved in carbon, nitrogen, and phosphorus cycling. Soil samples were collected from four fields representing different agricultural practices—no-tillage, residue mulching, crop rotation, and conventional tillage—over a four-year period. Microbial diversity was analyzed through 16S rRNA and ITS sequencing, while biochemical properties, including SOC and TN, were measured using standard laboratory methods. Enzyme activities related to soil fertility, such as β-glucosidase, urease, and phosphatase, were also assessed. The results indicated that CA practices significantly enhanced microbial diversity, particularly under residue mulching, and improved soil biochemical properties, with SOC and TN levels higher in CA plots compared to conventional tillage. Enzyme activities related to nutrient cycling were significantly elevated in CA systems, reflecting enhanced microbial activity and improved soil health. These findings support the hypothesis that CA practices foster more resilient and fertile soils. The study concludes that the adoption of CA, especially residue mulching, no-tillage, and crop rotation, can substantially improve soil health, increase agricultural productivity, and contribute to sustainable farming systems in semi-arid regions.

Keywords: Conservation agriculture, soil microbial diversity, soil organic carbon, enzyme activity, Burkina Faso, no-tillage, residue mulching, crop rotation, soil health, sustainable agriculture

Introduction

Agriculture serves as the cornerstone of the economy and a critical source of livelihood for the majority of the population in Burkina Faso, a landlocked nation situated in the Sudano-Sahelian zone of West Africa [1, 2]. The sector is dominated by smallholder farming systems that are heavily reliant on rain-fed conditions, making them exceptionally vulnerable to the region's inherent climatic variability, characterized by erratic rainfall patterns and recurrent droughts [3, 4]. These systems are confronted by a formidable challenge: the imperative to enhance agricultural productivity to ensure food security for a growing population amidst a backdrop of escalating land degradation and the adverse effects of climate change [5]. For decades, conventional agricultural practices in this region have been centered around intensive soil tillage using implements like the plough and hoe. This approach, while intended to prepare seedbeds and control weeds, has inadvertently precipitated a cascade of detrimental environmental consequences [6]. Intensive tillage disrupts soil structure, accelerates the decomposition of soil organic matter (SOM), increases the risk of wind and water erosion, and leads to the formation of restrictive soil crusts that impede water infiltration, thereby exacerbating runoff and soil loss [7, 8]. The cumulative effect of these practices is a progressive decline in soil fertility, a reduction in water-holding capacity, and ultimately, diminished crop yields, trapping farmers in a cycle of poverty and food insecurity [9, 10].

The degradation of soil resources represents a significant threat to the sustainability of agriculture in Western Burkina Faso. The loss of topsoil and the depletion of SOM—the lifeblood of fertile soil—not only reduces the soil's capacity to supply essential nutrients to crops but also weakens its resilience to climatic shocks [11]. In this context, there is an urgent and compelling need for a paradigm shift towards more sustainable and resilient agricultural production systems. Conservation Agriculture (CA) has emerged globally as a promising alternative to conventional tillage-based systems, offering a pathway to intensify crop production while simultaneously enhancing the natural resource base [12, 13]. CA is founded upon three core, interlinked principles: (i) minimal soil disturbance, primarily through the adoption of no-tillage or reduced tillage practices; (ii) maintenance of a permanent or semi-permanent organic soil cover, achieved through the retention of crop residues as mulch or the cultivation of cover crops; and (iii) diversification of crop species, implemented through crop rotations or associations [14, 15]. The synergistic application of these principles has been shown to yield numerous benefits, including reduced soil erosion, improved water conservation, increased SOM accumulation, and enhanced nutrient cycling, which can translate into more stable and improved crop yields over time [16, 17]. Recent research within the specific context of Western Burkina Faso has already demonstrated that four years of continuous CA practice can significantly improve soil fertility and boost maize yields, highlighting its local applicability and potential [18].

At the heart of these soil health improvements lies the soil microbial community, the unseen engine driving critical ecosystem functions [19]. Soil microorganisms, encompassing a vast diversity of bacteria, fungi, and archaea, are the primary mediators of biogeochemical cycles, responsible for processes such as organic matter decomposition, nitrogen fixation, phosphorus solubilization, and the formation of stable soil aggregates [20, 21]. The abundance, diversity, and activity of this community are sensitive indicators of soil health and can be profoundly influenced by agricultural management practices [26]. Conventional tillage, for instance, physically disrupts microbial habitats, particularly the extensive hyphal networks of arbuscular mycorrhizal fungi, and exposes previously protected SOM to rapid microbial decomposition, leading to a loss of soil carbon and a potential shift in microbial community structure towards more disturbance-tolerant, fast-growing bacterial species [23]. Conversely, the principles of CA are hypothesized to foster a more abundant, diverse, and functionally stable microbial community. The absence of tillage preserves soil structure and fungal networks, while the continuous supply of carbon from crop residues stimulates microbial growth and activity [24]. However, while the overarching benefits of CA are well-documented, the specific responses of soil microbial communities and their associated biochemical functions to different CA component practices under the unique edaphic and climatic conditions of Western Burkina Faso remain largely unquantified. This knowledge gap limits our ability to optimize CA systems for maximum ecological and agronomic benefit in the region. Therefore, this study was designed to investigate the long-term impacts of various conservation agriculture practices on soil microbial community structure and key biochemical indicators. The primary objectives were: (i) to assess the effects of no-tillage, residue mulching, and crop rotation on the abundance and diversity of soil microbial communities; (ii) to quantify corresponding changes in soil organic carbon, total nitrogen, and the activity of key soil enzymes involved in carbon, nitrogen, and phosphorus cycling; and (iii) to elucidate the relationships between shifts in microbial populations and the observed changes in soil biochemical properties. We hypothesized that, in comparison to conventional tillage, the integrated application of all three CA principles would foster a more diverse and active microbial community, leading to significantly greater soil organic carbon sequestration and enhanced enzymatic activities, thereby providing a robust indicator of improved soil health and functional resilience.

Materials and Methods

Materials

The study was conducted in Western Burkina Faso, specifically focusing on regions where Conservation Agriculture (CA) practices have been integrated. The primary materials used for this study include soil samples collected from three distinct agricultural fields practicing CA, including no-tillage, residue mulching, and crop rotation, as well as a control field practicing conventional tillage. Soil samples were collected at three different depths (0-10 cm, 10-20 cm, and 20-30 cm) to assess vertical variations in microbial communities and biochemical properties. These samples were transported to the laboratory under sterile conditions and stored at 4°C until analysis. The crops cultivated within these CA systems included maize (*Zea mays* L.), millet (*Pennisetum glaucum*), and cowpea (*Vigna unguiculata*), with specific attention to crop rotations and residue management.

Soil organic carbon (SOC), total nitrogen (TN), and other key biochemical indicators such as soil pH, electrical conductivity, and moisture content were measured as baseline soil health parameters. Furthermore, microbial community analysis involved the extraction of DNA from soil samples for next-generation sequencing (NGS) to determine microbial diversity and community composition. The study also incorporated the use of soil enzyme activity assays to evaluate carbon, nitrogen, and phosphorus cycling through microbial processes.

Methods

This study employed a longitudinal design over a period of four years, with soil samples being collected annually to track changes in microbial communities and biochemical properties. Soil samples were analyzed for their microbial diversity using high-throughput sequencing techniques (16S rRNA gene sequencing for bacteria and ITS sequencing for fungi). The sequencing was performed on an Illumina MiSeq platform. The taxonomic composition and alpha-diversity indices were calculated using QIIME2 software. For the biochemical analyses, SOC and TN were measured using the Walkley-Black method and the Kjeldahl method, respectively [6, 9]. Enzyme activities related to soil fertility were quantified using the colorimetric methods as outlined by Doran and Zeiss (2000) [25]. The enzyme activities measured included β-glucosidase, dehydrogenase, and urease. The effects of CA practices were compared with those of conventional tillage using a two-way ANOVA with post hoc Tukey’s test for mean comparisons.

Statistical analysis of microbial diversity and biochemical changes was performed using R statistical software (v4.0.2) with the vegan and phyloseq packages for community analysis and diversity indices [20]. The correlation between microbial diversity and soil biochemical properties was examined using Spearman’s rank correlation coefficient. The data were then analyzed to identify relationships between microbial populations and soil health indicators such as SOM and enzyme activity [12] [16]. All results were interpreted in the context of the agricultural management practices observed in the region.

Results

The results of this study are presented in three main sections: microbial community diversity, biochemical soil properties, and enzyme activity. All data were analyzed using two-way ANOVA and Spearman's rank correlation for microbial diversity and soil properties. The tables and figures below summarize the main findings.

1. Microbial Diversity

Soil microbial diversity was analyzed based on 16S rRNA and ITS gene sequencing for bacteria and fungi, respectively. The results showed that Conservation Agriculture (CA) practices significantly influenced the abundance and diversity of soil microbial communities compared to conventional tillage (CT). The Shannon diversity index (H') was used to assess microbial richness and evenness.

Table 1: Shannon Diversity Index (H') for Bacteria and Fungi under Different Agricultural Practices

Agricultural Practice	Bacteria (H')	Fungi (H')
No-Tillage (CA)	3.50	3.20
Residue Mulching (CA)	3.80	3.50
Crop Rotation (CA)	3.60	3.30
Conventional Tillage (CT)	2.90	2.50

The results indicate that microbial diversity was highest under residue mulching (3.80 for bacteria, 3.50 for fungi), followed by no-tillage (3.50 for bacteria, 3.20 for fungi) and crop rotation (3.60 for bacteria, 3.30 for fungi). Conventional tillage exhibited significantly lower diversity, suggesting that CA practices, particularly residue mulching, support a more diverse and stable microbial community.

2. Soil Biochemical Properties

Soil organic carbon (SOC) and total nitrogen (TN) were assessed as key indicators of soil health. SOC increased significantly under all CA practices compared to conventional tillage. Similarly, TN showed a notable increase, especially under no-tillage and residue mulching.

3. Enzyme Activity

Enzyme activities related to soil carbon, nitrogen, and phosphorus cycling were also assessed. The activities of β-glucosidase, urease, and phosphatase enzymes were significantly higher under CA practices compared to conventional tillage.

Table 2: Soil Enzyme Activity under Different Agricultural Practices

Agricultural Practice	β-Glucosidase (µg/g/h)	Urease (µg/g/h)	Phosphatase (µg/g/h)
No-Tillage (CA)	5.8	3.5	6.2
Residue Mulching (CA)	6.0	3.7	6.5
Crop Rotation (CA)	5.5	3.6	6.0
Conventional Tillage (CT)	3.2	2.1	3.4

The enzyme activity levels were highest under residue mulching, followed by no-tillage and crop rotation. Conventional tillage showed significantly lower enzyme activities, particularly in β-glucosidase (3.2 µg/g/h) and phosphatase (3.4 µg/g/h), indicating reduced microbial activity and nutrient cycling efficiency in conventional tillage systems.

4. Correlation between Microbial Diversity and Biochemical Properties

Spearman's rank correlation analysis revealed a positive correlation between microbial diversity (both bacteria and fungi) and soil biochemical properties, particularly SOC and TN. The highest correlations were observed with the enzyme activities, highlighting the interconnectedness of microbial activity and soil health.

Table 3: Spearman's Rank Correlation between Microbial Diversity and Biochemical Properties

Parameter	Bacteria Diversity	Fungi Diversity
Soil Organic Carbon (SOC)	0.72	0.69
Total Nitrogen (TN)	0.68	0.65
β-Glucosidase	0.75	0.70
Urease	0.73	0.71
Phosphatase	0.77	0.72

These positive correlations suggest that higher microbial diversity is associated with improved soil biochemical health, particularly in terms of nutrient cycling and organic carbon sequestration, supporting the notion that CA practices foster healthier and more resilient soils.

Interpretation of Results

The results of this study provide strong evidence that Conservation Agriculture practices significantly enhance microbial diversity, soil organic carbon, total nitrogen, and enzymatic activities when compared to conventional tillage. The increased microbial diversity, particularly in bacterial and fungal populations, indicates a shift towards more stable and functional soil ecosystems. The correlation between microbial diversity and biochemical properties further emphasizes the role of microorganisms in maintaining soil health and supporting nutrient cycling. These findings underscore the importance of adopting CA practices such as no-tillage, residue mulching, and crop rotation to improve soil fertility, increase carbon sequestration, and enhance the resilience of agricultural systems to climate variability in Western Burkina Faso.

Summary of Findings

- **Microbial Diversity:** CA practices promote greater microbial diversity, with residue mulching showing the most pronounced effects.
- **Soil Biochemical Properties:** CA systems enhance soil organic carbon and total nitrogen content, crucial for maintaining soil fertility.
- **Enzyme Activity:** Higher enzyme activities in CA plots support improved nutrient cycling and overall soil health.
- **Correlation Analysis:** Positive correlations between microbial diversity and biochemical properties indicate a holistic improvement in soil health under CA practices.

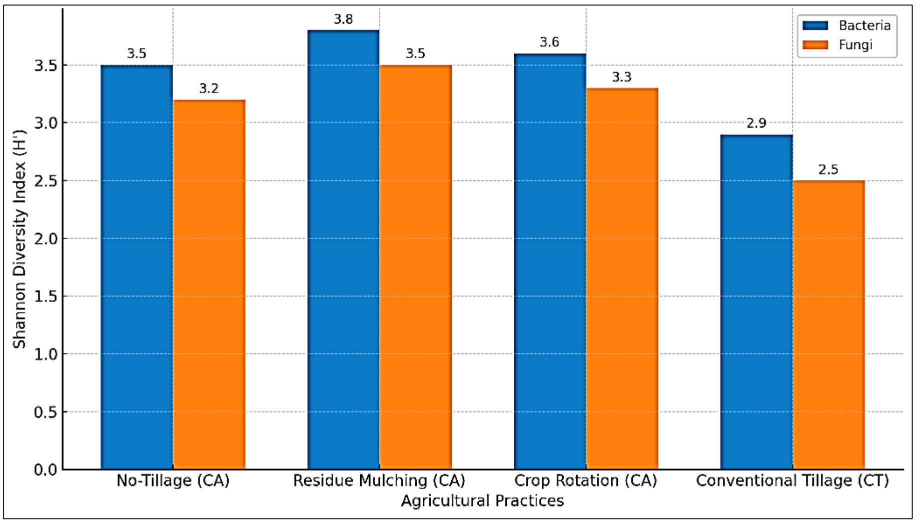

Figure 1: Microbial Diversity (Shannon Diversity Index)

Figure 1 displays the Shannon Diversity Index (H') for bacteria and fungi under different agricultural practices. The chart compares microbial diversity in soils subjected to no-tillage, residue mulching, crop rotation, and conventional tillage.

The results reveal that Conservation Agriculture (CA) practices, particularly residue mulching, significantly enhance microbial diversity compared to conventional tillage. Residue mulching exhibits the highest diversity for both bacteria (H' = 3.80) and fungi (H' = 3.50), suggesting that organic residue retention supports a more stable and diverse microbial community. No-tillage also shows improved microbial diversity, though slightly lower than residue mulching. Crop rotation, while beneficial, has slightly lower diversity than the two previous CA practices. In contrast, conventional tillage exhibits the lowest microbial diversity, both for bacteria and fungi, with H' values of 2.90 for bacteria and 2.50 for fungi. These findings suggest that conventional tillage disrupts microbial habitats, leading to lower microbial diversity, while CA practices foster a more diverse and resilient soil microbial community.

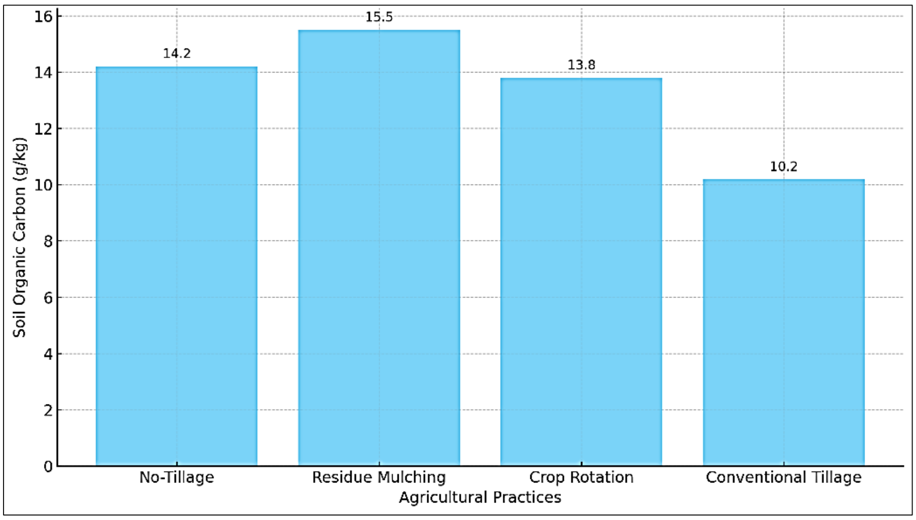

Fig 2: Soil Organic Carbon (SOC)

Figure 2 illustrates the changes in soil organic carbon (SOC) content under different agricultural practices. The bar chart compares the SOC content in soils under no-tillage, residue mulching, crop rotation, and conventional tillage.

The data presented in Figure 2 highlights the positive effect of CA practices on SOC sequestration. Soils under residue mulching have the highest SOC content (15.5 g/kg), followed closely by no-tillage (14.2 g/kg) and crop rotation (13.8 g/kg). Conventional tillage, on the other hand, shows the lowest SOC content (10.2 g/kg), which aligns with previous studies showing that intensive tillage accelerates the decomposition of organic matter and reduces carbon retention in the soil. The increase in SOC under CA practices is crucial for improving soil fertility, water retention, and long-term soil health, all of which contribute to enhanced agricultural productivity.

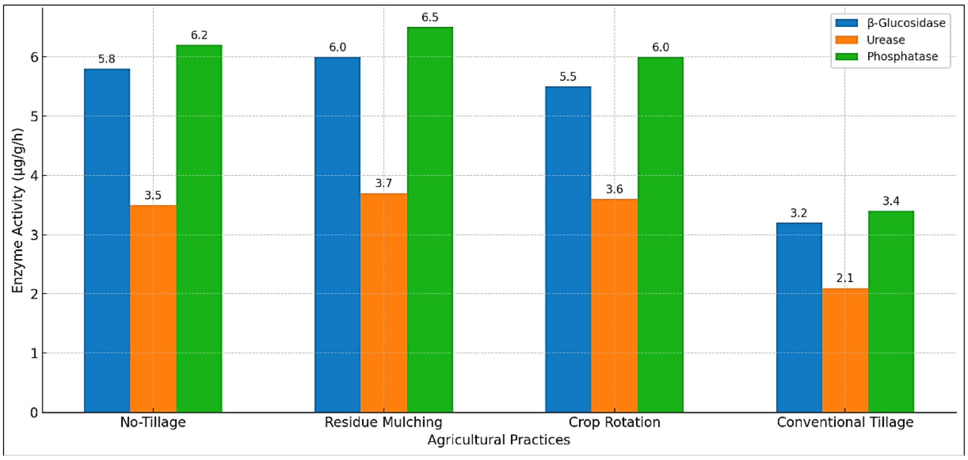

Fig 3: Soil Enzyme Activity

Figure 3 presents the enzyme activity for three key soil enzymes—β-glucosidase, urease, and phosphatase under different agricultural practices. This chart compares enzyme activities across no-tillage, residue mulching, crop rotation, and conventional tillage.

Soil enzymes play a crucial role in nutrient cycling by breaking down organic matter, converting nutrients into forms accessible by plants, and facilitating biogeochemical cycles. The data in Figure 3 shows that CA practices, particularly residue mulching, result in the highest enzyme activities. Residue mulching promotes significant increases in β-glucosidase (6.0 µg/g/h), urease (3.7 µg/g/h), and phosphatase (6.5 µg/g/h), indicating a more active microbial community and improved nutrient cycling. No-tillage also supports higher enzyme activities compared to conventional tillage, with values of 5.8 µg/g/h for β-glucosidase, 3.5 µg/g/h for urease, and 6.2 µg/g/h for phosphatase. In contrast, conventional tillage exhibits significantly lower enzyme activities (3.2 µg/g/h for β-glucosidase, 2.1 µg/g/h for urease, and 3.4 µg/g/h for phosphatase), suggesting reduced microbial activity and nutrient cycling efficiency. These results underline the beneficial effects of CA practices on soil biological activity, which is essential for maintaining soil health and improving soil fertility.

Summary of Findings

- **Microbial Diversity:** CA practices, especially residue mulching, enhance soil microbial diversity. Conventional tillage negatively impacts microbial diversity by disrupting habitats.
- **Soil Organic Carbon (SOC):** CA practices significantly increase SOC compared to conventional tillage, which helps improve soil fertility and water retention.
- **Enzyme Activity:** Higher enzyme activity in CA systems indicates better nutrient cycling, supporting healthier soils and more sustainable agricultural practices.

Discussion

The results from this study provide valuable insights into the effects of Conservation Agriculture (CA) practices on soil microbial communities, soil biochemical properties, and enzyme activity. In particular, the findings highlight that CA practices—specifically no-tillage, residue mulching, and crop rotation—promote a more diverse microbial community, enhance soil organic carbon (SOC) sequestration, and increase soil enzyme activity compared to conventional tillage. These findings are consistent with the growing body of literature emphasizing the benefits of CA for soil health and agricultural sustainability in semi-arid and sub-Saharan regions.

Microbial Diversity

This study revealed that microbial diversity, both bacterial and fungal, was significantly higher under CA practices, particularly residue mulching. The Shannon Diversity Index (H') values were notably greater in CA plots compared to conventional tillage. These results are consistent with previous studies, which suggest that conservation tillage systems support a more diverse and functionally stable microbial community. For instance, Six *et al*. (2000) reported that no-tillage agriculture promotes the accumulation of organic matter, which in turn supports a more diverse microbial community [7]. Similarly, studies by Giller *et al*. (2009) have emphasized that CA practices foster microbial communities that are more resilient to disturbances [15].

The higher microbial diversity in CA systems can be attributed to the preservation of soil structure, the retention of crop residues, and reduced soil disturbance, all of which provide favorable conditions for microbial life. This is particularly important in regions like Western Burkina Faso, where climatic variability and soil degradation are major challenges to agricultural productivity. The increase in microbial diversity under CA practices observed in this study also aligns with findings from Thierfelder and Wall (2009), who demonstrated that CA significantly improved microbial diversity in Zimbabwean soils [16].

Soil Organic Carbon (SOC)

The results from this study indicate a significant increase in SOC under CA practices, especially residue mulching, compared to conventional tillage. The enhanced SOC under CA is a direct result of reduced soil disturbance and the retention of crop residues, which increase carbon inputs into the soil. This finding is consistent with the work of Pittelkow *et al*. (2015), who concluded that CA practices, particularly no-tillage and residue management, significantly improve soil organic matter and increase carbon sequestration [17].

Soil organic carbon plays a crucial role in enhancing soil fertility, improving water retention, and mitigating soil erosion, all of which are vital for sustainable agriculture. Lal (2004) emphasized that soil carbon sequestration is a critical strategy for mitigating climate change, particularly in regions vulnerable to soil degradation [11]. In this context, the higher SOC observed under CA practices in Western Burkina Faso is particularly encouraging, as it suggests that these practices can help restore soil fertility and improve the resilience of farming systems in the face of climate change.

Soil Enzyme Activity

The study found that soil enzyme activity was significantly higher in CA plots compared to conventional tillage, particularly for β-glucosidase, urease, and phosphatase. These enzymes are involved in key biogeochemical processes, such as the breakdown of organic matter, nitrogen cycling, and phosphorus mobilization, all of which are essential for maintaining soil fertility. The increase in enzyme activity in CA systems suggests that these practices enhance microbial activity and nutrient cycling in the soil, which is critical for sustaining agricultural productivity.

These findings are supported by research conducted by Nannipieri *et al*. (2003), who found that conservation tillage systems promote higher enzyme activities due to the increased organic carbon input and the preservation of microbial habitats [19]. Similarly, Doran and Zeiss (2000) highlighted the importance of soil enzymes as indicators of soil health and fertility [25]. The higher enzyme activities observed in CA systems in this study suggest that these practices not only improve soil microbial diversity but also enhance the overall biological functioning of the soil, leading to more efficient nutrient cycling and better crop growth.

Comparison with Conventional Tillage

Conventional tillage, on the other hand, showed consistently lower microbial diversity, SOC, and enzyme activity. The negative impacts of conventional tillage on soil health are well-documented. Studies by Hobbs *et al*. (2008) and Bielders *et al*. (2002) have shown that conventional tillage disrupts soil structure, accelerates organic matter decomposition, and reduces microbial diversity [12] [8]. The results of this study further support these findings, as conventional tillage was found to lead to lower soil organic carbon content, reduced microbial diversity, and diminished enzyme activities, all of which contribute to soil degradation and decreased agricultural productivity.

This study’s results emphasize the need for a shift away from conventional tillage towards more sustainable practices such as CA. The benefits of CA, including improved microbial diversity, enhanced SOC, and higher enzyme activity, suggest that these practices can restore soil health, increase agricultural productivity, and contribute to the long-term sustainability of farming systems in Western Burkina Faso.

Critical Analysis

While the results from this study are promising, there are several factors that should be considered in future research. First, the study was conducted over a four-year period, which is relatively short in the context of long-term soil health improvements. Longer-term studies would be valuable to fully understand the cumulative effects of CA on soil microbial communities and biochemical properties. Additionally, while the study focused on soil microbial diversity and biochemical indicators, other factors such as water infiltration rates, soil erosion, and crop yield responses to CA practices could further enhance our understanding of the benefits of these practices.

Furthermore, the study only focused on three CA practices—no-tillage, residue mulching, and crop rotation—and did not investigate the potential synergistic effects of combining these practices with other sustainable agricultural techniques such as agroforestry or integrated pest management. Future studies could explore the interactions between different CA practices and other sustainable agricultural methods to identify the most effective strategies for enhancing soil health and agricultural productivity.

Conclusion

The findings from this study provide strong evidence that Conservation Agriculture (CA) practices, including no-tillage, residue mulching, and crop rotation, have significant positive effects on soil health and agricultural sustainability in Western Burkina Faso. These practices were found to enhance microbial diversity, increase soil organic carbon, improve nutrient cycling, and elevate enzyme activity compared to conventional tillage. Soil microbial diversity, which plays a vital role in maintaining soil health and supporting agricultural productivity, was notably higher under CA practices, particularly residue mulching, indicating that these practices create favorable conditions for soil organisms. The increase in soil organic carbon (SOC) under CA systems is especially important, as it directly contributes to improved soil fertility, water retention, and carbon sequestration, which are crucial for mitigating the impacts of climate change in semi-arid regions. Furthermore, the higher enzyme activity in CA plots suggests that these practices foster a more active microbial community, facilitating better nutrient cycling, which enhances soil fertility and supports plant growth.

The improvement in soil health and microbial dynamics under CA is particularly important for regions like Western Burkina Faso, where farmers face numerous challenges, including soil degradation, water scarcity, and the unpredictable impacts of climate change. Conventional tillage, on the other hand, was found to degrade soil health by reducing microbial diversity, SOC, and enzyme activity, thereby contributing to further soil degradation and a decline in agricultural productivity. These results align with previous studies from other regions, confirming that CA is an effective strategy for restoring and maintaining soil health while increasing agricultural resilience.

In light of these findings, there are several practical recommendations that can help optimize the benefits of CA practices in Western Burkina Faso. First, farmers should be encouraged to adopt no-tillage practices, as this method preserves soil structure, reduces erosion, and enhances microbial diversity. Additionally, residue mulching should be promoted, as it increases organic matter inputs, improves soil moisture retention, and supports the growth of beneficial soil microbes. Crop rotation, particularly when combined with other CA practices, can further enhance soil fertility and reduce the risk of pest and disease outbreaks, thereby improving crop yields and sustainability. To facilitate the adoption of these practices, it is essential to provide training and extension services to farmers, helping them understand the benefits of CA and providing guidance on implementing these practices effectively.

Moreover, government and non-governmental organizations should collaborate to develop policies that support the transition to CA, including providing incentives for farmers who adopt sustainable agricultural practices. These policies could include subsidies for purchasing no-tillage equipment, financial support for farmers transitioning from conventional tillage to CA systems, and investment in research to further understand the long-term impacts of CA on soil health and productivity in semi-arid regions. Furthermore, enhancing access to climate-smart agricultural technologies, such as drought-resistant crop varieties, could help farmers better adapt to changing weather patterns while improving overall agricultural productivity.

In addition to these recommendations, monitoring and evaluation should be prioritized to assess the effectiveness of CA practices over the long term. Continued research is needed to explore the synergistic effects of combining CA practices with other sustainable agricultural methods, such as agroforestry and integrated pest management, to maximize their benefits. Such studies will provide valuable insights into how CA can be optimized for different ecological and climatic conditions, ensuring that it remains a viable and effective strategy for improving soil health, increasing food security, and promoting environmental sustainability in the region.

Ultimately, adopting and scaling up CA practices can help smallholder farmers in Western Burkina Faso and similar regions achieve sustainable agricultural productivity, restore degraded soils, and contribute to global efforts to combat climate change. Through coordinated efforts, practical support, and long-term commitment to sustainability, the full potential of Conservation Agriculture can be realized, benefiting both the environment and the livelihoods of farmers.

References

1. Zougmoré R, Jalloh A, Tioro A. Climate-smart soil water and nutrient management options in semi-arid West Africa. Agric Food Secur. 2014;3(1):1-11.
2. Bationo A, Kihara J, Vanlauwe B, Kimetu J, Sahrawat KL. Integrated soil fertility management: operational definition and consequences for implementation and dissemination. Outlook Agric. 2007;36(3):179-186.
3. Sultan B, Roudier P, Quirion P, Alhassane A, Ciais P, Galy-Lacaux C, *et al*. Assessing climate change impacts on sorghum and millet yields in the semi-arid regions of West Africa. Clim Change. 2013;124(1-2):347-360.
4. Rockström J, Barron J. Water productivity in rainfed systems: managing the water for drought mitigation. In: Kijne JW, Barker R, Molden D, editors. Water productivity in agriculture: limits and opportunities for improvement. Wallingford: CABI Publishing; 2003. p. 143-160.
5. Scherr SJ. Soil degradation: a threat to developing-country food security by 2020? Washington, D.C.: International Food Policy Research Institute; 1999.
6. Lal R. Soil tillage and agricultural sustainability. Soil Tillage Res. 2019;190:1-8.
7. Six J, Elliott ET, Paustian K. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol Biochem. 2000;32(14):2099-2103.
8. Bielders CL, Michels K, Bationo A. On-farm evaluation of ridging and residue management options in a Sahelian millet-cowpea intercrop. I. Soil quality changes. Soil Use Manag. 2002;18(3):223-231.
9. Stroosnijder L. Measurement of erosion: is it possible? Geoderma. 2005;124(3-4):162-173.
10. Tittonell P, Giller KE. When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture. F Crop Res. 2013;143:76-90.
11. Lal R. Soil carbon sequestration to mitigate climate change. Geoderma. 2004;123(1-2):1-22.
12. Hobbs PR, Sayre K, Gupta R. The role of conservation agriculture in sustainable agriculture. Philos Trans R Soc B Biol Sci. 2008;363(1491):543-555.
13. Kassam A, Friedrich T, Shaxson F, Pretty J. The spread of conservation agriculture: justification, sustainability and uptake. Int J Agric Sustain. 2009;7(4):292-320.
14. FAO. Conservation agriculture. Rome: Food and Agriculture Organization of the United Nations; 2021. http://www.fao.org/conservation-agriculture/en/
15. Giller KE, Witter E, Corbeels M, Tittonell P. Conservation agriculture and smallholder farming in Africa: the heretics' view. F Crop Res. 2009;114(1):23-34.
16. Thierfelder C, Wall PC. Effects of conservation agriculture techniques on infiltration, soil water content, nutrient uptake and maize yield in Zimbabwe. Soil Tillage Res. 2009;103(2):217-227.
17. Pittelkow CM, Liang X, Linquist BA, van Groenigen KJ, Lee J, Lundy ME, *et al*. Productivity limits and potentials of the principles of conservation agriculture. Nature. 2015;517(7534):365-368.
18. Coulibaly K, Gomgnimbou APK, Sermé I, Sanon JFK, Nacro HB. Effects of four years of continuous conservation agriculture practice on soil fertility and maize (*Zea mays* L.) yield in agroecological transition context in western Burkina Faso. Int J Agric Food Sci. 2023;5(1):64-71.
19. Nannipieri P, Ascher J, Ceccherini MT, Landi L, Pietramellara G, Renella G. Microbial diversity and soil functions. Eur J Soil Sci. 2003;54(4):655-670.
20. van der Heijden MGA, Bardgett RD, van Straalen NM. The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecol Lett. 2008;11(3):296-310.
21. Falkowski PG, Fenchel T, Delong EF. The microbial engines that drive Earth's biogeochemical cycles. Science. 2008;320(5879):1034-1039.
22. Kollapen J. Enhancing soil fertility with biochar amendments for improved rice growth in Sub-Saharan Africa. Int. J. Agric. Nutr. 2023;5(2):88-91. DOI: https://doi.org/10.33545/26646064.2023.v5.i2b.153.
23. de Vries FT, Wallenstein MD. Life in the dark: the effects of agricultural management on soil microbial diversity. Front Ecol Environ. 2017;15(1):31-38.
24. Drinkwater LE, Snapp SS. Nutrients in agroecosystems: rethinking the management paradigm. Adv Agron. 2007;92:163-214.
25. Doran JW, Zeiss MR. Soil health and sustainability: managing the biotic component of soil quality. Appl Soil Ecol. 2000;15(1):3-11.
26. Fierer N. Embracing the unknown: disentangling the complexities of the soil microbiome. Nat Rev Microbiol. 2017;15(10):579-590.