

The role of conservation agriculture in enhancing biodiversity and common beans productivity

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ARTICLE INFO

Keywords:

Conservation agriculture
Biodiversity conservation
Nutrient cycling
Beans productivity
Tanzania

ABSTRACT

Conservation of biodiversity in agricultural landscapes is vital for maintaining ecosystem stability and resilience. Conservation agriculture, a sustainable farming approach that involves minimum tillage and reduced use of synthetic pesticides, herbicides, and growth promoters, has gained attention as a potential strategy to enhance biodiversity and reduce production costs. This study investigated the role of conservation agriculture in enhancing biodiversity and common bean productivity in Tanzania. The study compared plots practicing conservation agriculture (minimum tillage and reduced agrochemical use) with those using conventional farming methods. Biodiversity metrics, that is, earthworm populations, bird species richness, bird nest abundance, bird species diversity, bee visitation rates, and bean yield were assessed. The results showed significant positive effects of conservation agriculture on biodiversity, emphasizing its potential role in promoting sustainable agriculture, biodiversity conservation, and household improvement due to reduced production costs and increased yield per unit area. Earthworms per meter square observed to increase from 12 in the non-conservation plots to 34 in the conservation plots, which is likely to improve nutrient cycling and productivity. Furthermore, conservation plots had a higher number of bird species flying around (36–76) compared with 14–32 in non-conservation plots (4000 m²) at 50 % bean flowering. The number of bird nests observed in the two plots during bean harvesting varied significantly ($P < 0.05$), where the number of bird nests observed in 4000 m² of non-conservation plots ranged from 14 to 36, compared to 12–62 in conservation plots. High bird nest numbers in conservation plots indicated higher bird habitat quality in conservation plots than in non-conservation plots. Bees as chief pollinators, bees visiting conservation plots during 50 % flowering per square meter ranged from 5 to 11, compared to 2–6 in non-conservation plots. Bee visitation to bean flowers has a significant influence on productivity, as it influences pollen transfer and fertilization. Common beans yield among plots ranged 0.9 tons/ha to 1.4 tons/ha in conservation plots compared to 0.35–1.01 tons/ha, in non-conservation plots. Land use conservation contributes considerably to economic growth through increased productivity and reduced production costs, where the production cost is reduced by 50 % in conservation plots compared with non-conservation plots. However, the present study was conducted in a single location with smallholder farmers; hence, further experiments over larger areas and longer time periods are needed for a more robust conclusion.

1. Introduction

Biodiversity conservation is fundamental to maintaining ecological balance and supporting ecosystem services in agricultural landscapes (Grass et al., 2019; Kumar et al., 2021; Landis, 2017; Smith and Sullivan,

2014; Swift et al., 2004; Wu, 2013). Unsustainable farming practices such as intensive tillage and heavy agrochemical use can degrade biodiversity and harm the environment (Landis, 2017; Smith and Sullivan, 2014; Wu, 2013). In most tropical areas with higher land degradation and soil fertility decline, farmers intensively use the same area

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<https://doi.org/10.1016/j.soilad.2024.100018>

Received 18 February 2024; Received in revised form 9 August 2024; Accepted 6 September 2024

Available online 12 September 2024

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with heavy agrochemical use. Conservation agriculture, on the other hand, is recognized for its potential to mitigate these negative impacts and promote biodiversity conservation to maximize crop production. It involves a combination of minimum tillage, residue retention, and reduced use of synthetic pesticides and fertilizers (Bhan and Behera, 2014; Francaviglia et al., 2023; Mutuku et al., 2020). For instance, to minimize soil disturbance, conservation agriculture helps maintain the soil structure and reduces the risk of soil erosion. Furthermore, retention of crop residues on the soil surface enhances the retention of soil moisture and organic matter, thereby fostering healthier ecosystems for soil microorganisms that benefit both farmers and the environment (Dormaar and Carefoot, 1996). This study aimed to assess the biodiversity impacts of conservation agriculture in bean-growing areas of Uyole, Tanzania, focusing on earthworm populations, bird communities, bee visitation, and bean yield as indicators of biodiversity, as this area is less studied and explored in African agro-ecosystems.

One of the key aspects of biodiversity in agricultural systems is the presence and abundance of soil macro-organisms, particularly earthworms. Earthworms play a vital role in soil nutrient cycling and organic matter decomposition (Vidal et al., 2023). In this study, we investigated the effects of conservation agriculture on earthworm populations in bean-growing areas. Where comparison of earthworm counts between plots practicing conservation agriculture and those using conventional farming methods were conducted, the potential impacts of this sustainable approach on soil health and nutrient cycling were explored.

Bird communities are essential components of agricultural biodiversity as they contribute to pest control and pollination services. The presence of diverse bird species in farmlands helps to keep insect populations in check, reducing the need for chemical pesticides (Mayne et al., 2023a, 2023b; Tanalgo et al., 2015). Additionally, some bird species act as pollinators for crops, ensuring successful fertilization and fruit development (Bhan and Behera, 2014). The study focused on bird species richness and abundance in the bean-growing areas of Uyole under conservation agriculture and conventional farming systems. The influence of conservation agriculture on bird communities and, consequently, their ecosystem services in the agricultural landscape were assessed by comparing the number and diversity of bird species between the two types of plots. Bees, as the chief pollinators, also play a critical role in agricultural biodiversity and productivity (Ojija and Leweri, 2023). Bee pollination is essential for many crops, including beans (Ojija et al., 2023). They transfer pollen between flowers, leading to successful fertilization and fruit set (Khalifa et al., 2021). However, the widespread use of chemical pesticides in conventional farming can negatively affect bee populations (Kumar et al., 2021; Mayne et al., 2023b; Mutuku et al., 2020; Swift et al., 2004). Understanding how conservation agriculture affects bee populations and their activities in the field can shed light on its potential contribution to sustainable crop production. In this study, the bee visitation rates to bean flowers in conservation agriculture and conventional farming plots were investigated. To ensure farming and sustainability, bean yield was examined as an indicator of the overall impact of conservation agriculture on productivity. An assessment of whether sustainable practices can maintain or even improve crop productivity while conserving biodiversity is essential, and the present study compared the yields from conservation agriculture plots to those from conventional farming plots. Therefore, the present study explored conservation agriculture potential to promote biodiversity conservation which has implication on beans crop productivity in farming areas. Earthworm populations, bird communities, bee visitations, and bean yields were used to examine the complex interactions between sustainable farming practices and biodiversity. The findings provide valuable insights for farmers, policymakers, and conservationists in the pursuit of sustainable agricultural systems that balance food production with environmental protection, contributing to the adoption of biodiversity-friendly agricultural practices to safeguard ecosystems and support sustainable and safe food production.

2. Materials and methods

2.1. Study site and duration

The research was conducted on smallholder farmers' farms at the Uyole Agricultural Research Institute farm (8.914050–8.910257 S, 33.528093–33.528212 E), located in the Mbeya region, in the Southern Highland Tanzania. The area experiences a bimodal rainfall pattern, with long rains from February to May and short rains from October to December. The region has an average annual temperature of 18–22°C due to its temperate climate, which is influenced by its elevation. Common soil types in this area include volcanic and clay soils. Data collection was conducted on smallholder farmers' plots for five months (from March to July 2023), where beans were cultivated as the primary crop.

2.2. Experimental design

A comparative approach was adopted, where two groups of plots were studied: one practicing conservation agriculture, in which the treatment groups involved were reduced tillage and reduced synthetic pesticide and herbicide application, and the other using conventional farming methods. The study was conducted in six (6) plots (4000 m² each, 50 × 80 m) from March to July 2023.

2.3. Data collection

Biodiversity studies can comprise a collection of various data metrics. However, in the present pilot study, only selected biodiversity parameters were collected because of the short study period. The data collection spanned a five-month period (March to July 2023), covering different stages of the bean growth cycle and biodiversity indicators.

- a) **Earthworm population:** However, soil biodiversity can be determined by various soil parameters, and in the present study, earthworm counts were conducted by sampling in a unit square meter of soil in both treatment and control plots, whereby the one meter × one meter quadrant was demarcated and the soil was opened up to a depth of 30 cm, and the dug soil was spread in the plastic mat and the earthworms were collected. The number of earthworms per square meter was recorded (Mcinga et al., 2021).
- b) **Bird species richness and abundance:** Bird counts were conducted within a 4000 square meter area (one-acre farm plot) during the 50 % flowering stage of beans by virtual observation for a period of three days. The number of bird species and abundance of individual birds were documented.
- c) **Bird nest abundance:** Bird nests were counted in both types of plots during beans harvesting to assess nesting habitat availability. As beans were being harvested by hands, all found bird nest were counted and documented as indicator of bird nest abundance in the study plots.
- d) **Bird species diversity:** In this pilot study, virtual observations were used to estimate bird diversity in the study area, where bird species were not classified by name but by observable distinctive features, such as color, size, and shape, to determine overall species diversity (Gibru and Biru, 2022).
- e) **Bee visitation rates:** Bee counts visiting bean flowers were recorded per square meter during the 50 % flowering stage to understand pollinator activity for three days and the estimated bee visitation was documented.
- f) **Bean yield:** Bean yields were measured in both the treatment and control plots at the end of the growing season to assess the productivity of the different farming practices. Despite the fact that various bean varieties were grown across the study area, their growth potential was not significantly different; thus, any observed changes in yield are likely to be influenced by management practices.

2.4. Data processing and analyses

All collected data were analyzed using Jamovi 1.2.25, and all plots were generated using Minitab 14. Analysis of variance and Tukey's post hoc analysis were conducted to determine the differences between sampling points and farming practices ($P < 0.05$).

3. Results and discussion

The present study on conservation agriculture observed a significant ($P < 0.05$) effect on biodiversity in the studied area. The study found significant differences in the studied biodiversity parameters between the conservation and non-conservation plots. Where conservation plots observed to have better biodiversity parameters than the non-conservation plots shown in Table 1 and subsequent discussion subsections.

3.1. Earthworm population

Conservation plots exhibited significantly ($P < 0.01$) higher earthworm populations, with an average of 34 earthworms per meter square, compared to non-conservation plots, with an average of 12 earthworms per square meter (Fig. 1). This three-fold increase in earthworm abundance in conservation plots indicates enhanced soil health and nutrient cycling, which positively influence crop productivity (Ratsiatosika et al., 2024; Swift et al., 2004; Tondoh et al., 2015; Vidal et al., 2023). Number of earthworms determined in conservation and non-conservation plots per square meter (counts/m²), were observed to be lower than FAO minimum recommended number earthworms per meter square on health soils (Fig. 1) (Kamota et al., 2012). These findings underscore the positive impacts of conservation agriculture on biodiversity conservation in the Uyole bean-growing areas. The increased earthworm populations in conservation plots suggest improved soil health, which enhances nutrient availability for crops has been reported by other researchers (Ratsiatosika et al., 2021; Tondoh et al., 2015).

3.2. Bird species richness and abundance

Conservation plots supported a higher number of bird species, with 36–76 birds observed in the 4000 square meter area, compared to only 14–34 birds in non-conservation plots. The higher bird abundance in conservation plots suggests improved habitat quality and availability of food resources, which can lead to better pest control and ecosystem functioning (de Montaignu and Goulson, 2023). Higher bird species richness, abundance, and nest numbers in conservation plots indicate better habitat conditions, promoting natural pest control and pollination services (Duckworth and Altwegg, 2018; Keten et al., 2020; Silva et al., 2015). Farms with increased bird movement have been reported to have reduced insect pest infestations, as birds usually feed on bad micro- and macro-organisms, which could otherwise result in significant pest

Table 1
Influence of farming system on biodiversity parameters studied among conservation and non-conservation plots.

Parameter	Tillage method	Mean	SD	P-Value	Minimum	Maximum
Bird counts (Per 4000 m ²)	Conservation plots	40.75a	24.78	$P=0.36$	18.00	76.00
	Non-conservation plots	27.50a	9.98		14.00	36.00
Bird nest counts (Per 4000 m ²)	Conservation plots	36.75a	19.00	$P=0.917$	16.00	62.00
	Non-conservation plots	35.25a	20.06		14.00	62.00
Bird diversity	Conservation plots	7.50a	5.20	$P=0.273$	3.00	12.00
	Non-conservation plots	4.00a	1.16		3.00	5.00
Bee visitation (Per m ²)	Conservation plots	6.25a	3.20	$P=0.03$	4.00	11.00
	Non-conservation plots	4.50b	1.92		2.00	6.00
Bean Yield (ton/ha)	Conservation plots	0.98a	0.33	$P=0.391$	0.60	1.40
	Non-conservation plots	0.77a	0.31		0.35	1.01
Earthworm counts (Per m ²)	Conservation plots	30.75a	2.50	$P=0.001$	28.00	34.00
	Non-conservation plots	14.50b	3.00		12.00	18.00

Mean values with the same lower-case letters in the column are not statistically significant different at $P < 0.05$ level of significance.

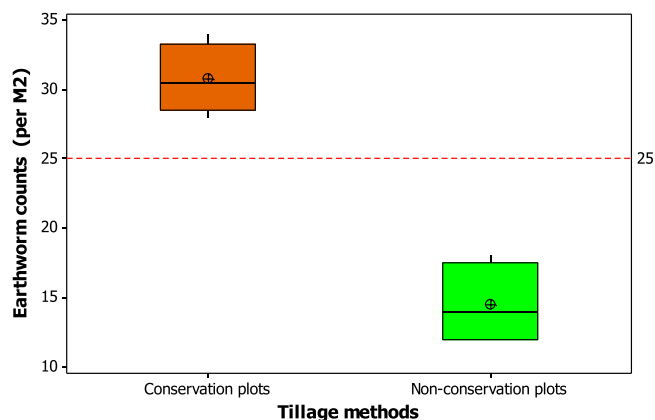


Fig. 1. : Box plot showing the effect of tillage method on earthworm abundance in conservation and non-conservation plots per square meter (counts/m²). The dotted line is the FAO minimum recommended number of earthworms per square meter of healthy soil. Where the non-conservation plots observed to have earthworm counts below 25.

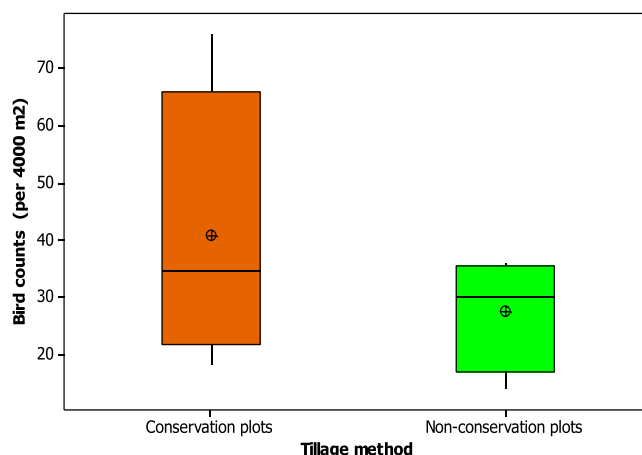


Fig. 2. : The effect of tillage method on bird abundance (number of birds counted among studied plots: the bird counting was conducted in 4000 m² farmer plots).

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3.3. Bird nest abundance

It was observed that conservation plots had a higher number of bird nests, ranging from 12 to 62 nests in the 4000 square meter area, compared to 14–36 nests in non-conservation plots (Fig. 3); however,

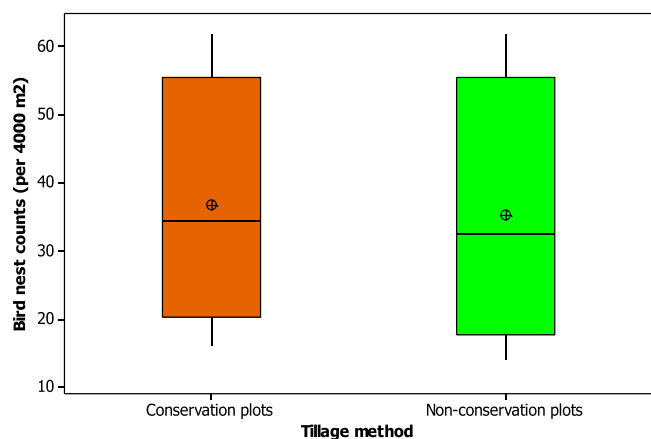


Fig. 3. : The abundance of bird nests varying with the tillage method, number of birds nest among studied plots, the bird nest counting was conducted in 4000 m² farmers plots during harvesting.

they were not significantly different between the two farming practices ($P>0.05$) (Table 1). The presence of more bird nests in conservation plots indicates a favorable nesting environment, further supporting the notion of improved habitat quality under conservation agriculture (de Montaignu and Goulson, 2023). The higher bird species richness, abundance, and nest numbers in conservation plots indicate better habitat conditions, promoting natural pest control and pollination services (Duckworth and Altwegg, 2018; Keten et al., 2020; Silva et al., 2015). These results suggest that conservation agriculture can play a vital role in fostering biodiversity conservation while maintaining or even improving crop productivity (Swift et al., 2004; Tanalgo et al., 2015; Vidal et al., 2023).

3.4. Bird species diversity

While in the present study, bird species were not classified by specific names, the observable features showed greater variability in bird species in conservation plots (3–12 species) compared to non-conservation plots (3–5 species, Fig. 4). This suggests that conservation agriculture may promote a more diverse bird community, which is beneficial for ecosystem resilience and function. Higher bird species in conservation plots may indicate better habitat conditions, promoting natural pest control and pollination services (de Montaignu and Goulson, 2023; Keten et al., 2020).

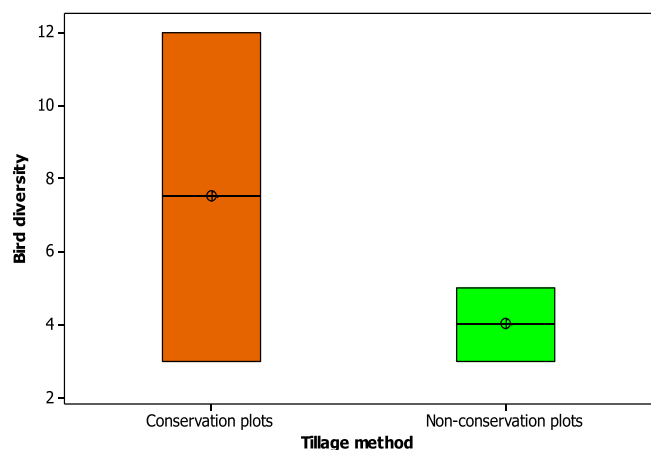


Fig. 4. : Number of bird species counted among the studied plots: bird species counting was conducted in 4000 m² farmer plots during the 50 % bean flowering stage.

3.5. Bee visitation rates

The present study observed that conservation plots attracted more bees during bean flowering, with visitation rates ranging from 5 to 11 bees per square meter, whereas non-conservation plots only had two to six bees per square meter (Fig. 5). Increased bee visitation in conservation plots indicates improved pollination services, which positively impacts crop yield and productivity (Khalifa et al., 2021). Increased bee visitation in conservation plots contributes to improved crop pollination, ultimately leading to higher bean yield. Therefore, conservation agriculture can help conserve biodiversity and improve crop productivity.

3.6. Bean yield

The bean yields in conservation plots were significantly higher, ranging from 0.9 to 1.4 tons/ hectare, compared to 0.35–1.01 tons/ hectare in non-conservation plots (Table 1, Fig. 6). The observed higher yields in the conservation plots can be attributed to the positive effects of enhanced nutrient cycling and improved soil moisture retention. Increased bee visitation in conservation plots contributes to improved crop pollination, ultimately leading to higher bean yields (Kinyua et al., 2023; Ratsiatosika et al., 2024; Tondoh et al., 2015). But also increase bird movement in conservation plots likely to influence common bean yields as has reduced insect pest infestations compared to non-conservation plots. Furthermore, higher bean yield will increase farmers' incomes and boost productions as well as increase in income through increased prices for farmers' living standards as they will be able to meet basic needs. The quantity increase in production will partly address the food insecurity problems through direct consumption and selling the excess to buy other desired foods.

4. Conclusion and recommendation

The present study highlighted the positive contribution of conservation agriculture (CA) on biodiversity in beans growing areas of Uyoale, Tanzania. The observed increases in earthworm populations, bird species richness, nest abundance, bird species diversity, bee visitation rates, and bean yields indicate that, CA can be an effective strategy for promoting sustainable farming practices to biodiversity in farming areas. However, it is essential to acknowledge the limitations of this study that it was conducted in a single location and involved smallholder farmers over a relatively short period of time. To strengthen these findings, we recommend conducting further

experiments over wider geographical areas and longer periods to provide more robust evidence of CA on biodiversity conservation since CA can be a crucial step towards achieving a balance between

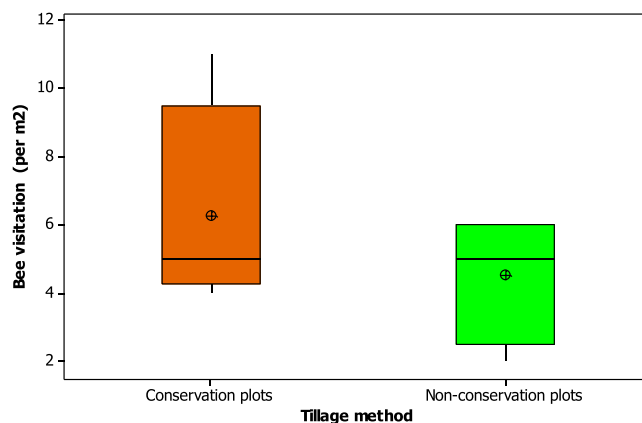


Fig. 5. : Number of bee visitations counted among the studied plots during the 50 % bean flowering stage in the conservation and non-conservation plots.

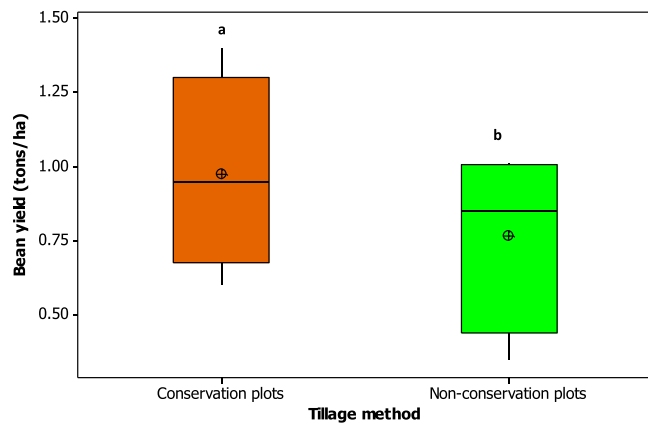


Fig. 6. : Bean yield among the studied plots, where appreciable yield variability was observed among conservation and non-conservation plots.

agricultural productivity and biodiversity conservation in farming landscapes, but also we suggest consideration of other parameters of biodiversity in addition to birds, bees and earthworms need to be considered, considering biodiversity three levels of diversity: species, genetic, and ecosystem.

CRediT authorship contribution statement

Marco Mng'ong'o: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Rehema Mwaipopo:** Writing – review & editing, Writing – original draft. **Frederick Ojija:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation. **Hadija Matimbwa:** Writing – review & editing, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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