Asian Journal of Environment & Ecology

Volume 23, Issue 9, Page 121-134, 2024; Article no.AJEE.122253
ISSN: 2456-690X

A Comparative Assessment of Soil Biodiversity and Physicochemical Characteristics in Conservation and Conventional Smallholder Farms in Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ajee/2024/v23i9603

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/122253

Original Research Article

Received: 25/06/2024
Accepted: 31/08/2024
Published: 07/09/2024

ABSTRACT

Agricultural soil is essential for sustainable crop production. However, distinct farming practices poses varying impacts on soil biodiversity and the physicochemical characteristics of the soil. Conflicting information exists about the effects of conservation and conventional farming practices

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Cite as: *Syokau, Benjamin Muteti, Cynthia N. Mugo Mwenda, Erastus S K. Mwangi, and John Mworia. 2024. "A Comparative Assessment of Soil Biodiversity and Physicochemical Characteristics in Conservation and Conventional Smallholder Farms in Kenya". Asian Journal of Environment & Ecology 23 (9):121-34. https://journalajee.com/index.php/AJEE/article/view/603.*

on soil health. This study assessed soil biodiversity and physicochemical properties of soils in 20 conservation and 20 conventional smallholder farms in Meru, Tharaka Nithi, Kirinyaga, and Laikipia counties in Kenya. The sampling was done twice during the dry and wet seasons, in the months of July and November 2023, respectively. Ten Soil samples from the smallholder farms was collected at 0 to 30 cm depth. Plot quadrats in combination with transect line sampling design were applied in all farms. Pitfall traps and heat extraction were used to extract earthworms, termites, and ants from the soil. Soil organisms' species richness and organisms' diversity were analyzed using Margalef's Diversity Index and Shannon's Index of Diversity, respectively. Different analytical techniques were used to determine the soil's physicochemical properties. One-way ANOVA was used to determine the significant differences between the two farming systems in the counties. The percentage of carbon, phosphorus, potassium, and pH values showed a significance difference between the conservation and conventional farms studied, while no significant difference was observed in the percentage nitrogen. A total of 5947 soil organisms were recorded in all the farms in the four counties. Out of the total soil organisms encountered 83.6% and 16.4% was recorded for conservation and conventional farms respectively. The results of soil organisms on Shannon's Index of Diversity, Shannon's Evenness Index, and Species Richness Diversity Index showed no significant differences, except for the species abundance which was significantly higher in conservation farms than conventional farms. In conclusion, conservation farms showed higher soil biodiversity and nutrient-rich soils than conventional farms. These findings imply that conservation farming methods create favorable conditions that promote the growth of soil organisms.

Keywords: Soil biodiversity; conservation farming; conventional farming; physico-chemical properties; smallholder farms.

1. INTRODUCTION

Agriculture remains a cornerstone in SSA countries economy such as Kenya, with smallholder farms playing a vital role in food production and rural livelihoods [1, 2]. However, the sustainability of these agricultural systems is increasingly threatened by practices that degrade soil health and reduce biodiversity [3]. Recently, according to FAO, [4]. poor agricultural methods such as conventional farming have resulted in decreased food production, endangering the lives of 2.7 million people in Kenya alone and more than 200 million people in SSA countries. To address these issues, there is a need for sustainable agricultural practices that prioritize soil health, water conservation, and resilience to climate change. This includes the use of agroecological practices such as crop diversification, conservation agriculture, and the use of drought-resistant crops [5,6].

Conventional farming methods, characterized by monocropping, intensive tillage, and the widespread use of synthetic fertilizers and pesticides, have been linked to declines in soil biodiversity and the deterioration of soil physicochemical properties. These changes not only affect crop yields but also undermine the long-term sustainability of agricultural ecosystems. In response to these challenges, conservation farming practices have gained attention for their potential to promote sustainable agriculture by enhancing soil health, conserving water, and fostering biodiversity [7 8]. Key practices include no-till farming, cover cropping, crop rotation, and agroforestry. No-till farming preserves soil structure and reduces erosion, which benefits soil microorganisms and invertebrates, thereby enhancing soil biodiversity [3,9]. Physiochemically, it improves soil organic matter and water infiltration. Cover cropping involves planting cover crops during off-seasons, providing habitats for various insects, birds, and soil organisms, thus increasing plant diversity. This method reduces soil erosion, improves soil structure, enhances nutrient cycling, and increases soil organic matter. Crop rotation prevents the buildup of pests and diseases, supports diverse soil biota, and promotes varied plant species, improving soil fertility and structure while reducing erosion [10]. Agroforestry, integrating trees and shrubs into agricultural systems, increases habitat complexity, supports diverse wildlife, and enhances ecosystem services, leading to improved soil fertility, reduced erosion, better water retention, and moderated microclimates. Despite the documented benefits, the adoption of conservation farming among smallholder farmers in Kenya remains limited, often due to economic constraints, lack of knowledge, and perceived risks of reduced yields during the transition period [11].

Soil physiochemical properties, which include aspects like soil structure, pH, organic matter content, nutrient availability, and water retention, are critical for agricultural productivity and environmental health [4]. Research indicates that conventional farming practices, such as intensive tillage and the use of synthetic fertilizers, often degrade these properties by causing soil erosion, compaction, and nutrient imbalances. According to Lal (2004), intensive tillage disrupts soil structure and reduces organic matter, leading to decreased soil fertility and increased carbon emissions (Paul 2019). In contrast, conservation farming methods, such as no-till farming and cover cropping, have been shown to improve soil physiochemical properties. For instance, Blanco-Canqui and Lal (2008) found that no-till farming enhances soil structure and increases organic matter content, while cover crops can enhance nutrient cycling and improve soil water retention. These sustainable practices help maintain soil health, which is essential for long-term agricultural productivity and ecosystem resilience.

Agricultural biodiversity describes the situation of biological diversity in areas of agricultural activity and land use. Land use or perhaps more exactly, land abuse is considered by most observers to be the major threat to soil organisms' diversity [12]. Soil biodiversity, which encompasses the variety of organisms living in the soil, plays a crucial role in maintaining soil health and ecosystem functions [13,14]. Conventional farming practices, such as monocropping and the extensive use of pesticides, negatively impact soil biodiversity by reducing habitat diversity and killing non-target organisms [15]. According to [5], such practices can lead to a decline in beneficial soil organisms, including fungi, bacteria, and invertebrates, which are essential for nutrient cycling and soil structure maintenance. Conversely, conservation farming methods, like crop rotation and agroforestry, have been shown to support higher levels of soil biodiversity. For example, research by Yang et al. [16] demonstrates that diversified cropping systems can enhance the abundance and activity of soil organisms, leading to improved soil fertility and resilience against pests and diseases. Despite these benefits, the transition to conservation farming can be challenging due to economic and knowledge barriers. Therefore, the study aims to compare the effects of conservation and conventional farming on soil biodiversity to develop strategies that promote sustainable agricultural practices without compromising productivity.

This study focuses on a comparative assessment of soil biodiversity and physicochemical characteristics in conservation and conventional smallholder farms in Meru, Tharaka Nithi, Kirinyaga, and Laikipia counties in Kenya. By evaluating these parameters across different farming practices, the research aims to provide insights into the impacts of agricultural methods on soil health and to inform strategies for promoting sustainable farming practices. The general objective of this research is to evaluate soil biodiversity and physicochemical properties on conservation and conventional smallholder farms in the specified counties, contributing to a broader understanding of sustainable agriculture in the Kenyan context.

2. MATERIALS AND METHODS

2.1 Study Area

The four counties studied were: Meru, Tharaka Nithi, Kirinyaga, and Laikipia within the Mt. Kenya region in Kenya as summarized in Table 1.

2.2 Methodology

The population: This research was conducted among the smallholder farmers in Kenya whose main activity is crop farming. The research targeted forty randomly sampled conventional and conservation farms in four purposively selected Counties in Kenya. It comprised of 20 conventional and 20 conservation smallholder farmers so as to have a credible and wide range of representation, as in Table 2.

The four counties were sampled purposively since they have smallholder farmers who practice both conventional and conservation farming systems, and there were high chances of homogeneity when it comes to small-scale farmers who practice mixed conventional and conservation farming systems. The sample population of forty was chosen because the number is manageable within the time duration and the scope of the research funding.

Ten (10) sampling points (for monoliths) were located and marked, equally spaced at an interval of five meters along the transect line. Using a 30 cm diameter soil auger core ring, soil samples were taken to a depth of 30 cm at each sampling point as described by CGIAR, [17].

Table 1. Counties and topographic characteristics of the study sites

Counties	Location	Area (Km^2)	Population [18]
Meru	Latitudes 0.22545 Longitudes 37.77726	1,478.1	1545714
Tharaka Nithi	Latitude - 0.19371 Longitudes 37.96140	2,662.1	393177
Kirinyaga	Latitudes - 0.46888 Longitudes 37.30277	1,478.1	610411
Laikipia	Latitudes 0.28585 Longitude 36.82577	9,462	518560

Table 2. Number of farms sampled and total Average size Area in hectare(ha) from each farming system in each county.

County		Tharaka Nithi	Kirinyaga	Laikipia	Meru
Farming Systems	**Conservation farms**	4	6	7	3
	Conventional farms	4	4	5	7
Total		8	10	12	10
Total Average size	**Conservation farms**	1.78	2.32	1.87	2.54
Area in (h 5ta)	**Conventional farms**	0.84	0.85	0.93	2.67

Sampling Design: In this study, Quadrants sampling design was applied in all farms. Using a tape measure, a transect line of 100 metres was laid out, then plots quadrats of 40 m x 5 m adjacent to the transect line were made [19].

The samples were bulked together and mixed thoroughly after collection. The transect line as a whole, therefore, yields 10 bulked samples of approximately 1kg per sample. Each sample from each farm was placed in a storage bag, sealed, labeled, and transported to Meru University of Science and Technology, Biological Laboratory, for the analysis and study of the soil biodiversity and soil physicochemical characteristics. Half of the transported soil samples were air-dried in a cool clean place with controlled temperature. The dried soil samples were ground and sieved through a 2 mm mesh, which was used for analysis of nitrogen, phosphorus, potassium, organic carbon, and pH.

Sample Collection and Analysis: The instruments of data collection were; field traps, laboratory experiments, counting, observation, and photography.

Pitfall traps: This method was employed in soil biodiversity, mainly for scrolling soil organisms (earthworms, termites, and ants) which can be seen by the naked eyes and counted one by one. Ten sampling points (for monoliths) were located and marked, equally spaced along the transect line. Ten pitfall traps of dimensions 25 cm ×25 cm ×30 cm were installed at an interval of five metres, along one flank of the transect. The traps were installed in during the afternoon or early evening and emptied 24 hours later. Each trap contained a little water, with a few drops of detergent added to immobilize the collected soil organisms by drowning. Glass jars of 25 cm mouth diameter were used to make suitable traps. At each sampling point, litter were collected and removed from within a 25 cm quadrat and hand-sorted at the site [20]. The trapped soil organisms were carefully transferred into clean storage jars, containing alcohol to preserve them for counting, recording, and for further analysis [21].

Berlese Apparatus (Heat Extraction): The soil organisms were quantitatively extracted from soil collected from study sites using the Berlese apparatus or heat extraction [22]. Using a 50ml measuring cylinder, thirty milliliters of 90% isopropyl alcohol was measured and placed in a collection jar. The funnel was placed at the top of the collection jar containing 90% isopropyl alcohol. A screen plug was placed in the base of the funnel. One hundred grams of soil sample was measured by the use of an analytical weighing balance and placed into the funnel. A fifty-watt electric lamp was fixed 15cm above the funnel containing the 100 g soil. The setup was left for five days, after the five days, the soil from the funnel Berlese trap was discarded. The isopropyl alcohol from the collection jars containing the organisms from the soil was

poured into a petri dish, and then, the soil organisms were observed under a stereomicroscope. The sample was separated into piles of like organisms within the petri dish. The total number of each type of organism was determined, identified, counted, and then recorded [23].

pH Determination: Ten grams of sieved air-dried soil was measured and placed in a 50 ml plastic beaker. Twenty-five milliliters of distilled water were added and the suspension was stirred several times for 30 minutes using a clean magnetic stirrer. Then, it was left to settle for 30 minutes undisturbed, to allow the temperature of the sample mixture to stabilize [24,25]. The pH meter was calibrated using pH buffers of 4, 7, and 9. The pH electrode was rinsed thoroughly with distilled water, and inserted into the 50ml beaker containing the soil suspension [26]. The pH of the soil samples was determined and recorded for data analysis [9].

Nitrogen Determination: Five grams of sieved air-dried soil sample was measured and placed into a Kjeldahl flask (digestion tube). Ten milliliters of distilled water was added and allowed to stand for 30 minutes. Five grams of the digestion mixture or Kjeldahl catalyst mixture (mixture of 500g of Na_2SO_4 + 50g of $CUSO_4$ + 0.5g of selenium catalyst ground to a fine powder) was added into the digestion tube. Then 20ml of concentrated sulphuric acid was added into the digestion flask containing the soil sample. The digestion tube was placed on the digestion board with an electric heater and heated gradually; low at 10-30 minutes, and the temperature was increased until the digest cleared. After the end of the fuming, the digestion continued for one hour after the solution cleared with the white colour of the digestion mixture. The flask was allowed to cool, and ten milliliters of water with care were gently added before washing the content into a 250ml volumetric flask. The content was also allowed to cool. The content in the digestion tube was transferred into a 250ml volumetric flask and filled with distilled water up to the mark. Ten milliliters were pipetted from the digest into a distillation flask as described by Upadhyay & Sahu [27].

Twenty milliliters of Boric acid (H_3BO_3) was placed in 100ml an Erlenmeyer flask and 4 drops of the mixed indicator (mixture of methyl red (MR) and methylene blue**)** were added and then, introduced to the bottom of the condenser. Ten milliliters of sodium hydroxide solution (NaOH) was added with the 10ml of the digest and was immediately introduced in the distilling unit to distill off the digest. The flask was placed so that the lower tip of the glass receiver tube was below the boric acid surface, and the cooling water in the condenser was allowed to run. The water in the boilers was heated to boiling. Twenty-five milliliters of the sample were placed in the funnel with distilled water. Ammonia trapped in boric acid was released. Ammonia solution (NH_3OH) was then titrated with 0.01N Sulphuric acid (H_2SO_4).

The percentage of nitrogen in the soil sample was calculated using the following formula [28]:

$$\text{N\% in soil} = \frac{\text{Sample titration X Blank X Normality X 14 X Dilution}}{\text{Sample weight}}$$

Determination of Phosphorus: Phosphorus was extracted from soil samples using the Sodium Bicarbonate Method. Forty-two grams of 0.5M sodium bicarbonate was dissolved in 900ml of distilled water, and by use of 50% sodium hydroxide, the pH was adjusted to 8.5. Distilled water was added to make 1000ml of the solution. Mineral oil was added to the solution in the absence of air.

Five grams of 2mm sieved air-dry soil sample was measured and placed into a conical flask, and suspended in 100ml of sodium bicarbonate extraction solution. The suspension was shaken for 30 minutes, and the solution was filtrated through a Whatman 40 filter paper [24].

The concentration of phosphorus in the filtrate was determined by the Micro-Vanadate-Molybdate method. Thirty-five milliliters of soil extract were transferred to a 50 ml volumetric flask, then ten milliliters of the vanadate solution was added and then, distilled water was added to the mark of 50 ml. The results were taken and recorded after 10 minutes at 405 nm wavelength by use of a UV-visible spectrophotometer [29].

The amount of phosphorus was calculated from the following formula [28]:

$$\text{BP } mg/100g = \frac{\text{Reading X Factor}}{10} \text{ X } \frac{100}{\text{Dry weight at 378K}}$$

Potassium Determination: Potassium was extracted from soil samples using the ammonium acetate method. Five grams of 2mm sieved air-dry soil sample was measured and (100) ml of ammonium acetate solution was added to the

plastic bottle containing the soil sample. The bottle was placed in a shaker for an hour, and filtrated through filter paper Whatman 41. The first third of the filtrate was discarded.

Standard curve solutions were prepared by 10, 20, 30, up to 100 ppm dilution from the standard Potassium chloride 1000 ppm solution in the solution of 1 N ammonium acetate pH 7.0.

The potassium concentration was quantitatively determined by the use of the flame photometer and the appropriate calibration curve [24].

Organic Carbon Determination: One gram of air-dry soil sample was weighed and placed into a 250ml Erlenmeyer flask. Ten milliliters of 1N Potassium Dichromate ($K_2Cr_2O_7$) was pipetted into a flask. The flask was swirled gently to disperse the soil. Exactly 10ml of (96% reagent grade) concentrated sulphuric (H_2SO_4) was rapidly added from a measuring cylinder and swirled again for one minute. The flask was allowed to stand on an asbestos sheet for 30 minutes. One hundred milliliters of distilled water were added to the flask and allowed to cool. Three drops of the indicator (phenanthroline) were added and were then titrated with ammonium ferrous sulphate solution with a white background. Blank determination was made in the same manner but without soil [30].

Counting: Counting was done using a variety of methods, depending on the type and size of the organisms being studied. For example, small soil organisms were extracted from soil using the heat extraction method and counted using microscopy techniques. while larger organisms such as termites, ants, and earthworms were counted by hand.

Observation and Photographs: Observation and photography were commonly used in this research. This method was used for documenting the diversity and abundance of soil organisms, as well as for studying the physical and chemical characteristics of the soil environment.

2.3 Data Analyses

Soil Biodiversity: The soil biodiversity was calculated using the following methods; Number of Individuals (N**),** species richness, and Simpson's Index of Diversity and recorded. According to Kumar et al. [31].

Number of Individuals (N) Determination: The total number of all soil organisms obtained from each and every soil sample collected were counted one by one, and recorded for data analysis.

Soil Organisms Species Richness: Soil Organisms' species richness was calculated using Margalef's Diversity Index (D) [31]. As follows

$$D_{mg} = \frac{(S-1)}{lnN}$$

N is the total number of individuals of all types present in the sample, and **S** is the number of the species recorded.

Shannon's Index of Diversity: The soil biodiversity was calculated using the following methods; species richness and Shannon's Index of Diversity and recorded. According to Omoro et al., 2010, the following formula illustrates how to calculate Shannon's Index of Diversity (H'):

$$H' = -\sum pi \ln pi$$

H' is the Shannon-Weiner index, pi=*ni/N; ni* is the number of individual plants present for species i, and N is the total number of individuals*;* log is the natural log of *pi.* The higher the H' the higher the diversity of the soil organisms' species and the lower the H' the lower the diversity of the soil organisms' species. The index ranges from 1.5 and 3.5 but can surpass 4.5 in some exceptional cases [32].

Shannon's evenness index: In any soil community, the index increases with an increase in the richness and evenness of soil organisms' species. According to Nyaga 2021, Shannon's evenness index formula is as shown below:

$$(J) = \frac{H'}{\ln (S)}$$

Where H' is Shannon's diversity index, S is Species richness, (Total number of species in a study site or community). In is the natural logarithm of the number, which is the power to which the base must be raised to obtain a number. The value of Shannon's evenness index varies between 0 and [31]. 1 means that all the species have the same abundance and signify complete evenness and 0 signifies no evenness and nearly all the total soil organisms are concentrated on only one species [31].

Overall, The Data obtained on population of individuals, Shannon's evenness and diversity

index, species richness, and Physico-Chemical Properties were subjected to one-way analysis of variance (ANOVA) using Statistical Package for the Social Sciences (SPSS) 22nd edition to determine the differences between the two farming systems, among the four study counties of Kenya [33].

3. RESULTS AND DISCUSSION

Analysis of soil organisms' species composition between conservational farm sites and conventional farm sites: A total of 5947 soil organism's species were recorded in the 20 conservation farms, and the 20 conventional farms under this study. The analysis of soil organisms' species richness between conservation farms and conventional farms were as follows: out of the total soil organisms encountered 4973 (83.6%) were obtained from conservation farming systems with all three (3) studied species, and 974 (16.4%) of them were encountered from conventional farming systems. The soil organisms' species analyzed included; Ants, Termites, and Earthworms, which were represented by 5335 (89.7%), 540 (9.1%), and 72 (1.2%) for ants, termites and earthworms, respectively. Out of all ant species recorded, Tharaka Nithi recorded 337 (7.1%), Kirinyaga recorded 974 (18.3%), Laikipia recorded 2791 (52.3%), and Meru recorded 1193 (22.4%). Out of all termite species recorded, Tharaka Nithi recorded 35 (6.5%), Kirinyaga recorded 44 (8.1%), Laikipia recorded 351 (65%), and Meru recorded 110 (20.4%). In all earthworm species studied, Tharaka Nithi recorded 9 (12.5%), Kirinyaga recorded 16 (22.2%), Laikipia recorded 28 (38.9%), and Meru recorded 19 (26.4%).

In the study of soil organisms' diversity using Shannon-Weiner's index method and comparison between conservation farms and conventional farms, Table 3 above, shows the soil organism species in the study area. The study indicates, the Ants species recorded the highest number of soil organisms with Laikipia Conservation farms recorded (606.891 ± 302.9), followed by Termites where, also Laikipia conservation farms recorded the highest number of (80.6128 ± 37.42). Finally, Earthworms registered the lowest numbers of soil organisms, the highest number being (9.0937 ± 5.51) in conservation farms. Ants were the most common soil organism species in all farms. While Earthworms recorded the least common soil species organisms.

Earthworms registered zero (0 ± 0.00) in Laikipia County Conventional farms. The higher number of Ants species soil organisms recorded in all studied farms was attributed by good conducive habits and conditions such as low soil moisture, presence of crop residues (organic matter), undisturbed soils, and low usage of chemical fertilizers, especially in conservation farms. The lowest population of earthworms was attributable by soil conditions which were characterized by low soil moisture, use of chemical fertilizers, and hot climate, especially in all conventional farms visited counties of Kenya. The ant species were the only soil organisms which were found in all studied farms in the selected counties of Kenya. Termites and earthworm's species were missing in some farms.

The findings of the study shows the number of the soil organisms' species increased from the conservation farming methods to the conventional farming sites, implying that conservation farming systems bring good and conducive environments or habitats which favours the growth and existence of the soil species organisms [34].

Table 3. Soil organisms Species population (mean ± SD) in the four study counties across the two farming systems in Kenya

Counties	Ants	Termites	Earthworms
THARAKA NITHI CF	156.11 ± (49.40) ^{a}	12.00 ± (2.99) ^{a}	4.25 ± (1.41) ^{ab}
THARAKA NITHI N-CF	31.92 ± (9.54) ^{a}	3.56 ± (1.29) ^{a}	1.05 ± (0.50) ^{a}
KIRINYAGA CF	249.55 ± (108.36) ^{a}	10.89 ± (3.54) ^{a}	3.60 ± (1.21) ^{ab}
KIRINYAGA N-CF	120.57 ± (50.79) ^{a}	1.05 ± (0.5) ^{a}	2.09 ± (1.00) ^{ab}
LAIKIPIA CF	606.89 ± (302.94) ^{b}	80.61 ± (37.42) ^{b}	9.09 ± (5.51) ^{ab}
LAIKIPIA N-CF	221.91 ± (97.54) ^{a}	13.32 ± (6.06) ^{a}	0 ± (0.00) ^{a}
MERU CF	539.80 ± (79.22) ^{b}	38.14 ± (5.29) ^{a}	8.13 ± (1.53) ^{b}
MERU N-CF	32.81 ± (10.15) ^{a}	8.89 ± (4.2) ^{a}	1.69 ± (0.90) ^{a}

a-b: Different letters in superscript within a row indicate significant differences ($p < 0.05$) for columns representing different factors (i.e. farming system, and county)

Analysis of Soil organisms' diversity using Shannon Species Diversity Index (*H*'), Shannon's Evenness Index (J), and Species Richness Margalef's Diversity Index (D_{mg}) and comparison between the conservation farm sites and conventional farm sites.

Shannon Species Diversity Index (*H*'): Table 4 shows the mean for the soil organisms' diversity using Shannon's diversity index in the four studied counties of Kenya were as follows; 1.5194, 1.6404, 2.0154, and 2.1304, for Tharaka Nithi, Kirinyaga, Laikipia and Meru, respectively. and the overall mean for Shannon's diversity index in all four study counties was 1.8264. From Table 4, as determined by the one-way ANOVA test ($p = 0.073$), the results show that there was a significant difference in species diversity among the four study counties of Kenya. Significantly higher ($p \leq 0.05$) species diversity was recorded (2.1304) in Meru County than in Laikipia County 2.0154, then Kirinyaga County 1.6404**,** and the lowest in Tharaka Nithi County 1.5194.

The results of the study revealed that the conservation farming systems for all study counties recorded a higher species diversity except Meru County which shows very different results, as shown below in Table 4. According to Nyaga, [32], any ecosystems with Shannon-Wiener Species Diversity Index (*H*') values of more than 2 are regarded as medium to highly diverse in terms of species. This implies that Laikipia and Kirinyaga county conservation farming systems and Meru County conventional farming system recorded the highest soil organisms' species diversity compared to the other remaining farming systems and counties. Therefore, the results from the study reveal that conservation farming systems as the potential to bring about greater Species Diversity compared to conventional farming systems in Kenya. The variation in soil organisms' species diversity between the two farming systems is influenced by a combination of human activities, such as vegetation clearing, burning, high soil disturbance, and monocropping in conventional farming, as well as natural factors like prolonged dry seasons and heavy rainfall. These factors collectively impact the diversity of soil organisms in conventional farming systems [35,36].

On the other hand, Higher soil organisms' species diversity in conservation farming is driven by the proper application of conservation agriculture principles, such as soil cover, minimized soil disturbance, and crop diversification. These techniques promote the growth and occurrence of diverse soil organisms, contributing to increased species diversity in conservation agriculture [37]. According to Turbé et al. [16], soil organisms' activity and diversity are influenced by abiotic factors like climate, temperature, moisture, soil texture, structure, salinity, and pH. Higher temperatures and moisture levels generally enhance soil organisms' growth and activity, but extreme conditions can reduce species diversity. Soil salinity, pH, and texture also play crucial roles in soil organisms' activity, nutrient availability, and stress levels. Soil pH ranges between 5.5 and 7.5 maximizes the availability of nutrients like phosphorus (P) in the soil.

Shannon's Evenness Index (J): Evenness is a measure of the homogeneity of abundance in an area or a community. The results from Table 4 above show that; Laikipia County conservation farming recorded the highest species evenness of (3.6214) whereas the Meru County conservation farming recorded the lowest evenness index of (0.8568). Conservation farming system showed a higher species Evenness compared to the conventional farming system, except Meru County which registered different results compared to the other counties of study. This could be influenced by a variety of factors related to ecology, agricultural practices, and local conditions such as; Ecological Impact, Habitat Creation, Chemical Usage, and Cultural and Socioeconomic factors. The total, mean of 1.9988 species evenness was recorded in all four counties of study. There was a significance difference ($P \leq 0.05$) recorded among the four selected and studied counties ($p = 0.397$). The lower species evenness recorded across the conventional farming systems shows that there is an uneven representation and large difference in the abundance of different species within the study counties. According to the report of Lamb et al. [38], species evenness increased with an increase in species diversity. From the results, the conservation farming systems recorded higher species diversity compared to conventional agriculture, hence higher species evenness. The difference in evenness across the study counties shows that the farms are dominated by many and a variety of soil organism species [38]. Reports have suggested that the species evenness increases with a decrease in disturbance, higher species population, higher species diversity, and others.

Table 4. Soil biodiversity Shannon Species Diversity Index (*H*'), Shannon's Evenness Index (J), and Species Richness Margalef's Diversity Index (D_{mg}) in different study counties of Kenya

Soil Biodiversity	Farming System	Regions (Counties)				
		Tharaka nithi	Kirinyaga	Laikipia	Meru	P Value
Shannon Species Diversity Index (*H*')	CF	1.7111	2.4438	3.2218	0.9413	**0.073**
	N-CF	1.3276	0.8369	0.8089	3.3194	
	MEAN	**1.5194**	**1.6404**	**2.0154**	**2.1304**	
Shannon's Evenness Index (J)	CF	1.5574	2.1146	3.6214	0.8568	**0.397**
	N-CF	1.9152	1.2074	1.1669	3.5499	
	MEAN	**1.7363**	**1.6610**	**2.3942**	**2.2035**	
Species Richness Margalef's Diversity Index (D_{mg})	CF	1.8773	2.6322	2.0214	1.0167	**0.193**
	N-CF	1.4541	0.9609	0.6324	3.2752	
	MEAN	**1.6658**	**1.7977**	**1.3269**	**2.1460**	

Table 5. Soil Physical and Chemical properties (mean ± SD) in different study counties of Kenya

Counties	% Carbon	%Ntrogen	%Potassium	Phosphorous (mg/100g)	pH
THARAKA NITHI CF	2.9 ± (0.88)^{a}	0.17 ± (0.01)^{a}	0.22 ± (0.06)^{a}	161.68 ± (113.16)^{a}	6.08 ± (0.05)^{a}
THARAKA NITHI N-CF	1.7 ± (0.37)^{a}	0.15 ± 0.02^{a}	0.14 ± (0.03)^{a}	75.60 ± (20.72)^{b}	5.78 ± (0.26)^{a}
KIRINYAGA CF	3.63 ± (1.51)^{a}	0.16 ± (0.05)^{a}	0.53 ± (0.32)^{b}	95.58 ± (38.35)^{a}	5.87 ± (0.32)^{b}
KIRINYAGA N-CF	2.00 ± (0.93)^{a}	0.16 ± (0.04)^{a}	0.24 ± (0.12)^{a}	64.05 ± (11.14)^{b}	5.43 ± (0.31)^{a}
LAIKIPIA CF	6.19 ± (1.21)^{b}	0.18 ± (0.10)^{a}	0.29 ± (0.17)^{a}	135.77 ± (78.93)^{b}	6.40 ± (0.39)^{a}
LAIKIPIA N-CF	5.98 ± (0.13)^{b}	0.16 ± (0.05)^{a}	0.18 ± (0.06)^{a}	97.18 ± (58.67)^{a}	6.26 ± (0.40)^{a}
MERU CF	6.87 ± (0.40)^{b}	0.26 ± (0.04)^{b}	0.90 ± (0.09)^{b}	156.77 ± (25.49)^{a}	6.47 ± (0.25)^{b}
MERU N-CF	3.34 ± (1.01)^{a}	0.12 ± (0.02)^{a}	0.22 ± (0.04)^{a}	62.04 ± (7.10)^{b}	5.50 ± (0.33)^{a}

Soil organisms' Species Richness Margalef's Diversity Index (D_{mg}): The species richness indicates the different variety number of species in a given community. The results shown in Table 4 reveal that the conservation farming system in the study registered the highest species richness compared to conventional farming systems, except Meru County which registered different results. The overall average Species Richness in all study sites was 1.7341. The soil organism's species richness changed significantly in the four study counties (p = 0.196) with Meru County recorded the highest Species Richness mean of (2.1460), followed by Kirinyaga 1.7977, then Tharaka Nithi County 1.6658, and finally Laikipia county registered the lowest Species Richness mean of (1.3269). The soil organism's species richness increases with the increase in the population and different varieties of soil organisms in a community. Therefore, the higher the number of soil organisms, the higher the species richness, and the higher the number of different varieties of soil organisms' the higher the species richness.

Soil organism's species richness is impacted by both natural and human influences. Natural factors include soil moisture, temperature, texture, salinity, and pH. Human actions that affect species richness include field fires that destroy habitats and harm surface organisms, soil disturbance through ploughing and tillage negatively impacting species richness, and the use of agricultural chemicals which can have negative effects. Conservation agriculture avoids the use of agricultural chemicals and others and relies on crop diversification, soil cover for weeds, and minimum soil disturbance [39,37].

The study of Physical and Chemical (Physicochemical) properties of soil in conservation farm sites and conventional farm sites in different study counties of Kenya

Organic percentage carbon: Table 5 shows, The highest value for percentage carbon (6.87 ± 0.40) was observed at Meru County conservation farming, but it was statistically similar to Laikipia County conservation farming system (6.19 ± 1.21), and Laikipia County conventional farming (5.98 ± 0.13), The lowest percentage carbon (%C) value was recorded by Tharaka Nithi county conventional farming system (1.70 ± 0.37), which was not statistically different with (3.63±1.51), (2.00 ± 0.93), and (3.34 ± 1.01) of Kirinyaga conservation farming, Kirinyaga conventional farming, and Meru county conventional farming, respectively. within all the study counties of Kenya, all conservation farming systems registered the highest percentage carbon (%C) contents compared to conventional farming systems.

Results with same superscript are not significantly different at 95% confidence level: High contents of soil organic carbon within conservation agriculture were due to minimized soil disturbance (no ploughing, no tillage, no mounding of agricultural soils), where these practices lower the disturbance of soil and also increase soil aggregation and soil organic carbon accumulation, or caused by high levels of organic matter used for soil cover, which provided through crop residues cover and crops cover [7].

Soil organic matter (SOM) plays a critical role in soil biodiversity, health, and quality functions. It significantly influences soil fertility, agricultural productivity, and the fixation of atmospheric carbon (iv) oxide (CO_2). Conservation farming practices that preserve SOM result in improved soil structure, water and nutrient retention, and overall soil health. The storage of soil organic carbon (SOC) is crucial in mitigating global climate change by reducing greenhouse gas emissions [40]. However, human activities such as clearing farms with fire and soil disturbance through ploughing and tillage can lead to the loss of organic carbon and greenhouse gas emissions. The amount of SOC in the soil is affected by factors like climate, native vegetation, soil texture, drainage, pH, and vegetation cover. In conclusion, various physical and chemical properties impact the amount of SOC, making it essential to implement sustainable practices to maintain healthy soils and combat climate change [41].

Soil pH: pH is a measure of hydrogen ion concentration, the amount of hydrogen ions (H^+) in a soil sample is determined by its pH. According to the study's findings, as shown in Table 5, Meru County Conservation Farming had the highest value of pH (6.47 ± 0.25), while Kirinyaga County Conservation Farming (5.87 ± 0.32) had the lowest., though no significance difference. The conventional agricultural system in Kirinyaga County reported the lowest mean pH value (5.43 ± 0.31), which was statistically identical to (5.50 ± 0.33) for the conventional farming system in Meru County. In comparison to conventional farming systems, all conservation farming systems in Kenya's study counties had higher mean pH levels.

The study shows that both conventional and conservation farming methods produce soils with a pH range of 5.43 to 6.47, influenced by factors like carbonic acid and various sources of H+ ions. Soil pH affects soil organisms and fertility, with different organisms thriving in specific pH ranges. Maintaining appropriate pH levels is vital for crop growth and productivity. Natural methods like soil testing, organic matter addition, cover crops, and crop rotation help maintain pH, while chemical methods like liming and sulfur application should be used cautiously to avoid harm to plants and soil fertility, requiring consultation with a soil testing professional before significant adjustments [16].

Soil phosphorus: Phosphorus is one of the primary nutrients that plants need to grow and thrive, along with nitrogen and potassium [42]. From the results of the study, the highest phosphorus value was produced by conservation farming in Tharaka Nithi County (161. 68 ± 113.16), but it was statistically comparable to Kirinyaga conservation farming (95.58 ± 38.35), Laikipia conventional farming (97.18 ± 58.67), and Meru County conservation farming (156.77 ± 25.48). The Meru County conventional agricultural system had the lowest value of phosphorus (62.04 ± 7.10), however, there was no statistically significant difference between that system and that of Tharaka Nithi County or Kirinyaga (75.60 ± 20.72 and (64.05 ± 11.14), respectively.

In our study, Conservation farming systems recorded higher levels of phosphorus compared to conventional farming systems. this could be attributed to incorporating organic matter, such as crops residues, compost, cover crops, or animal manure, into the soil [42].

Soil percentage Nitrogen: Table 5 indicates the highest and lowest values for percentage nitrogen (0.26 ± 0.04) and (0.12 ± 0.02) were recorded at Meru County conservation and conventional farming, respectively. but it was statistically similar with other counties all conservation farming systems registered a higher percentage of Nitrogen (%C) contents compared to conventional farming systems. According to Mwende Muindi [42], soil nitrogen is essential for plant growth, and conservation farming, a sustainable agricultural practice, aims to preserve soil health and minimize environmental degradation through minimal soil disturbance, soil cover, and diversified crops. This approach can increase nitrogen content in the soil. However, Imoudu Oyeogbe [43] warns that in certain cases, conservation farming may lead to elevated levels of soil nitrogen.

Soil potassium: The findings of the study in Table 5 representing %K, the highest value for percentage potassium (0.90 ± 0.09) was observed at Meru County conservation farming, but it was statistically similar to Kirinyaga County conservation farming (0.53 ± 0.32). The lowest percentage potassium (%K) value was recorded by Tharaka Nithi County conventional farming system (0.14 ± 0.03), which was not**)** statistically different from, Tharaka Nithi County conservation farming all conservation farming systems registered the highest percentage potassium (%K) contents compared to conventional farming systems.

Conservation farming systems may have higher soil potassium levels compared to conventional agriculture due to the use of organic amendments, reduced tillage, and cover cropping. Conventional agriculture relies more on synthetic fertilizers, which can also lead to elevated soil potassium levels if over-applied. Various factors influencing soil potassium levels include soil type, climate, weathering, fertilizer application, crop residue management, and crop uptake and removal [34]

4. CONCLUSIONS

Conservation farms had higher soil biodiversity and soil nutrients than conventional farms. Laikipia County conservation farms exhibited the highest soil biodiversity and soil nutrients among the farms studied. This indicates that conservation farming promotes the growth of soil biodiversity and soil nutrients which plays a critical role in supporting healthy soil ecosystems and providing essential ecosystem services, such as nutrient cycling, carbon sequestration, and pest regulation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/122253