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Assessment of soil properties under termites' biodiversity in dryland soil conserved with animal dung and plant biomass

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ABSTRACT

Soil termites played key roles in soil formation and soil development. Soil termites decomposed plant biomass and animal dung for soil quality and nutrients enrichment. This study assessed the soil properties under termites' biodiversity in dryland soil conserved with animal dung and plant biomass. The study used five (5) experimental plots into fifteen (15) different treatments [(5 x 3 = 15: Control (C_1 to C_5,), Plant biomass (P_1 to P_5) and Animal dung (A_1 to A_5)]. Across the treatments, soil texture and soil structure were improved from grain particles (silt <%10) to more granular in nature (silt >%10). The EC was recorded from $0.07dsm^{-1}$ to $1.97dsm^{-1}$ indicating a very low saline soil. Soil pH was rated as moderate (ranged between 4.05 and 5.82). The %OC was enhanced (from 1.26% to 2.48%) indicating a favorable soil condition for plant growth. The %OM was increased (from 1.17% to 2.48%) indicating a favourable soil condition for varieties of cereals crop production. The addition of plant biomass and animal dung under dryland soils can be considered useful for soil quality and soil fertility improvement. This study suggests that regular supply of organic materials to the dryland soil such as animal dung and plant biomass should be encouraged.

Keywords: Soil, Termite activities, Plant biomass, Animal dung, Soil ecosystem

1. INTRODUCTION

Termites are insects that belong to the order *Isoptera* and are considered most frequent organisms that inhabit the soil and modify soil particles (Frageria and Baliga, 2004; Usman *et al.,* 2016; Usman, 2026a). The termites' abundance, composition, and impact on soil processes, depend very much on vegetation, land use, and overall environmental ecosystems (Ayuke *et al.,* 2003). Land use practices such as tillage affects termites' population and reduces their activities in agricultural soils. In terms of numbers, termites and ants predominate under an agro-ecosystem (Bignell *et al.,* 2011). Thus, plant biomass availability under cropping systems may help rebuild the great activities of termites in dryland ecosystems (Alfred, 2001). However, the diversity of termite groups are considered superior in natural sites than in cultivated sites (Frageria and Baliga, 2004; Usman et *al.,* 2016). There are about

2100 species of termite. Kambhampati and Eggleton, (2000) noted that there are close to 3000 species of termite in the order of Isoptera that are phylogenetically separated into Mastotermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae and Serritermitidae (lower termites), and Termitidae (higher families of termite). Termites are further divided into either wood-dwelling or soil-dwelling (Usman, 2026a). Majority of the soil dwelling termites formed the nests above the surface soil while others dig underground galleries; however, the wood-dwelling termites lived in excavated galleries of vacant trees (Eggleton, 2000).

Termites consumed detritus material and building mounds (FAO, 2005; Usman, 2026a). Depending on the species and the surrounding environment, the termite mounds take on a variety of shapes and sizes. The mounds where termites lived show how they are well-suited for the environment they survived (Ebersohn *et al.,* 1999). Construction of mounds from a soil or a mixture of a soil and other material or within soil horizon, affects the physical and chemical characteristics of soil as well as the surrounding environment (Eskelinen *et al.,* 2009). During the period of occupation of the mound by termites, organic debris or living plant tissues are collected and transported (Usman *et al.,* 2016). These plant tissues are subjected to intense modification by termites when digested (Frageria and Baliga, 2004). Plant nutrients and organic matter that termite moved are withheld from circulation in the plant-soil system until they finally decay (Usman, 2024a & 2024b). Therefore, termite activities in the soil affect the nutrients, organic matter dynamics and soil structure (Usman, 2013a). These termite activities also affect the productivity of the ecosystem, carbon sequestration, nutrient cycling and soil texture (Brady and Weil, 2021).

Plant biomass is one of the most nutritious and abundant carbon sources utilized by a range of organisms (FAO, 2005). They primarily consist of cell walls, presenting a complex structure of polysaccharides, proteins, and lignin, differing between plant species in their monomeric composition and linkages (FAO, 1976). The complex arrangements of different plant cell-wall polymers make them resistant to soil degradation; however, microorganisms can effectively break them through the secretion of enzymes (FAO, 2004). Therefore, termites are considered the major decomposers of plant biomass that are playing a vital role in the turnover of dead plant materials (Jungerius *et al.,* 1999; Jouquet *et al.,* 2019).

Termites have been recognized to play a vital role in the decay of dead plant material and nutrient circulation (Usman, 2013a). They also play an important role in soil formation, soil development and transformation (Jenney, 2009). Termites play a significant role in landscape transformation and soil profile configurations (Brady and Weil, 2021). They transport the fine soil from the deeper profile to ground level (Garg *et al.,* 2023). In the savannah region, termites build huge termite mounds, which are several meters high. In some areas, these mounds occupied the landscape and can be identified physically by naked eyes (Usman, 2013b). Termites build galleries for foraging belowground and translocate large quantities of soil on the ground for harvesting litter (leaves, wood, and herbivore dung), called termite sheeting (Bottinelli *et al.,* 2015). These activities of termites substantially modify the physical, chemical, and biological properties of the soils (Jouquet *et al.,* 2015; Usman *et al.,* 2016).

The effect of termite activities on soil conditions and growth of plant biomass is crucial as they create a suitable soil condition beneficial to other soil function and soil biodiversity (Usman, 2013a). Termites modify physical (e.g., texture, structure) and chemical (chemical composition) properties of soil (Garg *et al.,* 2023). However, when litter is in sufficient supply, a much diversified soil flora and fauna will exist not only of termites, but also of other soil organisms; and, on the other hand, when litter is in short supply, for instance in regions with a dry climate, in poor soils or in overgrazed land, certain termite species may still get enough food, while most other litter feeders starve (Castro-Huerta *et al.,* 2015; Usman *et al.,* 2016). Buxton (1981) studied the relation between termite species diversity and habitat productivity and reported a major decline in termite diversity and habitat productivity under heavy rainfall. This might mean that in a soil environment where termites' diversity is high, a decline in the productivity of soil flora and fauna is possible (Buxton, 1981). This suggests regular assessment of termites activates in agricultural soils. Therefore, this study aimed to assess soil properties under termites' biodiversity in dryland soil conserved with animal dung and plant biomass. This study will contribute to the broader understanding of the relationship between soil termites and soil properties under agricultural production.

2. MATERIALS AND METHODS

Study area

The study was conducted at Teaching and Research Farm, Faculty of Agriculture, Federal University Dutse, Jigawa State, Nigeria. The area s located within the latitude of 11.76° and 13°North, 9.34° and 10°East longitude. The average annual rainfall is 743 mm to 800 mm, and monthly temperature is between 30°C and 45°C. The common crops are millet, sorghum, cowpea, groundnut, soybean and sesame. The common types of farming system are mixed-cropping and inter-cropping of millet, sorghum and cowpea or millet, sesame, and groundnut. Also, production of date palm is very common in the study area (Usman 2018a). The vegetation is occupied by the varieties of plants such as Acacia, Baobab, Neem and Palm (Dabino) (Usman, 2018a). Soil of the site can be classified as Aridisol and Alfisols according to Soil Survey Staff (2010).

Soil survey

A reconnaissance survey was conducted for the evaluation of termites in the study area. However, using several fragmented mound, different nests, and residues at different stages of decomposition by termites, five different plots have been considered for the assessment. The materials used for this assessment are as follows:

a. Plant biomass (crop residues and wood materials – specifically wood husk)
b. Animal dung (specifically cow and sheep/goat dung)
c. Poly bag nylon (specifically for soil sample collection in the field)
d. Laboratory equipment (for chemical analysis)

The wood husk was obtained from the market, while plant residues (plant biomass) and animal dung were obtained from the Federal University Dutse Teaching and Research farm.

Experimental design

The experimental design was conducted at the Teaching and Research Farm Faculty of Agriculture Federal University Dutse. The study site was grouped into five different plots with three (3) designed treatments on each plot as demonstrated in Figure 1. There were three different plots, and fifteen designed treatments (3 x 5 = 15 designed treatments). The treatment 1 represents the control area, whereas the other two subsequent treatments are for the plant biomass and animal dung, respectively.

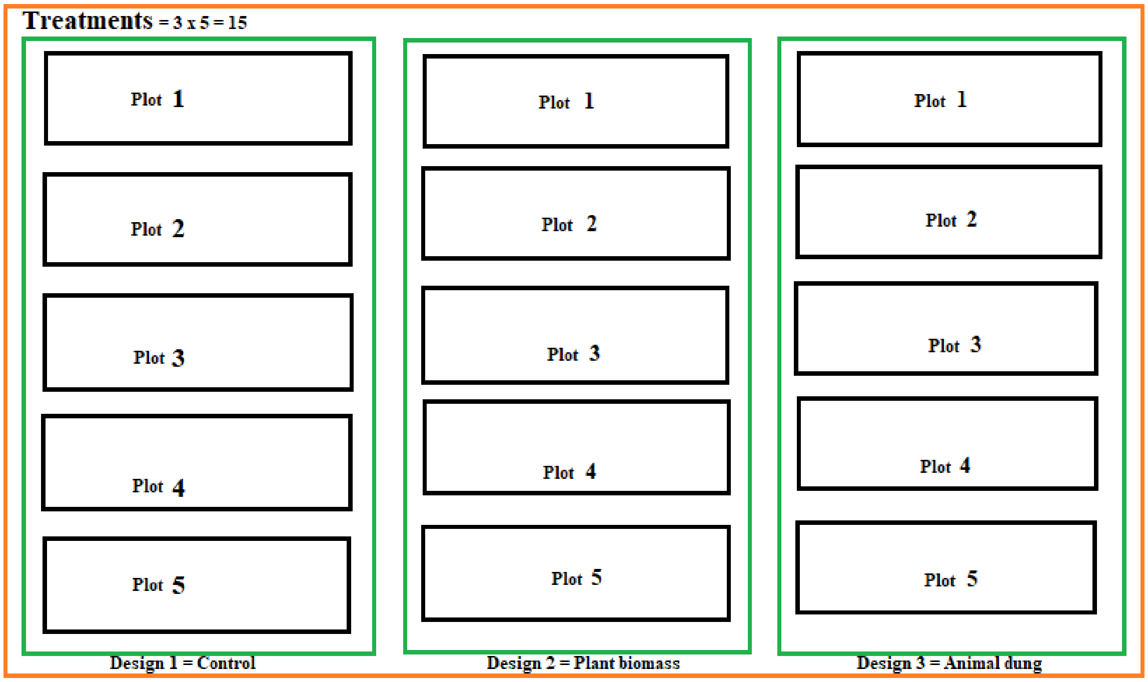

Figure 1. Typical treatments design

Soil samples collection

Soil samples were collected using soil auger at the experimental site. These samples were taken to the soil laboratory for analysis. Fifteen (15) different soil samples were recorded [3 x 5 = 15 soil samples].

Field exercise

Plant biomass and animal dung samples were collected from the Teaching and Research Farm Faculty of Agriculture Federal University Dutse. However, under each designed treatment for P and A plots, the plant biomass and animal dung materials were discarded and mulched all over, and allowed to stay for seven (7) months (between January and July 2023). Throughout this period, some observations were made prior to the collection of soil samples for laboratory analysis; and these are as follows:

a. *First 2-month period*: Biodegradation/breakdown of plant biomass and animal dung by the termites' was recorded based on three (3) classes, namely: weak, rapid and very rapid.
b. *Second 2-month period*: The biophysical relationship between the plant biomass, animal dung, and surface soil condition were observed based on two classes namely: low soil modification and complete/total soil modification.
c. *Third 2-month period*: Soil physical properties were assessed and classified in the field based on the updated USDA-NRCS field manual version 4.0 (Schoeneberger *et al.*, 2021). The soil properties assessed are soil texture, soil structure, and soil colour appearance by visual soil assessment procedure described in FAO (2006) Guidelines for Soil Descriptions and Munsel Colour Chart.
d. *Last month period*: Fifteen (15) different composite soil samples were analysed in the lab for soil texture, pH, organic carbon and organic matter.

Laboratory analysis

Soil samples were air dried, crushed and passed through 2 mm sieve for soil analysis. Soil pH was recorded using pH meter and particle size distribution as determined by hydrometer method (FAO, 2022a). Soil organic carbon (SOC) and organic matter were determined by the modified Walkley-Black chromic acid wet oxidation method described by Nelson and Sommers (1982). Total nitrogen was determined by the Kjeldahl digestion and distillation procedure while available phosphorus and potassium were determined using Bray's No. 1 (Bray and Kurtz, 1945). Soil organic carbon (SOC) and organic matter were determined by the modified Walkley-Black chromic acid wet oxidation method (Nelson and Sommers, 1982). Exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{2+}) and potassium (K^{+}) were determined using flame photometry (FAO, 2022a). Sodium and potassium were measured openly in the percolate by flame photometry at wavelengths of 589.0 mm and 766.5 mm, respectively.

3. RESULTS

Physical properties

Table 1 gives the evaluation of soil physical properties (Soil texture, structure and colour) of the treatments plots in the study site. There were more sands particles at C plots (between 77% and 83%), which appeared to be loose and non-cohesion compared to the A = 66% to 72% and P = 60% to 71%. The percentage soil textural particles recorded from A and P treatments, are stable and organized probably because of the decomposed organic materials, which is believed to have transformed the soil and enhanced soil structural cohesion. Visual assessment showed that soil colour was improved from yellowish-brownish to darker and greyish. This is indicating the changes that occurred at A and B plots, which also believed to have transformed the soil condition into good quality because of the added organic materials to the surface soil. Across the C_{1-5} sites, the silt values were recorded from 7% to 10%, but were improved at A_{1-5} and P_{1-5} sites (10% to 14% and 8% to 12%, respectively). Clay formation and clay mineral deposition have also been improved. This improvement noted 10% to 32% and 14% to 25% for A_{1-5} and P_{1-5}, respectively as compared to 7% to 20% for C_{1-5} (Table 1). This probably provided an additional deposition of mixed soil particles to the surface soil condition and changes that occurred are primarily as a result of biodegradation of the added organic materials to the soil (Table 2). This biodegradation was notably observed as rapid and very rapid, and led to a low and complete breakdown of the organic materials in the soil. Thus, soil textural particles, soil structure and soil colour were affected, surface soil condition changed to darker-brown, grayish and brownish black – attributed to an indication of good soil health (Table 1, 2).

Table 1. Treatment, %Sand, %Silt, %Clay, Textural class, Structure and Color

Treatment	%Sand	%Silt	%Clay	Textural class	Structure	Colour
C_1	83	10	07	Sandy	Grains	Brownish
C_2	77	08	15	Sandy loam	Grains	Yellowish
C_3	78	09	14	Sandy loam	Single-grains	Brownish-yellow
C_4	79	07	14	Sandy	Grain	Yellowish
C_5	78	06	14	Sandy loam	Granules	Grayish

A_1	72	14	14	Loamy sand	Granular	Dark-brown
A_2	70	10	20	Loamy sand	Granular	Dark-brown
A_3	70	10	20	Loamy sand	Granular	Dark-brown
A_4	71	12	24	Loamy sand	Granular	Dark-brown
A_5	66	12	32	Loam	Platy-like	Grayish-black
P_1	71	12	17	Sandy loam	Granules	Brownish-dark
P_2	70	08	22	Loamy sand	Granular	Grayish-black
P_3	70	08	20	Loamy sand	Granular	Grayish
P_4	60	10	24	Loam	Granular	Brownish-black
P_5	60	10	25	Loam	Granular	Brownish-black

C_1, C_2, C_3, C_4, C_5 are control site

A_1, A_2, A_3, A_4, A_5 are treatments representing Animal dung

P_1, P_2, P_3, P_4, P_5 are treatment representing Plant biomass

Table 2. Treatment, biodegradation/breakdown and biophysical relationship

Treatment	Biodegradation/breakdown	Biophysical relationship	Remark: visual assessment
A_1	Rapid	Low soil modification	Low biodiversity of biota
A_2	Very rapid	Complete soil modification	Improved soil health
A_3	Very rapid	Complete soil modification	Improved soil health
A_4	Rapid	Low soil modification	Low biodiversity of biota
A_5	Rapid	Low soil modification	Low biodiversity of biota
P_1	Rapid	Low soil modification	Low biodiversity of biota
P_2	Rapid	Low soil modification	Low biodiversity of biota
P_3	Rapid	Low soil modification	Low biodiversity of biota
P_4	Very rapid	Complete soil modification	Improved soil health
P_5	Rapid	Low soil modification	Low biodiversity of biota

A_1, A_2, A_3, A_4, A_5 are treatments representing Animal dung

P_1, P_2, P_3, P_4, P_5 are treatment representing Plant biomass

Chemical properties

Tables 3 and 4 presented data on nitrogen, phosphorus, potassium, pH, EC, organic carbon and organic matter. There were credible improvements on soil fertility (e.g. mean N = 1.9% for A_1 compared with 0.5% for C_1). This can be observed accordingly for other chemical properties reported. Also, soil pH was improved from acidic/strongly acidic to slightly acidic, indicating more favorable condition for soil biodiversity as noted in Table 2 earlier. Organic carbon and organic matter were increased, and established a good reason for an improved soil health noted in Table 2.

Table 3. Treatment, %N, Available P and K

Treatment	%N	Available P	Available K
C_1	0.6	0.42	1.68
C_2	0.4	1.01	2.02
C_3	0.7	0.81	1.76
C_4	0.3	0.29	1.91
C_5	0.5	1.10	1.99
Mean	**0.5**	**0.73**	**1.87**
A_1	2.07	1.03	1.71

A_2	2.00	1.09	2.22
A_3	1.88	1.05	1.87
A_4	1.56	1.00	1.98
A_5	2.06	2.11	2.41
Mean	**1.91**	**1.26**	**2.04**
P_1	1.19	1.11	2.33
P_2	1.08	1.09	2.54
P_3	2.04	0.84	2.01
P_4	1.99	0.46	2.59
P_5	1.79	1.19	2.91
Mean	**1.62**	**0.94**	**2.48**

C_1, C_2, C_3, C_4, C_5 are control site

A_1, A_2, A_3, A_4, A_5 are treatments representing Animal dung

P_1, P_2, P_3, P_4, P_5 are treatment representing Plant biomass

Table 4. Treatment, pH, EC, % OC and %OM

Treatment	pH	EC(ds/m)	OC (%)	OM (%)
C_1	5.11	1.08	1.00	1.91
C_2	5.02	0.02	0.44	1.00
C_3	4.05	0.01	0.91	1.01
C_4	5.01	0.61	0.78	1.09
C_5	4.59	0.27	0.89	1.09
Mean	**4.76**	**0.39**	**0.80**	**1.22**
A_1	5.65	1.97	1.44	2.48
A_2	5.43	0.07	0.73	1.26
A_3	5.51	0.04	1.02	1.76
A_4	5.42	0.71	0.97	1.67
A_5	5.01	0.47	1.06	1.83
Mean	**5.40**	**0.65**	**1.04**	**1.80**
P_1	5.82	1.77	1.21	2.08
P_2	4.81	0.09	0.68	1.17
P_3	5.19	0.81	1.01	1.74
P_4	5.16	0.78	0.93	1.60
P_5	5.11	0.48	0.96	1.65
Mean	**5.22**	**0.79**	**0.96**	**1.65**

C_1, C_2, C_3, C_4, C_5 are control site

A_1, A_2, A_3, A_4, A_5 are treatments representing Animal dung

P_1, P_2, P_3, P_4, P_5 are treatment representing Plant biomass

4. DISCUSSION

Termites and termite activates affect the soil condition by altering the physical and chemical properties of soil (Garg *et al.,* 2023). These activities of termites affected the physical and chemical composition of the soil at the study sites (Table 1–4). This technological engineering of termites through the process of decomposition is an important component of soil formation and transformation (Holt and Lepage, 2000; Jenney, 2009). Surface soil quality is believed to have been improved by this change (Kambhampati and Eggleton, 2000; Loveridge and Moe, 2004). Soil texture described as the most important physical properties and related to all other soil properties (Usman, 2026a), was noted to have been improved as a result of the added organic materials to the soil (Table 1). The study site is vulnerable to soil erosion due to climate change impact and poor management (FAO, 2022b; IPCC, 2023); however, the activities of termites' have been found useful in binding soil structure and improving the surface soil quality (Jouquet *et al.,* 2019). Taking into consideration, the decomposed animal dung and plant biomass added to the soil as a result of termites' activities, transformed the surface soil from single-grain described as loose to more granular form described as stable (Tables 1, 2). This transformation is believed to have added more cohesion to surface soil against erosion and runoff (Tables 1, 2; Usman, 2026b). This use of animal dung and plant biomass to enhance soil properties by microbial decomposition was considered an alternative for best soil conservation approach in African drylands (Usman, 2026a & 2026b). This conservation approach supported by the activities of soil termites, has been looked positive for the improvement of soil quality and soil fertility (Usman *et al.*, 2019; Usman *et al.*, 2025; Usman and Jayeoba, 2025). The soil textural configuration and mineral particles cohesion are good indication of surface soil improvement for agricultural production in the study area (Figure 2).

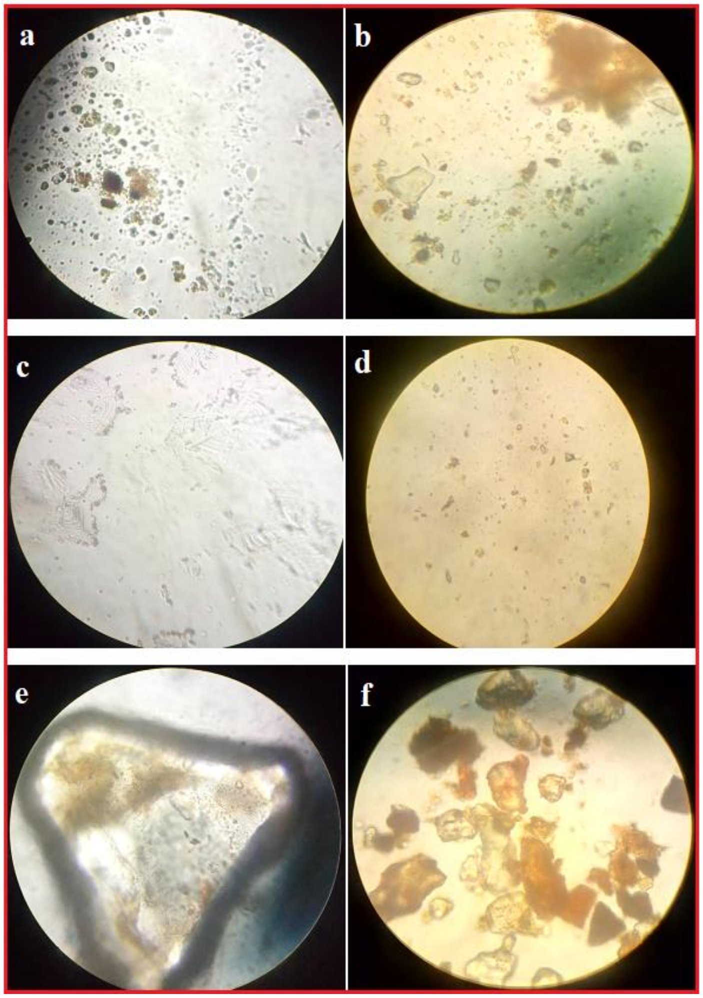

Figure 2. Macroscopic photographs of different soil textural particles observed under C, A and P samples: (a) Loam (b) Loamy sand (c) Loamy sand (d) Sandy-loam: no added organic materials (e) Loam (f) Sandy with larger voids: no added organic materials

There was an improved composition of soil chemical properties across the treatment plots probably as a result of organic materials deposited at the surface soil (Table 3, 4). This deposition is believed to have mixed-up soil particles and formed a new organic layer that can support plant growth and oppose to surface soil erosion (Garg *et al.,* 2023). Percentages sand particles were modified by termites' activities, which is believed to have been increased due to the added binding organic agents contained in the animal dung and plant biomass (Usman and Kundiri, 2016). Soil structure described as an arrangement of sand, silt and clay (Brady and Weil, 2021), was transformed from grains to more granular form (Table 2). This was probably occurred because of the properties of organic materials added to the soil couple with the engineering decomposition process by the termite population (Usman, 2018b). This means that the activities of termites and their broad biodiversity can be considered as a significant contribution to soil management and surface soil conservation in dryland agricultural systems (Usman, 2026b). Soil pH described the degree of acidity and alkalinity in soil (FAO, 2022a), and the values recorded ranged between 4.05 and 5.82 for all the sites (C_{1-5}, A_{1-5} and P_{1-5}). This described the study sites as acidic (strongly/moderately acidic) (Schoeneberger *et al.,* 2021). However, the treated study sites responded very well to the added organic materials, and changed from acidic to slightly acidic (Table 4). This suggests that an incessant application of animal dung and plant biomass is likely to create more positive changes to the soil of the study sites if manage properly (Usman, 2024a). On average [5.60 (A_{1-5}) and 5.21 ($P1_{-5}$) compared to 4.90 (C_{1-5})], treatments sites were noted to have a substantial changes in pH value (Figure 3).

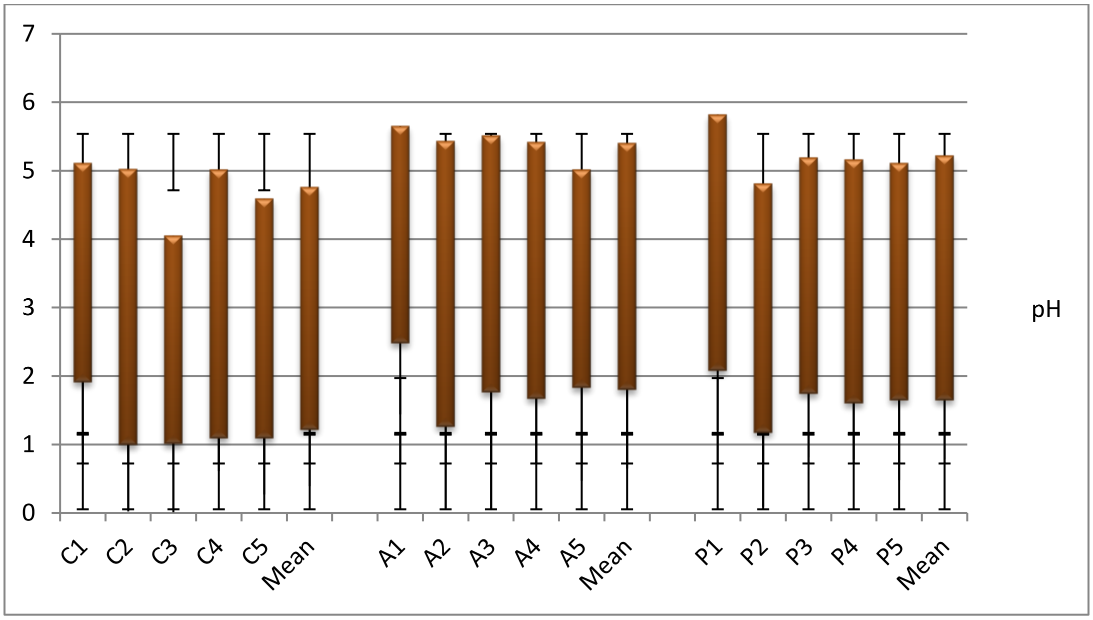

Figure 3. Chart showing pH distribution across the treatments

The Electrical conductivity (EC) of the site ranged between $0.07 dsm^{-1}$ and $1.97 dsm^{-1}$ (Figure 4). This indicated that the salinity level in the area can be described as very low (critical limit = $4.0 dsm^{-1}$) as defined by Landon (1991). This could probably suggest that the site is suitable for crop production, although regular application of both plant biomass and animal dung remain vital (Usman and Burt, 2013).

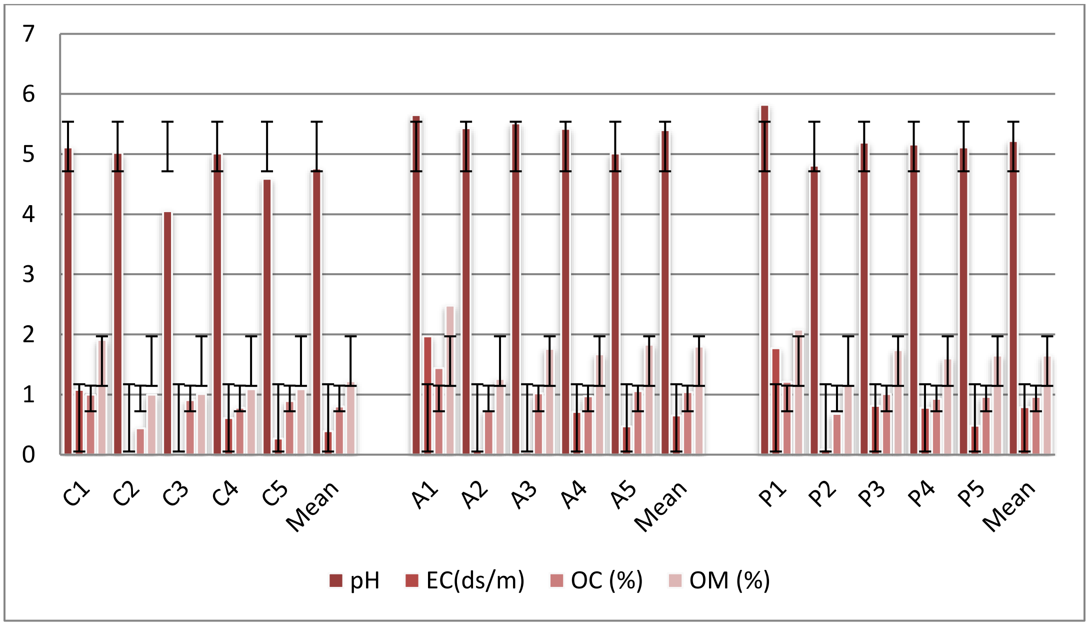

Figure 4. pH, EC, %OC and %OM distribution across the treatments

The percentage organic carbon was recorded from 1.26% to 2.48% (Figure 4). This indicated a substantial improvement of soil organic carbon in the study site, and closely agreed with the recommended values (e.g., 1.27%) by Usman (2018c). Soil organic matter ranges between 1.17% and 2.48%, and shows that the soil is suitable for agricultural production (Landon, 1991). This is probably because, since the fact that the organic carbon and organic matter content were enhanced by the activities of termites, as similarly reported by Usman *et al.* (2016). This enhancement of chemical properties and of organic matter for the study sites could be probably because of the rapid and vary rapid decomposition of plant biomass and animal dung by the termites (Table 3, 4; Jones and Wild, 1996). Likewise, this transformation of organic matter and organic carbon is believed to help increase soil and water management and substantially enhance food security in the study area (Usman, 2024b).

5. CONCLUSION

This study assessed the soil properties under termites' biodiversity in dryland soil conserved with animal dung and plant biomass. The study reported soil data that described the role of soil termites in soil formation and soil productivity. Soil termites modified soil physical and chemical properties and their biodiversity reflect on the greater surface soil transformations and soil development. Addition of plant biomass such as wood husk and silages or crop residues and animal dung to the soil, can be considered one of the advanced soil conservation approaches useful for soil quality and soil fertility management in dryland areas. This study demonstrated the importance of mulching, soil organic amendment and soil composting for rehabilitation and conserving dryland soil in Africa. Soil termites and their biodiversity played a key role in soil formation and soil development. The population of termites under agricultural soil environment needs to be conserved for varieties of benefits including decomposition of various added organic materials, enhancing soil nutrients and soil productivity, and environmental friendly. Rural farmers in Africa should be guided towards low-income and more affordable soil conservation approach which can be demonstrated in an easy manner. This study justified the importance of organic amendments, and could help farmers reduced reliance on inorganic fertilizers. Soil properties can be managed and improved simply by adding plant biomass and animal dung to the surface soil.

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Author Contributions

Dr. Suleiman Usman designed the study, Umar Muhammad conducted the analyses and presented the results. Dr. Usman and Dr. Umar Osuh Ujih reviewed the work, edited and improved the quality. Auwal Abubakar review the results presented on the Tables and statistical analysis. Samaila Usman recorded the macroscopic imagery data at Usumanu Danfodiyo University Sokoto.

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Conflict of interest

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical approval

This work is mainly on soil and soil resources and does not involve any information on humans or animals; thus, an ethical statement is not applicable to the context of the manuscript.

Informed consent

Not applicable.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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