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Diffusion of innovative soil management practices for sustainable vegetable farming

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ABSTRACT

Vegetable farmers in Sokoto state, Nigeria are disadvantaged by problem soils that are generally low in nutrient content, leading to below optimum output. As a result, this research was undertaken to disseminate innovative soil management practices through participatory on-farm trials using household waste compost, vermicompost, and biochar as treatments toward ensuring sustainable vegetable farming. The research covered a sequence of 3 main activities; including baseline survey through focus group discussion (FGD), pre and post project soil sample analyses (0-15cm and 15-30cm depths) and trials, and dissemination of findings via result demonstration, respectively. Findings from the baseline revealed that, the vegetable farmers were vulnerable and never had contact with an extension worker, living below $50/month and confronted by dwindling vegetable output due to acidity and low nutrient content of the soil. Amaranth, cabbage, lettuce, tomatoes, peppers, onions, and carrot were the mainly cultivated vegetables by the farmers. Soil management practices in the research sites were occasional application of inorganic fertilizers and traditional application of municipal waste, crop residue and refuse, which was due to inadequate knowledge on sustainable management practices of the soil. Application of organic amendments including household waste compost, vermicompost, and biochar caused tremendous variation in post-project soil properties (EC, K, Na, Ca, Mg, CEC, N, OC and P). Similarly, yield and benefit cost ratio of the trial crop (amaranth) significantly improved due to the amendments. Hence, application of organic soil amendments especially household waste and biochar would be worthwhile for sustainability of vegetable farming in Sokoto state, Nigeria.

Contribution/Originality: The research findings contribute to the knowledge on participatory management of soils through sustainable application of organic soil amendments. Therefore, the uniqueness of the present research lies in its use of multi-methods including focus group discussion and participatory field experiment to arrive at a sustainable solution to soil management for vegetable production.

1. INTRODUCTION

Soil degradation has been an important global issue in the last and present 21st century, affecting environment, agriculture, food security, and wellbeing of living organisms (Borrelli et al., 2017; Karlen & Rice, 2015). It was estimated that nearly 2 billion hectares of soil resources in the world have been degraded, approximately 22% of the total cropland, pasture, forest, and woodland (Jie, Jing-Zhang, Man-Zhi, & Zi-tong, 2002). In fact, Thomas (2016) reported that degradation affected the livelihoods of 900 million people across 5 continents including Africa, and decreases global biodiversity with a loss of 27,000 species/annum, costing between USD 6.3 - 10.6 trillion/annum, equivalent to 10 – 17% global GDP.

In Nigeria, soil degradation has negatively contributed to the decreasing state of agricultural productivity, food insecurity, malnutrition and further increased poverty (Osuji, Ukoha, Nwaru, & Onyenweaku, 2017). In essence, degraded soils means less food, and the worst hit by degradation is the soil organic system because of the huge influence it has on soil properties (White, Crawford, Alvarez, & Moreno, 2012). The vitality of the soil organic system is a function of sustainable soil management practices (Shrestha, 2015; Tugrul, 2019). However, in Africa, depletion of soil nutrients and poor management have been identified as the major limiting factors to sustainable agricultural production, not the lack of improved varieties (Tully, Sullivan, Weil, & Sanchez, 2015). The challenging question is that in a country like Nigeria with rapid population growth how can poverty and hunger be reduced without sustainable management of soils that would cost-effectively produce nutritious food like vegetables? This is not impossible since it has been tried and succeeded upon in other parts of the world (Congreves, Voroney, & Van Eerd, 2014; Morra, Pagano, Iovieno, Baldantoni, & Alfani, 2010; Sullivan, 2017).

Sustainable management of soils is basic for viable farming practices. Research has established a close link between good and profitable farming; improvement or maintenance of soils and good environmental management (Adeyemo, Oladoja, Famakinwa, & Alabi, 2017; Prodhan, Islam, Islam, Haque, & Islam, 2018). But, over the time however, anthropogenic activities have negatively affected soils. These have depleted the soil, which in turn jeopardises its productive capacity and ability to meet the sustainability needs (FAO, 2015). So, in order to sustain vegetable farming, adoption of appropriate management practices is inevitable. Unfortunately, Junge, Deji, Abaidoo, Chikoye, and Stahr (2009) demonstrated that sustainable soil management technologies exist in Nigeria, but their application is limited due to lack of multi locational trials, and participatory development and dissemination of the technologies. In addition, most of the past soil researches centred on determining the appropriate amount, type and fertilizer need for better yield (Adeyemo et al., 2017). In the study area (Sokoto, Nigeria) in particular, a few researches (Haliru et al., 2014; Sharu, Yakubu, Noma, & Tsafe, 2013) have been conducted, yet the following gaps were identified: (i) the scope was either narrow or broad such that vegetable farming was given little or no attention let alone soil management practices; and (ii) all the researches adopted top-bottom approach instead of bottom-up approach that ensures sustainability. Thus, the uniqueness of the present research was its participatory nature which built upon the existing knowledge through making best use of farmers' knowledge and the resources at their disposal. This ensures sustainable application of the soil management practices, failure of which has hitherto led to the collapse of many development projects and policies (Aga, Noorderhaven, & Vallejo, 2018; Ika, 2012; Kutter, 2014).

Therefore, a systematic approach was undertaken for sustainable vegetable farming through improved soil health. It involved the use of organic amendments such as biochar; house waste compost (HWC), and vermicompost. Noman, Huda, and Rahman (2014) reported that materials required to make (HWC) are available in the rural areas and farmers can prepare HWC easily using their house hold waste with minimum costs. As for biochar, it has the stable organic carbon which may help to enrich soil organic matter and also decreases soil exchangeable acidity (Masud, Jiu-Yu, & Ren-Kou, 2014). The specific objectives of the research were to: evaluate the existing soil management practices; try biochar, house waste composting, and vermicomposting in farmers' field level; and determine the effect of biochar, house waste composting, and vermicomposting on yield and benefit cost ratio of the trial crop (Amaranth).

2. MATERIALS AND METHODS

The following outlines the methods and materials employed in conducting the research which each activity corresponding to an objective:

2.1. Activity I

Research sites which included Kofar Kware, Dundayen Bakin Gulbi and Kwalkwalawa were selected based on commonality and dominance of vegetable farming practice. The villages fall under Sokoto North and Wamakko local government areas of Sokoto state. Twenty (20) participants including both male and female vegetable farmers were selected from each of the villages to make a total of sixty (60) participants for the project. That was followed by focus group discussions (FGD) with some of the participants to establish the existing status of soil management practices. Based on the analysis of the data generated from activity I, inference was drawn for activity II.

2.2. Activity II

Following the findings from activity I, pre-trial soil samples were collected from the allocated vegetable farmers' field in the villages to evaluate the initial soil fertility status. Thus, surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected for conducting chemical analysis.

Different soil management practices like biochar, household waste compost (HWC), and vermicompost (VC) were then applied for improving soil fertility to sustain the existing vegetable farming (amaranth was chosen by the participants as the trial crop) using the usual practice of applying organic matter to the soil. Thus, the treatments were: T1 = Farmer Practice (Control); T2 = Household waste compost (3t/ha); T3 = Vermicompost (3t/ha); and T4 = Biochar (3t/ha).

The materials used for preparation of biochar, HWC and VC were available with the participating farmers, so, they supplied them at a proposed cost. However, they were trained on the preparation process. The preparation process is described below:

2.3. Biochar

Biochar was prepared using different organic residues like rice straw, saw dust, and tree cuttings through pyrolysis process at 300-5500C temperature in anaerobic condition in a modified biochar preparation device in the laboratory of Soil Science Department of Usmanu Danfodiyo University. Using the same materials as in the case of laboratory condition, biochar can also prepared by earthen covered partial anaerobic condition. In this situation, the temperature was less than the laboratory condition. The prepared biochar was applied at the rate 3t/ha to increase soil carbon, which in turn increases soil fertility.

2.4. Vermicompost (VC):

VC was prepared on the allocated farmers' field and applied at the rate of 3t/ha. VC preparation in this project involved the use of earthworm to degrade cow dung, papers, neem leaves, and non-pungent fruit and vegetable wastes.

2.5. Household Waste Compost (HWC)

HWC was prepared along with the participating farmers in their household condition following the training given to them and applied in the field at the rate of 3t/ha. It involved the use of biodegradable household wastes of organic source, such as food waste, egg shells, animal waste, and crop residues.

The trials were conducted May to June, 2023 and November to December, 2023. Each of the trials lasted for 6 weeks. Yield data of amaranth were collected and analyzed using STATISTIX 10 computer package. The mean differences of the treatments were obtained from least significant difference (LSD) test at 5% level of probability for the interpretation of results (Gomez & Gomez, 1984).

2.6. Field Days

After completion of the two trials, there was a field day. The field days reviewed and provided Extension Advisory Service (EAS) on quality assurance to the participating farmers, and how to explore accessible ICTs for information. There was also feedback from the participating farmers concerning their observations on the management practices.

2.7. Activity III: Dissemination

Location specific best management practice (biochar) was selected after results from activity II and feedback from the participating farmers. Result demonstration was subsequently conducted to better equip the participating farmers with the rudiments of biochar preparation, application, and efficacy in various field conditions.

3. RESULTS AND DISCUSSION

3.1. Existing Soil Management Practices

In order to establish the existing soil management, the project participants (vegetable farmers) were engaged in FGD. Findings from the discussions is presented as follows:

The project participants were mostly male, middle age (30 – 50 years), with less formal education (secondary school certificate) living below $50 per month. Their water source was shallow tube well. They never had a contact with extension worker (vegetable) or any other information source on soil management practices, except what was passed down to them from generations before. Despite their major livelihood being vegetable farming, they could not expand their production due to gradual depletion of soil nutrients and no commensurate replacement, as well as inadequate knowledge on soil management practices, which could have helped improve soil health for continuous optimum if not high productivity. One of the project participants had this to say:

> *Our observation is that, if the soils we cultivate vegetables on could receive adequate management we would not have resort to the application of costly inorganic fertilizers during every growing season. However, we are shortened by inadequate knowledge on soil management practices, except for the traditional application of municipal waste, crop residue and refuse. In fact, over the past two (2) years we have observed that, the soil management practices we employ cannot sustain our production.*

On the other hand, the participants in all the three selected villages mainly cultivate cabbage, amaranth, lettuce, tomatoes, peppers, and onions, and carrot. However, for the trials they unanimously suggested the use of amaranth. Basically, because they believe it makes them more money compared to other crops. Thus, if the soil management practices tried would lead to increase in their income from amaranth it will definitely increase their income from other vegetables.

3.2. Effect of Biochar, House Waste Compost, And Vermicompost on Soil in Vegetable Farmers' Field Level (0-15 and 15-30 cm Depth)

3.2.1. Pre-Trials

The pre-project soil samples were collected from the project sites and analysed to establish the initial status of the soil before the trials. Results in Table 1 and 2 present findings from the analyses. In both depths considered, the soils were found problematic in all the project sites given their pH and low nutrient content as indicated. However, at 15-30cm, the soils in Dundayen Bakin Gulbi (pH 5.20) and Kofar Kware (pH 5.16) were strongly acidic with very low nutrient content.

Table 1. Pre-project soil status (0-15cm depth).

Sites	pH	EC	K	Na	Ca	Mg	CEC	N	OC	PO4
Kofar Kware	6.09	505	0.19	0.22	1.50	2.90	6.26	0.10	0.54	0.60
Dundayen Bakin Gulbi	5.79	574	0.32	0.15	0.65	2.22	4.66	0.07	0.48	0.63
Kwalkwalawa	5.94	596	0.29	0.13	0.66	2.35	4.02	0.06	0.14	0.58

Note: EC is in µs/cm, K, Na, Ca, Mg, and CEC are in Cmol/kg, N and OC in %, while PO4 is in mg/kg

Table 2. Pre-project soil status (15-30 cm depth).

Sites	pH	EC	K	Na	Ca	Mg	CEC	N	OC	PO4
Kofar Kware	5.71	495	0.11	0.16	0.99	2.07	5.21	0.06	0.32	0.49
Dundayen Bakin Gulbi	5.20	507	0.13	0.09	0.51	1.92	3.98	0.03	0.37	0.46
Kwalkwalawa	5.16	507	0.16	0.11	0.02	2.09	3.96	0.05	0.12	0.32

Note: EC is in µs/cm, K, Na, Ca, Mg, and CEC are in Cmol/kg, N and OC in %, while PO4 is in mg/kg

The results in Table 1 and 2 justified the points raised by focus group discussion participants that the soils could no longer sustain optimum production, and the need to improve upon the soils in the selected vegetable farming villages.

Similarly, the nutrient status of the household waste compost, vermicompost, and biochar was evaluated after their preparation and found containing very good quantity of nutrients (Table 3). Therefore, they are likely to improve soil health as well as better vegetable production in the project sites.

Table 3. Chemical characterization of organic manure used in the trial.

Organic manures	OC (%)	N (%)	P (%)	S (%)	Zn (%)	K (%)
Household waste compost	16.52	1.97	1.32	0.73	0.32	0.63
Vermicompost	15.46	1.71	1. 41	0.61	0.43	0.62
Biochar	43.61	2.26	0.13	0.21	0.24	0.57

3.2.2. Post-Trials

3.2.2.1. The Soil pH

Following application of organic amendments during the two conducted trials, pH of the soils improved considerably (Table 4 and 5). At 0-15cm depth (Table 4), in Kofar Kware, the pH change from acidic to neutral ranged from 6.97 to 7.01, where T_2 (HWC) influenced the most remarkable rise in the pH. In Dundayen Bakin Gulbi, the pH changed to neutral as well, ranging from 6.98 to 7.01, with T_3 (VC) influenced highest change. In Kwalkwalawa, pH change ranged from 6 .96 to 7.01, where T_4 (Biochar) caused the most rise in the pH.

At 15-30cm depth, results in Table 5 indicate that, the pH in Kofar Kware also changed from acidic to neutral ranging from 6.50 to 6.51, where T_2 (HWC) led to highest rise in the pH. Similarly, in Dundayen Bakin Gulbi the pH changed to neutral, but with T_4 (Biochar) influencing the highest (6.51). Also, in Kwalkwalawa the pH changes were not much different (6.50 to 6.53) from the other sites. However, T_1 (farmer practice) remained acidic in all the project sites despite slight rise in the pH compared to the initial soil status as shown in Table 2.

3.2.3. Electrical Conductivity (EC)

Except for T_1 (farmer practice) at both 0-15cm (592 µs/cm) and 15-30cm (591 µs/cm) in Kwalkwalawa, the EC has improved down to acceptable limits (110 - 570 µs/cm) sequel to application of the amendments (Table 4). However, T_4 (Biochar) in Kofar Kware, and T_2 (HWC) in Dundayen Bakin Gulbi and Kwalkwalawa, respectively, caused better improvement in the EC at 0-15cm depth. At 15-30cm indicated on Table 5, T_4 (VC) in Kofar Kware, and T_2 (HWC) in Dundayen Bakin Gulbi and Kwalkwalawa influenced reduction in EC values. But, all the changes maintained within the acceptable limits of 110 - 570 µs/cm.

3.2.4. Total Nitrogen (N)

The total N increased at both depths after the trials as a result of the amendments applied (Table 4 and 5). At 0-15cm depth, in Kofar Kware, the total N changes in the soil ranged from 0.79 to 0.91 (%); 0.67 to 0.84 (%) in Dundayen Bakin Gulbi; and 0.69 to 0.82 (%) in Kwalkwalawa. At 15-30cm depth, in Kofar Kware, the total N changes in the soil ranged from 0.71 to 0.81 (%); 0.29 to 0.34 (%) in Dundayen Bakin Gulbi; and 0.12 to 0.29 (%) in Kwalkwalawa. In all the project sites, the amendments caused a remarkable increase in the total N in the soil, with T_2 (HWC) having the most effect in Kofar Kware.

3.2.5. Available Phosphorus (P)

Results in Table 4 and 5 indicated that, available P in the soil was caused to change by the applied amendments after the trials, with T_2 (HWC) causing the highest change at both soil depths. At the soil depth of 0-15cm, change in available P ranged from 0.65 to 0.83 (mg/kg) in Kofar Kware; 0.66 to 0.69 (mg/kg) in Dundayen Bakin Gulbi; and 0.63 to 0.67 (mg/kg) in Kwalkwalawa. At 15-30cm depth, the change ranged from 0.43 to 0.62 (mg/kg) in Kofar Kware; 0.64 to 0.65 (mg/kg) in Dundayen Bakin Gulbi; and 0.59 to 0.62 (mg/kg) in Kwalkwalawa. In all the project sites, available soil P has increased from the initial 0.49, 0.46, and 0.32 (mg/kg) in Kofar Kware, Dundayen Bakin Gulbi, and Kwalkwalawa, respectively.

3.2.6. Potassium (K)

In comparison with the results in Table 1 and 2, K in the soil was increased by the amendments as shown in Table 4 and 5, ranging from 0.26 to 0.43 (Cmol/kg) in Kofar Kware; 0.33 to 0.42 (Cmol/kg) in Dundayen Bakin Gulbi; and 0.48 to 0.56 (Cmol/kg) in Kwalkwalawa at soil depth of 0-15cm. At 15-30cm soil depth, the change ranged from 0.19 to 0.31 (Cmol/kg) in Kofar Kware; 0.19 to 0.27 (Cmol/kg) Dundayen Bakin Gulbi; and 0.18 to 0.49 (Cmol/kg) in Kwalkwalawa. The K has changed in all the project sites, with T_2 (HWC) influencing the highest changes in soil K content at both depths.

3.2.7. Cation Exchange Capacity (CEC)

Results in Table 4 and 5 revealed considerable increases in the CEC of the soils at both depths in all the project sites. Though, the increase is less than 10 Cmol/kg due to the dominating low organic matter content established in pre-project soil test results. At 0-15cm depth, change in CEC ranged from 6.33 to 6.76 (Cmol/kg) in Kofar Kware; 4.73 to 4.76 (Cmol/kg) in Dundayen Bakin Gulbi; and 4.71 to 4.76 (Cmol/kg) in Kwalkwalawa. At 15-30cm depth, CEC change ranged from 5.21 to 6.61 (Cmol/kg) in Kofar Kware; 4.70 to 4.71 (Cmol/kg) in Dundayen Bakin Gulbi; and 4.64 to 4.67 (Cmol/kg) in Kwalkwalawa. However, T_2 (HWC) and T_4 (Biochar) influenced more increase in the CEC at all the project sites.

3.2.8. Organic Carbon (OC)

The OC content of soils in the project sites was noticeably increased by different organic amendments applied after the trials (Table 4 and 5), with T_4 (Biochar) having the most influence. Perhaps, due to its carbon sequestration effect. At 0-15cm depth, the OC increase ranged from 0.71 to 1.79 (%) in Kofar Kware; 0.50 to 1.71 (%) in Dundayen Bakin Gulbi; and 0.29 to 0.70 (%) in Kwalkwalawa. At 15-30cm depth, the increase ranged from 0.69 to 0.97 (%) in Kofar Kware; 0.49 to 0.64 (%) in Dundayen Bakin Gulbi; and 0.17 to 0.41 (%) in Kwalkwalawa.

3.2.9. Sodium (Na), Calcium (Ca) and Magnesium (Mg)

When compared with the results in Table 1 and 2; Na, Ca and Mg have minimally increased, but also decreased owing to application of the soil amendments. The scenario goes in order of Mg > Ca > Na (Table 4 and 5). At 0-15cm depth, in Kofar Kware, T_3 (VC) and T_4 (Biochar) caused increase for Na, while T_2 (HWC) caused its decrease from the pre-project status. For Ca, it decreased owing to all the treatments with T_2 (HWC) causing the most effect. The case of Mg was similar to that of Ca. In Dundayen Bakin Gulbi, there was no change in Na content of the soil due to T_2 (HWC), but decrease caused by T_3 (VC) and T_4 (Biochar). Ca decreased in all the soils applied the amendments, while Mg remained unchanged for T_3 (VC), but decreased for T_2 (HWC) and T_4 (Biochar). In Kwalkwalawa, Na decreased owing to T_4 (Biochar), but decreased for T_2 (HWC) and T_3 (VC). With regards to the Ca and Mg contents of the soil, they decreased due to all the treatments.

At 15-30cm soil depth, in Kofar Kware, Na remained unchanged due to T_2 (HWC), but increased as a result of T_3 (VC) and T_4 (Biochar). The Ca decreased due to all the amendments. But, Mg decreased due to T_2 (HWC) and increased due to T_3 (VC) and T_4 (Biochar). In Dundayen Bakin Gulbi, both Na and Ca decreased due to the applied amendments, while Mg increased due to T_2 (HWC) and T_3 (VC), and decreased for T_4 (Biochar). In the case of Kwalkwalawa, Na and Ca decreased in the soils due to application of all the treatments, while Mg decreased due to T_2 (HWC) and T_4 (Biochar) and increased for T_3 (VC).

Table 4. Post-project soil status (0-15cm depth).

Sites	pH	EC	K	Na	Ca	Mg	CEC	N	OC	PO4
Kofar Kware										
T_1	6.09	505	0.19	0.22	1.50	2.90	6.26	0.10	0.54	0.60
T_2	7.01	546	0.43	0.20	1.15	2.60	6.76	0.91	0.73	0.73
T_3	6.97	418	0.32	0.39	1.36	2.61	6.65	0.87	0.71	0.65
T_4	6.99	323	0.26	0.36	1.48	2.91	6.33	0.79	1.79	0.83
Dundayen Bakin Gulbi										
T_1	5.79	504	0.13	0.15	0.65	2.22	4.66	0.07	0.48	0.63
T_2	7.00	473	0.42	0.15	0.62	2.21	4.74	0.84	0.51	0.68
T_3	7.01	479	0.32	0.13	0.59	2.22	4.73	0.82	0.50	0.66
T_4	6.98	501	0.33	0.10	0.61	2.16	4.76	0.67	1.71	0.69
Kwalkwalawa										
T_1	5.94	592	0.16	0.13	0.66	2.35	4.02	0.06	0.14	0.58
T_2	6.99	310	0.56	0.10	0.61	2.31	4.76	0.82	0.31	0.67
T_3	6.96	457	0.52	0.12	0.65	2.32	4.74	0.80	0.29	0.65
T_4	7.01	463	0.48	0.14	0.63	2.29	4.71	0.69	0.70	0.63

Note: EC is in µs/cm, K, Na, Ca, Mg, and CEC are in Cmol/kg, N and OC in %, while PO4 is in mg/kg

Table 5. Post-project soil status (15-30 cm depth).

Sites	pH	EC	K	Na	Ca	Mg	CEC	N	OC	PO_4
Kofar Kware										
T_1	6.01	502	0.16	0.21	1.48	2.76	6.24	0.05	0.50	0.58
T_2	6.51	415	0.31	0.21	1.25	2.61	6.61	0.81	0.71	0.62
T_3	6.50	378	0.21	0.41	1.43	2.91	6.59	0.72	0.69	0.50
T_4	6.50	283	0.19	0.37	1.47	2.90	5.21	0.71	0.97	0.43
Dundayen Bakin Gulbi										
T_1	5.77	514	0.09	0.16	0.69	2.19	4.67	0.03	0.46	0.60
T_2	6.50	377	0.27	0.14	0.61	2.22	4.71	0.34	0.49	0.65
T_3	6.50	476	0.21	0.11	0.61	2.21	4.70	0.32	0.48	0.64
T_4	6.51	469	0.19	0.11	0.60	2.18	4.71	0.29	0.64	0.64
Kwalkwalawa										
T_1	5.44	591	0.18	0.16	0.69	2.33	3.97	0.05	0.12	0.51
T_2	6.51	298	0.49	0.11	0.59	2.30	4.65	0.29	0.19	0.61
T_3	6.50	457	0.43	0.11	0.63	2.33	4.64	0.26	0.17	0.59
T_4	6.53	416	0.18	0.13	0.61	2.31	4.67	0.12	0.41	0.62

Note: EC is in µs/cm, K, Na, Ca, Mg, and CEC are in Cmol/kg, N and OC in %, while PO4 is in mg/kg

3.3. Effects of Biochar, Household Waste Compost, and Vermicompost on Yield and Benefit Cost Ratio (BCR) of Fresh Amaranth

Owing to changes exerted by the amendments in the soils, yield of fresh amaranth (t/ha) was observed to have significantly increased in all the project sites save for T1 (farmer practice) as indicated in Table 6. Maximum fresh yield (15.77 t/ha) was obtained in Kofar Kware as influenced by T4 (biochar). However, the yield was statistically similar to what was obtained in both Dundayen Bakin Gulbi and Kwalkwalawa. The highest mean yield (15.72 t/ha) was influenced by T4 (biochar). On the other hand, there was a significant influence of the amendments on BCR of amaranth in all the project sites. The highest significant mean BCR was influenced by T2 (HWC) and T4 (Biochar) (mean 3.24) (Table 7).

Table 6. Effect of biochar, HWC and VC on yield of fresh of amaranth (t/ha) during first trial.

Treatments	Yield			Mean
	Kofar Kware	Dundayen Bakin Gulbi	Kwalkwalawa	
T1	8.90b	8.89b	8.91b	8.90
T2	15.71a	15.67a	15.66a	15.68
T3	15.70a	15.70a	15.70a	15.70
T4	15.77a	15.70a	15.70a	15.72
CV (%)	2.22	2.61	3.08	
SE (±)	0.04	0.05	0.06	

Note: T1 = Farmer practice (Control); T2 = Household waste compost (3t/ha); T3 = Vermicompost (3t/ha); and T4 = Biochar (3t/ha); CV (Co-efficient of variation); SE (Standard error for comparison); superscript a,b represent statistical differences (different superscript letters on numbers indicate a significant difference between them while the same superscript letters on values represent an insignificant difference between them..

Table 7. Effect of biochar, HWC and VC on BCR of fresh amaranth during first trial.

Treatments	BCR			Mean
	Kofar Kware	Dundayen Bakin Gulbi	Kwalkwalawa	
T_1	1.56b	1.55b	1.58b	1.56
T_2	3.25a	3.24a	3.24a	3.24
T_3	3.23a	3.22a	3.24a	3.23
T_4	3.25a	3.24a	3.22a	3.24
CV (%)	1.05	1.41	1.09	
SE (±)	0.025	0.035	0.025	

Note: T1 = Farmer practice (Control); T2 = Household waste compost (3t/ha); T3 = Vermicompost (3t/ha); and T4 = Biochar (3t/ha); CV (Co-efficient of variation); SE (Standard error for comparison); superscript a,b, represent statistical differences (different superscript letters on numbers indicate a significant difference between them while the same superscript letters on values represent an insignificant difference between them. .

Following the second trial, the yield of fresh amaranth (t/ha) increased higher, except in T1 (Table 8). Maximum fresh yield (17.90 t/ha) was obtained in Kofar Kware as influenced by T4 (Biochar). Though, the yield was statistically similar to what was obtained in Dundayen Bakin Gulbi, but different in Kwalkwalawa. The highest mean yield (17.50 t/ha) was influenced by T4 (biochar).

Table 8. Effect of biochar, HWC and VC on yield of fresh of amaranth (t/ha) during second trial

Treatments	Kofar Kware	Fresh yield (t/ha)	Kwalkwalawa	Mean
		Dundayen Bakin Gulbi		
T1	8.91b	8.89b	8.90b	8.90
T2	17.75a	17.32b	17.06b	17.38
T3	17.15a	17.45a	17.46a	17.35
T4	17.90b	17.15b	17.46bc	17.50
CV (%)	1.45	1.39	1.91	
SE (±)	0.72	0.71	0.95	

Note: T1 = Farmer practice (Control); T2 = Household waste compost (3t/ha); T3 = Vermicompost (3t/ha); and T4 = Biochar (3t/ha); CV (Co-efficient of variation); SE (Standard error for comparison); superscript a,b,c represent statistical differences (different superscript letters on numbers indicate a significant difference between them while the same superscript letters on values represent an insignificant difference between them..

With regards to the BCR as influenced by the amendments, it was obtained significant in all the project sites. The highest significant mean BCR was influenced by T4 (biochar) (mean 2.41) (Table 9).

Table 9. Effect of biochar, HWC and VC on BCR of fresh amaranth during second trial.

Treatments	BCR			Mean
	Kofar Kware	Dundayen Bakin Gulbi	Kwalkwalawa	
T1	1.81c	1.76c	1.86d	1.81
T2	2.15b	2.16b	2.16c	2.16
T3	2.15b	2.15b	2.11c	2.14
T4	2.39a	2.38a	2.46a	2.41
CV (%)	2.51	3.05	2.25	
SE (±)	0.05	0.05	0.03	

Note: T1 = Farmer practice (Control); T2 = Household waste compost (3t/ha); T3 = Vermicompost (3t/ha); and T4 = Biochar (3t/ha); CV (Co-efficient of variation); SE (Standard error for comparison); superscript a,b,c,d represent statistical differences (different superscript letters on numbers indicate a significant difference between them while the same superscript letters on values represent an insignificant difference between them.

4. CONCLUSION

The research was carried out to disseminate innovative soil management practices through participatory on-farm trials toward ensuring sustainable vegetable farming in Sokoto state, Nigeria. Findings from the baseline evaluation exposed that, the vegetable farmers were vulnerable and never had contact with an extension worker, living below $50/month and confronted by dwindling vegetable output due to soil acidity and low nutrient content. Amaranth, cabbage, lettuce, tomatoes, peppers, onions, and carrot were the mainly cultivated vegetables by the farmers. Soil management practices in the project sites involved the occasional application of inorganic fertilizers and traditional application of municipal waste, crop residue and refuse, which was due to inadequate knowledge on sustainable management practices of the soil. However, application of organic amendments including household waste compost, vermicompost, and biochar caused tremendous variation in post-project soil properties such as EC, K, Na, Ca, Mg, CEC, N, OC and P. Similarly, yield and benefit cost ratio of the trial crop (amaranth) significantly improved as a result of the amendments. Hence, practicing the application of the organic soil amendments, especially household waste and biochar would be worthwhile for the sustainability of vegetable farming in Sokoto state, Nigeria.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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Authors' Contributions: Conceptualised the research, collected the samples and data, conducted analysis and interpret the results and develop the manuscript, A.A.B.; assisted in field experimentation and mobilisation of participating farmers, S.H. Both authors have read and agreed to the published version of the manuscript.

REFERENCES

Adeyemo, R. A., Oladoja, A. M., Famakinwa, M., & Alabi, D. L. (2017). Assessment of utilisation of soil management practices among arable crop farmers in Ogun State: Implication for sustainable agriculture in Nigeria. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 17*(3), 37-46.

Aga, D. A., Noorderhaven, N., & Vallejo, B. (2018). Project beneficiary participation and behavioural intentions promoting project sustainability: The mediating role of psychological ownership. *Development Policy Review, 36*(5), 527-546. https://doi.org/10.1111/dpr.12241

Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., . . . Ferro, V. (2017). An assessment of the global impact of 21st century land use change on soil erosion. *Nature communications, 8*(1), 1-13. https://doi.org/10.1038/s41467-017-02142-7

Congreves, K. A., Voroney, R. P., & Van Eerd, L. L. (2014). Amending soil with used cooking oil to reduce nitrogen losses after cole crop harvest: A 15 N study. *Nutrient Cycling in Agroecosystems, 100*, 257-271. https://doi.org/10.1007/s10705-014-9643-8

FAO. (2015). Status of the world's soil resources: Main report. In (pp. 650). Rome, Italy: Food and Agriculture Organisation.

Gomez, K. A., & Gomez, A. A. (1984). Statistically procedures for agricultural research. An international rice research institute book. In (2nd ed., Vol. 28, pp. 442–443). New York: A Wiley-Inter Science Publication.

Haliru, M., Audu, M., Lukman, S., Sauwa, M., Aliyu, I., & Hayatu, N. (2014). Effect of cow dung, NPK and their combinations on soil properties and performance of sweet potato (Ipomoea batatas L.) in Sudan Savanna, Nigeria. *American Journal of Experimental Agriculture, 6*(3), 189-195. https://doi.org/10.9734/ajea/2015/14464

Ika, L. A. (2012). Project management for development in Africa: Why projects are failing and what can be done about it. *Project Management Journal, 43*(4), 27-41. https://doi.org/10.1002/pmj.21281

Jie, C., Jing-Zhang, C., Man-Zhi, T., & Zi-tong, G. (2002). Soil degradation: A global problem endangering sustainable development. *Journal of Geographical Sciences, 12*, 243-252. https://doi.org/10.1007/bf02837480

Junge, B., Deji, O., Abaidoo, R., Chikoye, D., & Stahr, K. (2009). Farmers' adoption of soil conservation technologies: A case study from Osun state, Nigeria. *Journal of Agricultural Education and Extension, 15*(3), 257-274. https://doi.org/10.1080/13892240903069769

Karlen, D. L., & Rice, C. W. (2015). Soil degradation: Will humankind ever learn? *Sustainability, 7*(9), 12490-12501. https://doi.org/10.3390/su70912490

Kutter, R. W. (2014). Demystifying beneficiary participation and its effects in international development. PhD Dissertation, Arizona State University.

Masud, M., Jiu-Yu, L., & Ren-Kou, X. (2014). Use of alkaline slag and crop residue biochars to promote base saturation and reduce acidity of an acidic Ultisol. *Pedosphere, 24*(6), 791-798. https://doi.org/10.1016/s1002-0160(14)60066-7

Morra, L., Pagano, L., Iovieno, P., Baldantoni, D., & Alfani, A. (2010). Soil and vegetable crop response to addition of different levels of municipal waste compost under Mediterranean greenhouse conditions. *Agronomy for Sustainable Development, 30*, 701-709. https://doi.org/10.1051/agro/2009046

Noman, M. R. A., Huda, K. S., & Rahman, M. S. (2014). Constraints and scope for practicing sandbar cropping technology in riverine areas of Bangladesh. *International Journal of Agricultural Extension, 2*(3), 169-176.

Osuji, E., Ukoha, O., Nwaru, J., & Onyenweaku, C. (2017). Impact of sustainable soil management techniques on land productivity of arable crop farmers in Imo State, Nigeria. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 17*(3), 271-276.

Prodhan, A., Islam, M., Islam, M., Haque, M., & Islam, M. (2018). Effect of soil and environment on winter vegetables production. *MOJ Food Processing and Technology, 6*(4), 384-389. https://doi.org/10.15406/mojfpt.2018.06.00192

Sharu, M., Yakubu, M., Noma, S., & Tsafe, A. (2013). Land evaluation of an agricultural landscape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Sciences, 21*(2), 148-156. https://doi.org/10.4314/njbas.v21i2.10

Shrestha, S. K. (2015). Sustainable soil management practices: A key to combat soil desertification in the hills of Nepal. *World Journal of Science, Technology and Sustainable Development, 12*(1), 13-24. https://doi.org/10.1108/wjstsd-07-2014-0015

Sullivan, D. M. (2017). *Nutrient management for sustainable vegetable cropping systems in Western Oregon. Nutrient Management Guide, Oregon State University, USA.* Retrieved from https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9165_0.pdf

Thomas, R. (2016). *Why land degradation is our greatest issue today. Research program on dryland systems.* Montpellier, France: Consultative Group for International Agricultural Research.

Tugrul, K. M. (2019). *Soil management in sustainable agriculture.* London, UK: IntechOpen.

Tully, K., Sullivan, C., Weil, R., & Sanchez, P. (2015). The state of soil degradation in Sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability*, 7(6), 6523-6552. https://doi.org/10.3390/su7066523

White, P. J., Crawford, J. W., Alvarez, M. C. D., & Moreno, R. G. (2012). Soil management for sustainable agriculture. *Applied and Environmental Soil Science*, *3*, 850739. https://doi.org/10.1155/2012/850739