International Journal of Plant & Soil Science
13(3): XX-XX, 2016; Article no.IJPSS.30001
ISSN: 2320-7035

SCIENCEDOMAIN *international*
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Quantifying Short-term Effects of Soil Improving Legumes on Soil Properties and Carbon Sequestration in a Degraded Paleustult in Agbani, Enugu Southeast Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author MANA designed the study, wrote the protocol and wrote the first draft of the manuscript. Author EEI managed the literature searches and analyses of the study and authors JCE and CGC managed the experimental process. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2016/30001
Editor(s):
(1)
(2)
Reviewers:
(1)
(2)
Complete Peer review History:

Received 11th October 2016
Accepted 8th November 2016
Published 14th November 2016

Original Research Article

ABSTRACT

A field trial was conducted at Enugu Southeast Nigeria (6°29'N; 7°14 54'E), during the 2014 and 2015 growing seasons to quantify short-term effects of soil improving legumes [groundnut (*Arachis hypogaea*), Bambara groundnut (*Vigna subterranean* L), Soybean (*Glycine max*) and Pigeon pea (*Cajanus cajan*)] on soil properties and carbon sequestration in a degraded Typic Paleustult. The experiment was laid out in a Randomized Complete Block Design with four legumes as treatments and six replications. Some soil quality attributes, plant shoot and root biomass, and soil carbon sequestration of the legumes were measured at 90 days after planting (DAP). Results show that soil dry bulk density (1.41-1.46 Mg m^{-3}) and gravimetric water content (GWC) (23.16 - 26.00%) in pigeon pea and Bambara groundnut plots were lower than that in other plots by about 10-14% whereas soil saturated hydraulic conductivity (Ksat) was higher in pigeon pea and Bambara groundnut plots (23.45 - 33.10 Cm hr^{-1}) by 14-28% for both seasons. The soil organic carbon

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content (SOC) (0.75 - 0.83%) and Total N (0.074 - 0.091%) in pigeon pea and Bambara groundnut plots were higher than that in soybean and groundnut plots by about 17 and 5-6% respectively for both seasons. The highest carbon sequestration was obtained in fields of Pigeon pea and Bambara groundnuts. These results depict that the legumes used improved soil quality, increased above- and below-ground biomass and improved carbon sequestration. Pigeon pea and Bambara groundnut exerted the most positive influence on soil carbon sequestration in the study area. Efficient cropping systems can be used to optimize carbon sequestration which in turn enhances soil productivity, reduces the enrichment of atmospheric CO_2 and mitigates climate change in soils.

Keywords: Soil physicochemical properties; legumes; carbon sequestration.

1. INTRODUCTION

Legumes, broadly defined by their unusual flower structure, podded fruit, and the ability of 88% of the species examined to date to form nodules with rhizobia, are second only to the Gramineae of their importance to humans [1]. Legumes have long been recognized and valued as "soil building" crops. Growing legumes improve soil quality through their beneficial effects on soil biological, chemical and physical conditions. Increases in organic matter in soil as a result of legume incorporation into the soil improve soil physical properties by increasing soil aggregate stability and decreasing soil bulk density [2]. Most legumes grow exuberantly and build up extensive vegetative cover that protects the soil from rain drop impact energy which prevents soil surface sealing and therefore reduces soil erodibility and influences the soil moisture and temperature dynamics [3]. The reduction of moisture losses can be attributed to the combination of several factors including a significant reduction in the rate of surface evaporation and surface runoff and increases in infiltration rates and moisture retention capacity of the soil [4]. The soil physical properties that are affected by incorporation of the legumes include the structure, moisture retention capacity, consistency, and density. Other properties such as the porosity, aeration, conductivity, hydraulics, and infiltration are allied to the modifications to the soil structure [3,5].

Legumes symbiotically fix N_2 in association with the soil rhizobacteria, increasing soil carbon content, and stimulating the productivity of the crops that follow. Moreover, legumes decompose quickly due to their high litter quality, which accelerates nutrient cycling and can improve soil productivity [6]. Improved soil fertility can provide more niches for other plants to establish, which can be advantageous for maintaining higher species diversity and increasing resource complementarity [7]. Therefore, legumes can have huge economic and ecological potential as N donors to soils. Legumes are able to produce N through a symbiotic relationship with nitrogen-fixing soil bacteria that live inside their root systems. Instead of using fossil fuels to power the creation of fertilizer, legumes use solar energy to power a biological process that provides nearly all the nitrogen required for their growth. Legumes also improve the fertility of the soil, reducing the nitrogen fertilizer requirement of other crops grown in rotation. So legumes not only use half the non-renewable energy of other crops, they also reduce the use of fossil fuels of an entire crop rotation [8]. Finally, legumes will help to counteract nitrogen deficiency in the soil, add large quantities of biomass and contribute to carbon sequestration. Changes in agricultural practices-notably changes in crop varieties, application of fertilizer and manure, rotation and tillage practices influence how much and at what rate carbon is stored in, or released from soils [9].

The top metre of the world's soils stores approximately 2 200 Gt (billion tonnes) of carbon, two-thirds of it in the form of organic matter [10]. This is more than three times the amount of carbon held in the atmosphere. Inputs of carbon (C) into the soil organic C (SOC) pool originate from the fixation of atmospheric CO_2 C through photosynthesis by plants into simple sugars, and subsequently into the most complex materials (i.e., cellulose and lignin), eventually deposited in their leaves, stems, and roots [11]. Carbon storage as SOC is controlled by the soil environment and the quality of the organic matter in which the carbon resides. Increasing SOC levels can be achieved by increasing carbon inputs to soils. In the case of managed soils, this can be done by increasing the input and retention of above- and below-ground biomass. Incorporation of perennial grasses and grass/legume mixtures can be especially effective to allocate a higher percentage of plant biomass C to below-ground soil C sequestration, extend the growing season, better utilize soil water, and reduce tillage disturbance compared to annual crops [12]. Improved practices on croplands can increase SOC sequestration rates to 0.1 to 1 Mg C $ha^{-1}yr^{-1}$, with accumulation rates diminishing as soils approach new equilibria [13]. Higher rates are expected in the conversion of annual croplands to perennial grasses/legumes as conservation set-asides or pastures [5].

Most soils in Southeast Nigeria have low productivity because of problems associated with their pedogenesis (kaolinitic clay mineralogy, low organic matter content, high rate of nutrient loss by soil erosion and leaching, etc.). Technologies such as growing of soil 'improving' legumes, integrated nutrient management, more efficient use of mineral fertilizers, recycling of organic products, exploitation and use of locally available soil amendments like phosphate rocks, and 'improved' land use systems are needed to improve soil productivity without putting too much strain on the environment. Soil organic matter plays a very important role in crop productivity and its deficiency is one of the major yield limiting factors in crop production.

Sustainable land management for enhanced SOC levels is based on (a) Optimal plant productivity (crop selection, appropriate soil nutrient management, irrigation). (b) Minimal losses of organic matter in the soil (reduced tillage, erosion control, cover crops). (c) High carbon returns to the soil (i.e. leaving post-harvest crop residues or importing organic matter such as animal manures, biochar, and domestic or industrial wastes, after consideration of the potential risks associated with using these materials) [14].

Critical research needs for further enhancing C sequestration of cropped systems include (a) clarifying the interactions among tillage, climate, and soil type on C sequestration, (b) quantifying above- and below-ground plant contributions to SOC and (c) evaluating C sequestration practices for total GHG emissions, since recommended practices like incorporation of legumes or fertilizer additions, which enhance soil C, may enhance the soil release of N_2O [11]. Although positive impacts have been observed even with short-term legume cropping, several studies have indicated several risks to soil quality and subsequent crop yield. Four main risks involved with legume cropping are: (i) loss of land for cash crops, (ii) immobilization of soil N in some cases (iii) increase in incidence of weeds and other pests, if not adequately managed, and (iv) cost of growing versus buying N. Thus, it is important to understand the effects of growing legumes on soil quality during the initial years, i.e., short-term effects of legume crop under specific soil type and management [15].

The present study, therefore, was conducted to test the hypothesis that some soil properties [e.g., pH, bulk density (BD) and SOC concentrations] will be changed following short-term legume cropping. The objective of the study is to quantify short-term effects of soil improving legumes [Groundnut, Bambara groundnut, Soybean and Pigeon pea] on soil physicochemical properties and carbon sequestration in a degraded Typic Paleustult.

2. MATERIALS AND METHODS

2.1 Soil Characterization

The experiment was carried out for 2 consecutive plant growing seasons (2014 and 2015) at the Research Farm, Faculty of Agriculture and Natural Resources Management, Enugu State University of Science and Technology, Nigeria. The farm is located in Latitude 6°29'N and Longitude 7°54'E; mean elevation 450 m above sea level). The area has an annual rainfall of 1700 – 2010 mm. The rainfall pattern is bimodal between April and October, and the dry season is between November and March. The soil is of shale parent material classified as Typic Paleustult and has a loamy sand texture with an isohyperthermic soil temperature regime [16]. The initial soil properties are presented in Table 1.

2.2 Field Method

The experimental site was previously tilled with traditional hoes, planted with cassava and thereafter left fallow for three years after harvest. The dominant weed species before clearing was *Imperata cylindrica*. The site was slashed and cleared with cutlass and traditional hoe. The total land area of 10.7 m × 9.7 m (103.8 m^2) divided into 24 experimental units of 1.2 m × 1.8 m (2.2 m^2) with 1m alley was marked out carefully using randomized complete block design (RCBD) with 4 treatments and 6 replications. The experimental beds (raised beds, 0.30 m high) were prepared manually using conventional tillage with traditional hoes. The experimental units comprised four legume crops grown in the area- Groundnut (*Arachis hypogea*) (cultivar 'Nwakara'), Soybean (cultivar TGX 1448-2E from

IITA Ibadan Nigeria) and Bambara Groundnut (*Vigna subterrena*) (Cultivar TVSU 1061 from IITA Ibadan Nigeria) and local Pigeon pea (*Cajanus cajan*) variety obtained from Enugu State Agricultural Development Project, Nigeria. The soil improving legumes were planted at 5 cm depth using 0.75 m x 0.25 m planting distance at one seed per hole giving a plant population of 55,000 plants per hectare. Lost stands were replaced. One weeding regime was carried out manually using small hoe at 21 DAP. Subsequently, rouging was employed to reduce weed competition in each of the seasons.

Table 1. Initial soil properties of the study sites collected at 0–30 cm depth

Soil properties	Values
Clay (%)	19 ± 0.28
Silt (%)	11 ± 0.20
Sand (%)	70 ± 0.53
pH (KCl)	4.6 ± 0.54
Organic Carbon (%)	0.45 ± 0.75
N (%)	0.06 ± 0.67
Na^+ (cmol kg^{-1})	0.12 ± 0.33
K (cmol kg^{-1})	0.06 ± 0.74
Ca (cmol kg^{-1})	1.40 ± 0.77
Mg (cmol kg^{-1})	2.8 ± 0.40
CEC (cmol kg^{-1})	9.1 ± 0.18
Al (cmol kg^{-1})	1.67 ± 0.11
Available P(cmol kg^{-1})	14.92 ± 0.31
Bulk density (Mg m^{-3})	1.46 ± 0.46
Total Porosity (%)	46.04 ± 0.21
Hydraulic conductivity (Cm hr^{-1})	24.42 ± 0.29

NB: Figures ± standard deviations

2.3 Determination of Soil and Plant Parameters

Soil samples (collected from 4 points at 0.30 cm depth in each plot at 90 DAP) were analyzed in the laboratory for total nitrogen (N), available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), pH, SOC, and cation exchange capacity (CEC). Total N was determined by the macro-Kjeldahl method [17]. Available P was determined using Bray-II method as outlined by Olsen [18]. Organic carbon (OC) was analyzed by the Walkley and Black procedure [19]. Soil pH in 1 M *KCl* was measured by the glass electrode pH meter [20]. The exchangeable cations and cation exchange capacity (CEC) were determined by the ammonium acetate method described by Thomas [21]. Particle size distribution was determined by hydrometer method [22]. Soil bulk density was determined by the core method [23]. Total porosity values were derived from bulk density data using the formula: 1 - Bulk Density/ Particle Density x 100. Saturated hydraulic conductivity (Ksat) was determined by the method of Klute and Dirksen [24]. Five plants were selected at random in each plot and measured, which was averaged to give the top and root dry weight per plant. In determining the top and root dry weight, the selected plants in each experimental unit were cut at the base of the stem and washed free of soil. After severing the plant tops, the soil together with the roots around the area of 20 cm^2 from the base of the roots were dug up using a spade, transferred into a wash basin filled with water and the soil carefully and gradually washed off until the roots were recovered in a wooden (0.2 mm) sieve. The roots were further cleaned in the sieves to remove all debris. Care was taken to avoid loss of the roots. The shoot and roots were put in envelopes and kept in the screen house to dry for 3 days. Thereafter, the samples were transferred to the oven to dry at 65°C to a constant weight after which they were weighed. The carbon stock in each plot was calculated using the formula: C (%)/100 × soil bulk density × area (1 ha) × soil depth [9].

2.4 Data Analysis

The data collected from the experiment were analyzed using Analysis of Variance (ANOVA) for randomized complete block design using Fisher's least significant different at P = 0.05 according to the procedures outlined by Steel and Torrie [25] and detection between treatment means as described by Obi [26].

3. RESULTS AND DISCUSSION

3.1 Pre-planting Soil Properties

The pre-planting analysis of soil properties of the site is presented in Table 1. The result indicated that the textural class is sandy loam. Percentage organic carbon, nitrogen and available P were 0.45%, 0.064% and 14.95 cmol kg^{-1}, respectively. The soil pH in 1 M *KCl* was 4.6 indicating "slightly acid" for the site according to the ratings of Landon [27]. The site had CEC 9.1, Mg^{+2} 80, K^+ 0.06, Na^+ 0.12, and Al^{+3} 1.67 cmol kg^{-1}. The bulk density of the site was 1.46 Mg m^{-3} whereas the total porosity was 44.90%. Saturated hydraulic conductivity of 24.42 cm hr^{-1} was found at the site. Gong et al. [28] elucidated that soil properties are influenced by certain factors such as continuous tillage (cultivation), climate, soil amendments and other farming activities and management which in turn will affect the growth characteristics and yield indices of crops, fertility or nutrient status of the soil.

3.2 Soil Physical Properties of the Study Sites at 90 DAP

Table 2 show significant differences in soil bulk density between the legume treated plots at 90 DAP for both growing seasons. The lowest soil bulk density was recorded in pigeon pea and Bambara groundnut plots (1.41-1.46 Mg m^{-3}). The soil bulk densities in these plots were lower than that in soybean and groundnut plots by about 10% for both seasons. Non-significant treatment differences in soil bulk density were found between groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both growing seasons at 90 DAP. In contrast, as expected, soil total porosity values were higher by the same margin in groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both growing seasons at 90 DAP. There were significant differences in soil GWC between the legume treated plots at 90 DAP for both growing seasons (Table 2). The lowest soil GWC was recorded in pigeon pea and Bambara groundnut plots (23.16 - 26.00%). The soil GWC in these plots were lower than that in soybean and groundnut plots (26.20 - 30.12%) by 12 – 14% for both seasons. Non-significant treatment differences in soil GWC was found between groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both growing seasons at 90 DAP.

The results in Table 2 also showed significant treatment differences in soil saturated hydraulic conductivity (Ksat) between the legume treated plots at 90 DAP for both growing seasons. The highest soil Ksat was recorded in pigeon pea and Bambara groundnut plots (23.45 - 33.10 Cm hr^{-1}). The soil Ksat in these plots were lower than that in soybean and groundnut plots (20.22 - 24.00 Cm hr^{-1}) by about 14 – 28% for both seasons. Non-significant treatment differences in soil Ksat was found between groundnut and soybean treated plots and whereas pigeon pea treated plots had 19% higher Ksat than Bambara groundnut treated plots for both growing seasons at 90 DAP.

These results depict that the soil physical properties measured were affected by the different legumes. The extent of soil cover by the legumes indirectly affected key soil physical properties.

Pigeon pea and Bambara groundnut positively influenced soil physical properties than the other legumes probably because they possessed more shoot and root density which protected the soil from agents of erosion. As noted by Sultani et al. [28] vegetative cover prevents the build-up of the aggregates, which could lead to the formation of surface crusts that reduce water infiltration. Legume cover crop influences topsoil by reducing runoff as well as the concentration and the size of the transported sediment particles and thus, the rates of loss of both soil and moisture. Lal and Shukla [4] noted that reduction of moisture losses can be a result of a combination of the reduction in the rate of surface evaporation and surface runoff, and increases in infiltration rates and moisture retention capacity of the soil. The soil physical properties that are affected by incorporation of the green manure include the structure, moisture retention capacity, consistency, and density [29]. Increases in organic matter in soil as a result of green manure incorporation improve soil physical properties by increasing the distribution and stability of soil aggregates and decreasing soil bulk density [5].

3.3 Soil Chemical Properties of the Study Sites at 90 DAP

The results in Table 3 showed significant treatment differences in soil organic carbon (SOC) between the legume treated plots at 90 DAP for both growing seasons. The highest SOC was recorded in pigeon pea and Bambara groundnut plots (0.75 – 0.83%). The SOC in these plots were higher than that in soybean and groundnut plots (0.62 – 0.70%) by about 16 – 17% for both seasons. Non-significant treatment differences in SOC was found between groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both growing seasons at 90 DAP. Studies by Mukherjee and Lal [15] showed a higher SOC concentration under a short-term legume cover crop and concluded that it may be related to higher C-input from the cover crop biomass and possibly an association with diverse microbial populations under turnip and pea. The short-term introduction of a cover crop can also significantly affect different soil-C pools but to variable extents. For example, while SOC concentration under oat-vetch cover crop was increased by 20%, soil microbial biomass C and carbohydrates increased significantly by 2–3 folds compared to those of control indicating a strong relationship of SOC with microbial activity under cover cropping [30].

The different legume treatments did not affect soil pH. These results showed significant treatment differences in soil total nitrogen content (Total N) between the legume treated plots at 90 DAP for both planting seasons (Table 3). The highest Total N was recorded in pigeon pea and Bambara groundnut plots (0.074 – 0.091%). The Total N in these plots were higher than that in soybean and groundnut plots (0.070 – 0.085%) by about 5.4 –6.0% for both seasons. Non-significant treatment differences in Total N was found between groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both growing seasons at 90 DAP. For percent base saturation (PBS), the results in Table 3 showed significant treatment differences in the legume treated plots at 90 DAP for both growing seasons. The highest PBS was recorded in pigeon pea and Bambara groundnut plots (38.50 – 65.50%). The PBS in these plots was higher than that in soybean and groundnut plots (34.14 – 42.60%) by about 11.3 – 35.0% for both seasons. Non-significant treatment differences in PBS was found between groundnut and soybean treated plots, however, pigeon pea treated plots recorded a 35% higher PBS when compared with Bambara groundnut treated plots for both growing seasons at 90 DAP.

Pigeon pea and Bambara groundnut plots had higher SOC, Total N, and PBS than soya bean and groundnut plots. The rate of photosynthetic CO_2 assimilation depends on soil fertility, climate, and management, which, in addition to other soil and plant factors, influence rates of C return to the atmosphere. Incorporation of perennial grasses and grass/legume mixtures can be especially effective to allocate a higher percentage of plant biomass C to belowground soil C sequestration. This process improves soil physicochemical properties by reducing soil compaction, improving water transmissivity, release of nitrogen, buffering of soil pH and release of other oxide solids during decomposition of organic matter [31,32].

3.4 Plant above Ground Biomass, Root Biomass and Soil Carbon Sequestration as Influenced by Groundnut, Bambara Groundnut, Soybean and Pigeon Pea at 90 DAP

The results in Table 4 showed significant treatment differences in plant above ground biomass between the legume treated plots at 90 DAP for both growing seasons. The highest plant above- ground biomass was recorded in pigeon pea (122-130 g plant^{-1}) and Bambara groundnut plots (89.5 - 95.0 g plant^{-1}). The plant above ground biomass in these plots was higher than that in soybean (68.2 - 70.9 g plant^{-1}) and groundnut plots (45.2 - 51.3 g plant^{-1}) by about 26–27% for both seasons. Non-significant treatment differences in plant above ground biomass were found between groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both growing seasons at 90 DAP. These results showed significant treatment differences in plant root biomass content between the legume treated plots at 90 DAP for both growing seasons (Table 4). The highest plant root biomass was recorded in pigeon pea and Bambara groundnut plots (10 – 12.1 g plant^{-1}). The plant root biomass in these plots was higher than that in soybean and groundnut plots (8.4 – 8.9 g plant^{-1}) by about 16 – 24% for both seasons. Non-significant treatment differences in plant root biomass were found between groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both growing seasons at 90 DAP.

Table 2. Effect of four soil improving legumes on selected soil physical properties at 90 DAP

Treatments	Bulk density (Mg m^{-3})		Total porosity (%)		K-Sat (Cm hr^{-1})		Gravimetric water content (%)	
	2014	2015	2014	2015	2014	2015	2014	2015
Groundnut	1.57	1.55	40.75	41.51	20.40	24.00	29.25	30.12
Bambara	1.46	1.43	44.90	46.04	23.45	26.70	25.32	23.16
Soybean	1.54	1.55	41.89	41.51	20.22	22.00	27.17	26.20
Pigeon Pea	1.42	1.41	46.41	46.79	29.10	33.10	24.10	26.00
F-LSD$_{(p=0.05)}$	0.08	0.11	2.07	2.29	2.10	2.75	2.30	3.10

Table 3. The effect of growing groundnut, bambara groundnut, soybean and pigeon pea on selected soil chemical properties at 90 DAP

Treatments	pH (KCl)		SOC (%)		Total N (%)		Base Sat. (%)	
	2014	2015	2014	2015	2014	2015	2014	2015
Groundnut	4.6	4.5	0.62	0.65	0.075	0.085	34.14	40.50
Bambara	4.4	4.6	0.75	0.78	0.074	0.086	38.50	42.60
Soybean	4.6	4.8	0.66	0.70	0.070	0.073	39.34	39.24
Pigeon Pea	4.5	4.8	0.80	0.83	0.086	0.091	62.88	65.50
$F\text{-}LSD_{(p=0.05)}$	ns	ns	0.09	0.11	0.040	0.03	7.20	10.20

Table 4. The effect of growing groundnut, bambara groundnut, soybean and pigeon pea on plant above ground biomass, root biomass and soil carbon sequestration at 90 DAP

Treatments	Above-ground biomass (g plant^{-1})		Root biomass (mg plant^{-1})		Quantity of carbon sequestered (t ha^{-1})	
	2014	2015	2014	2015	2014	2015
Groundnut	89.5	95.0	10.0	12.1	29 .2	30.23
Bambara	45.2	51.3	8.4	8.9	32.85	33.46
Soybean	68.2	70.9	15.7	17.4	30.49	32.55
Pigeon Pea	122.4	130.3	36.4	40.1	37.49	35.11
$F\text{-}LSD_{(p=0.05)}$	31.2	22.0	7.2	8.00	3.20	2.20

The results in Table 4 above also showed significant treatment differences in soil carbon sequestered between the legume treated plots at 90 DAP for both growing seasons. The highest quantity of carbon sequestered in the soil was recorded in pigeon pea plots (35.11-37.49 Mg C ha^{-1}) and Bambara groundnut plots (32.85-33.46 Mg C ha^{-1}). The quantity of carbon sequestered in the soil in these plots was higher than that in soybean (30.49 - 32.55 Mg C ha^{-1}) and groundnut plots (29.20 – 30.23 Mg C ha^{-1}) by about 4.6 – 7.1% for both seasons. Non-significant treatment differences in quantity of carbon sequestered in the soil were found between groundnut and soybean treated plots and between pigeon pea and Bambara groundnut treated plots for both planting seasons at 90 DAP. The results showed that pigeon pea and Bambara groundnut plots produced a higher shoot and root biomass than other plots and these coincided with the plots with better soil quality and higher quantity of sequestered carbon. Incorporation of soil improving legume mixtures can be especially effective to allocate a higher percentage of plant biomass C to belowground soil C sequestration. Plant material and its organic C can be consumed by animals or become humified into soil organic matter (SOM), which contains SOC, through the action of microorganisms. Carbon storage as SOC is controlled by the soil environment and the quality of the organic matter in which the carbon resides. Sequestering C within the soil organic matter (SOM) is among the best options for C storage in terrestrial ecosystems. Besides helping offset CO_2 emissions into Earth's atmosphere, C sequestration into SOM provides multiple benefits, such as improved soil quality through enhanced fertility, soil structure and aggregate stability, water holding capacity, and the capacity to reduce toxic elements [33].

4. CONCLUSION

The increase in both above and below ground organic substrates attributed to grain legumes resulted in the build-up of OC. Compared to the fallow field, the OC obtained in the fields of Bambara and Pigeon peas was higher by 10 and 14%, respectively. It follows, therefore, that Bambara and Pigeon peas produced more organic substrates as compared to groundnuts. This is in agreement with Anikwe and Atuma [32] who reported that some legumes produced more organic substrates to consequently improve the OC and eventually SOC. Relatively lower soil bulk density was found in the soils under the four legumes studied in both seasons. Bulk density is a measure of soil compaction and the results showed lower bulk density in pigeon pea and Bambara groundnut planted plots when compared to other plots. Total porosity measurements followed a reverse trend as bulk density measurements. The soil gravimetric water content (GWC) in Pigeon pea and Bambara groundnut plots were lower than those in other plots whereas Ksat, SOC, total nitrogen and percent base saturation of the soil were higher when compared to that of soybean and groundnut plots for the two growing seasons studied. The quantity of carbon sequestered in the soil in these plots was higher than that in soybean and groundnut plots for both seasons. Results of the study depict that Pigeon pea and Bambara groundnut plots provided higher SOC, total nitrogen and base saturation which are positive productivity indicators. These legumes used exerted a positive effect on some physicochemical properties of the soil, increased plant and root biomass and soil organic carbon content, which can be qualified as improving C sequestration. Pigeon pea and Bambara groundnut exerted the most positive influence on Soil C sequestration in the study area. They did not just contribute in terms of food, feed, and fertility. They also enhance C sequestration and the delivery of co-benefits including reduced greenhouse gas (GHG) emissions. Enhancing C sequestration in the soil is linked to increased biomass and hence to soil fertility.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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