SOIL PHYSICAL PROPERTIES, ORGANIC CARBON DYNAMICS, AND MAIZE PERFORMANCE UNDER LONG-TERM GRAZING AND CONTINUOUS CULTIVATION IN ADO EKITI, SOUTHWEST NIGERIA

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ABSTRACT

The development of climate smart strategies for improved soil health and sustainable crop production requires an understanding of the responses of soil properties to grazing and cultivation. This study was aimed at quantifying the stock, distribution, and sequestration of soil organic carbon (SOC), soil physical properties, and maize yield on grazed pasture (GP) and cultivated land (CL). Soil samples collected from two adjacent fields: GP and CL, were analysed using standard laboratory procedures. Texturally, the two soils alternated from loamy sand at the surface 20 cm for CL and sandy loam for GP to sandy clay loam for GP and sandy loam for CL respectively at the subsoil. In addition, bulk density and cone index averaged 1.7 and 1.5g/cm3; 4.75 and 2.5kg/cm2 respectively on GP and CL showing higher soil compaction of the soil under GP. With dispersion ratio (DR) standing at 55 and 80 for GP and CL soils respectively indicating more structurally stable aggregates for the GP soil. Higher infiltration rate, saturated hydraulic conductivity and hence soil moisture content were also recorded for the grazed soil. Moreover, after 20 years of cattle grazing, SOC content varied widely from 3 to 13% on the grazed pasture and was significantly higher than on cultivated plot which was less than 1%. At the surface 10cm, SOC stocks of the GP was almost 10 times higher (136 mg/ha) than that under CL (14mg/ha). Maize yield was 4.3tons/ha on GP in contrast to 0.3 ton/ha) on CL. The heavy SOC addition into the GP soil and the attendant improvements in soil aggregate stability, water retention plus the resultant nutrient level and soil health has further confirmed the benefits that can accrue from integrating light to moderate animal grazing into crop cultivation in a humid tropical environment.

Keywords: *grazing, conservation tillage, soil compaction, aggregate stability, climate smart agriculture*

INTRODUCTION

Agricultural practices such as reduced tillage, cover cropping, and optimized grazing management have been shown to enhance soil organic carbon (SOC) storage (Conant *et al*., H2001). In tropical soils, the potential for carbon sequestration is particularly high due to the rapid decomposition rates and high biological activity associated with warm temperatures and abundant rainfall (Ayodele *et al*., 2019). Soil physical properties, including texture, bulk density, porosity, and aggregate stability, are key determinants of SOC dynamics. These properties influence the soil's ability to protect organic carbon from decomposition and facilitate its incorporation into stable soil fractions (Six *et al*., 2002). Soil texture, particularly the proportion of clay, has been found to enhance SOC sequestration by providing physical protection to organic matter through the formation of microaggregates that reduce microbial access to SOC (Lal, 2004). Bulk density and porosity, on the other hand, influence the movement of water, air, and roots within the soil, thereby affecting carbon input and retention in soils (Bronick and Lal, 2005). In grazed pastures, the intensity and duration of grazing can significantly affect soil physical properties and, consequently, SOC sequestration. Franzluebbers and Stuedemann (2009) demonstrated that moderate grazing can enhance SOC accumulation in the soil profile by promoting plant growth and increasing root biomass, while heavy grazing can lead to soil compaction, reduced porosity, and accelerated carbon loss. The management of grazing systems, therefore, plays a crucial role in maintaining the soil's structural integrity and its ability to sequester carbon.

The rainforest agro-ecological region of Nigeria, characterized by high rainfall and rich biodiversity, presents unique challenges and opportunities for SOC sequestration. The high rainfall in this region often results in leaching and soil erosion, which can limit SOC retention (Ayodele *et al*., 2019). However, the potential for SOC sequestration in grazed pastures remains significant, particularly when grazing is managed in ways that promote soil health and minimize degradation (Smith *et al*., 2020). SOC sequestration. in tropical regions also depends on the balance between carbon inputs from vegetation and carbon losses due to decomposition. The rapid decomposition rates in tropical climates, driven by high temperatures and microbial activity, can reduce SOC stocks unless management practices are implemented to offset these losses (Six *et al*., 2002). Research conducted by Bronick and Lal (2005) suggests that maintaining soil structure and promoting aggregate stability are crucial for protecting SOC from decomposition and enhancing long-term carbon storage.

Continuous cultivation involving conventional tillage which is used for loosening soils to grow crops influences soil responses and behaviours. Similarly, long-term soil disturbance by tillage is believed to be one of the major factors reducing SOC in agriculture (Bakker *et al.,* 2005). Nevertheless, SOC pool plays a significant role in the global carbon cycle and is a key determinant of the physical, chemical and biological properties and is required for the proper functioning of the soil system. Soil physical properties, such as bulk density, porosity, and aggregate stability, significantly influence SOC sequestration (Adesodun *et al*., 2011; Ezeaku *et al.,* 2012). Research has shown that reduced bulk density and increased porosity can enhance SOC sequestration (Oyedele *et al*., 2010). Moreover, soil aggregate stability has been linked to improved SOC sequestration and reduced soil erosion (Oluwatobi *et al*., 2015). The rainforest region of Nigeria, characterized by high temperatures and rainfall, presents unique challenges and opportunities for SOC sequestration (Adeyeye, 1997). Soil physical properties, such as bulk density, porosity, and aggregate stability, play a crucial role in influencing SOC sequestration (Adesodun *et a*l., 2011; Ezeaku *et a*l., 2012). More research is needed to quantify SOC sequestration potential under different grazing intensities and management practices in this agro-ecological region. Additionally, there is a need to explore the long-term effects of grazing on soil physical properties and SOC dynamics, particularly in the context of climate change and land-use pressures.

It is therefore the objective of this study to evaluate the soil physical properties and organic carbon sequestration of a grazed pasture and a continuously cultivated field while both were planted with maize. The findings of this study will contribute to the development of sustainable soil management practices that promote SOC sequestration, improve soil fertility, and support climate change mitigation efforts in Nigeria.

MATERIALS AND METHODS

Description of Experimental Site

The study was carried out on two adjacent fields on the Teaching and Research Farm of The Federal Polytechnic, Ado Ekiti, Ekiti State, a rain forest, humid tropical zone in Southwestern Nigeria. The map of Nigeria showing the details of the experimental site within The Federal Polytechnic campus is presented in Fig 1.

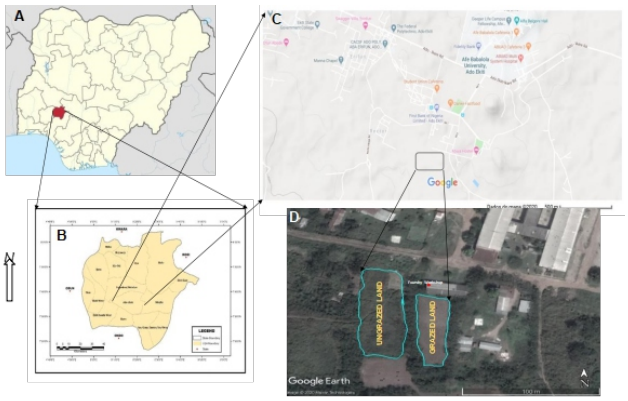

Fig1. Map of Nigeria (A) showing Ekiti State (B), the Federal Polytechnic, Ado Ekiti (C) and the location of the experimental site (D).

The two fields, separated by a wire fence and established in the year 2000 A.D., consisted of an ungrazed (continuously cultivated) plot and a grazed pasture. On each of the meadows, an area of 80 m by 30 m was clearly marked out for the experiment. The cultivated plot, while employing conventional tillage practices, was planted with maize, yam, cassava, and cowpeas in an irregular sequence. Over the course of using the pasture, the number of cattle generally fluctuated between 10 and 27, with an average of 17 cows, at any given time. Both fields were left to fallow in the year 2018 before this study was conducted between 2020 and 2022.

Soil Sampling

The soil of the area had been previously classified as an Alfisol by Adeosun (2017). From the area of land carved out, two sets of twenty random soil samples were collected. One set of soil samples (undisturbed) was collected using core samplers (100cm3) while the other set (disturbed samples) was done with a hand trowel, shovel and soil auger. Sampling was done at three depths, namely: 0 – 10, 10 – 20, and 20 – 40cm. GPS (Garmin Model, USA) was used to geo-reference each sampling point. The soil samples were sealed, placed in clearly labelled polythene bags, and brought to the laboratory for physical and chemical analyses.

The disc infiltrometer was used to conduct *in situ*. infiltration tests (Bouwer, 1986). Using a hand-held cone penetrometer (Etrex, USA), penetration resistance, also known as cone index (CI), was determined *in situ* as a measure of soil strength.

Land Preparation and Planting

Bush clearing was done with the use of cutlass while the hoe was used to make ridges. Maize was sown at a spacing of 25 cm along and 1 m distance between the ridges. The removed debris was spread upon the ridges. Measurements of crop growth parameters were taken at two weeks interval until maturity. To determine the crop yield, twenty matured maize crops were randomly selected from each of the two fields: grazed pasture and cultivated land.

Laboratory Study

(a) Bulk (disturbed) samples were air-dried and carefully examined to remove roots, leaves, and other unwanted materials. The samples thereafter were gently crushed and made to pass through 2-mm sieve. One portion of the sieved soil samples was used to determine the following soil physical properties, namely: (i) particle size distribution was determined using hydrometer meter method Bouyoucos (1962); and (ii) soil dispersion ratio, DR was used to estimate aggregate stability using the method proposed by Middleton (1930). The dispersion ratio (DR) was calculated thus:

$$DR = \frac{\%\ \text{Water dispersible silt + clay}}{\%\ \text{Calgon dispersible silt + clay}} \times 100\ \%$$

(b) The core (undisturbed) soil samples were used to determine the following physical properties: (i) gravimetric moisture content (GMC) was obtained from the oven-drying method; and (ii) bulk density, BD was evaluated also by using the oven-dried core soil samples following the methodology described in Blake and Hartge (1986).

© Another portion of the sieved soil was used for the determination of soil organic matter (SOM) content for each location and at different depths using the Walkley – Black method. This method is by titrating a known volume of dichromate solution against a solution of known weight of soil. The formula given by Walkley- Black (1962) was used in computing the percentage organic carbon as shown below:

Percentage organic carbon, (% OC or SOC):
SOC = V1- V2 × 0.003×100×f…………….. 1

Where, V1 = Volume of dichromate V2 = volume of titrant (Ferrous ammonium sulphate) W = weight of air-dried soil, f = correction factor (usually 1.33)

Percentage organic matter (%OM)
OM = SOC ×1.724……………………….... 2

Carbon sequestration: Following studies by The World Bank (IDRC, 2012) and Franzluebbers (2021) which reported concentrations of carbon in soil samples (Cc in g kg−1). These were converted to volumes and then areas to calculate carbon stocks (Cs in kg−1 ha−1).

Carbon sequestration rates, Cs (kg ha−1 yr−1) using bulk density (BD, in g cm−3) and sample soil depth (D, in cm) were calculated as follows:
Cs = BD x Cc x D x 10,000..………………….. 3

The value was given in terms of percent soil organic matter, concentrations of Cc (g kg−1) were calculated as:
Cc = 0.58 x OM% x 10……………….4

Data Analysis

Data collected were analysed, using SPSS (2020) software, to determine descriptive statistics like minimum, maximum, mean, standard deviation, and coefficient of variation. Others were kurtosis, skewness, analysis of variance and Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Soil Textural Composition

Table 1 shows the distribution of particle sizes in the two soil types under grazed pasture and cultivated field. The grazed soil had a sand concentration of 88.9% at the top 10 cm of both soils, which was substantially greater ($p < 0.05$) than the grazing soil's 73.92%. The percentage of silt and clay particles in the grazed soil was 26.15%, which was considerably greater ($p < 0.05$) than the 9.21% found in the ungrazed pasture soil. For grazed and ungrazed grassland, the two soil textural classes varied from sandy loam to loamy sand, respectively. At a depth of 10 to 20 cm, the two soils' textural compositions distributed similarly. Nevertheless, the grazed soil's texture had significantly changed from sandy loam at the top 20 cm of depth to sandy clay loam at the 20–40 cm depth, and from sandy loam in the top 20 cm to loamy sand down the profile. These findings are in good agreement with those of related studies conducted by Aina (1979), Lal (1986), and Echebiri and Awe (2022), which reported increased amounts of sandy soil on the surface as a result of ongoing cultivation that involved plowing and harrowing, which raised the subsoil to the surface. These studies have been blamed for the change in the landscape. Furthermore, the changing of soil texture has been linked to the loss of fine soil particles (clay and silt) during the water erosion transport process (Lal, 2020 and Franzleubbers, 2021).

Table 1.Textural classes of grazed and cultivated soils

	Sand %	Silt %	Clay %	Silt + Clay	SCR	Texture
			(0-10cm depth)			
Grazed	73.92[a]	10.43[a]	15.72[a]	26.15	0.66	SL
Cultivated	88.90[b]	4.79[b]	4.32[b]	9.21	1.11	LS
LSD	7.3	2.7	5.4	8.7	-	-
			(10-20cm depth)			
Grazed	71.3[a]	12.4[a]	17.12[a]	29.6	0.72	SL
Cultivated	87.1[b]	5.67[b]	7.53[b]	13.2	0.75	LS
LSD	7.6	3.1	5.1	8.2	-	-
			(20-40cm depth)			
Grazed	66.1[a]	12.2[a]	21.2[a]	33.4	0.57	SCL
Cultivated	86.3[b]	5.9[b]	8.8[b]	14.7	0.67	SL
LSD	8.7	2.9	6.2	10.2	-	-

Key: SL = Sandy Loam, LS = Loamy Sand, SCL = Sandy Clay Loam, SCR = Silt: Clay Ratio

Soil Compaction Indices and other Physical Properties

The pressure that animal hoofs exert on the land causes soil compaction. Bulk density (BD) and cone (penetrometer) index (CI) are two good indicators of the degree of soil compaction. From Table 2, on the grazed pasture, BD was averaged 1.71 g/cm3 with CI of 4.65 kg/cm2; both above the critical values of 1.2 g/cm3 and 2.5 kg/cm2 respectively. Comparatively, for the cultivated soil, the mean BD and CI were 1.37 g/cm3 and 1.65 kg/cm2 respectively. It is possible that the high organic matter content subsumed the impact of compaction index on the grazed soil. The GP soil had more stable aggregates compared to the CL as shown by the lower dispersion ratio (54.5). Furthermore, the GP soil had higher infiltration rate and saturated hydraulic conductivity than the soil under CL. Consequently, the GP retained more soil moisture (15%) than the CL soil that was less than 10%.

Table 2.Compaction indices and other physical properties of grazed and cultivated soils

Land use	Min.	Max.	Mean	Std	CV	Skew	Kurt
Grazed							
BD	1.46	1.84	1.71	0.53	30.99	0.44	0.86
CI	3.5	6.75	4.65	0.23	4.95	0.68	1.12
DR	42.2	68.6	54.5	0.51	0.94	-0.35	-0.41
Ir	65.1	92.5	72.2	0.61	0.88	1.17	1.22
Ksat	56.3	75.4	65.8	5.25	7.97	0.16	-0.94
GMC	12.8	24.9	14.8	4.29	29.79	1.38	1.18
Cultivated:							
BD	1.33	1.55	1.37	0.05	3.65	0.14	-0.30
CI	1.35	2.45	1.65	0.21	12.72	0.27	-0.15
DR	71.7	95.8	80.4	11.92	14.83	0.43	-0.22
Ir	30.2	46.3	35.9	5.87	16.35	0.46	-0.17
Ksat	26.3	38.5	33.6	1.19	3.54	0.42	1.39
GMC	8.3	9.8	8.7	1.85	21.26	0.29	-0.75

Key: Min. = minimum, Max. = maximum, Std. = standard deviation, CV (%) = coefficient of variation, Skew. = skewness, Kurt. = kurtosis. Soil Organic Carbon Distribution

On a decadal basis, the SOC stock, or concentration, is a renewable resource that plays a crucial role in determining soil quality, functionality, and ecosystem services (Lal, 2021). The distribution and amount of soil organic carbon in agricultural soils are crucial for managing soil and reducing the effects of climate change. Table 3 shows the distribution of soil organic carbon under the grazed pasture and the ungrazed area. After nearly two decades of cattle grazing, the lowest value of soil organic carbon (SOC) measured at the surface, 0–10 cm depth, was 3.23%, while the maximum value was 12.6% with a mean of 6.77%. These values dropped for depths of 0–10, 10–20, and 20–40 cm, respectively, along the soil profile from 7.67, 5.11, to 2.53%. According to Chandler (2016), soil organic carbon reduced to stable amounts below 40 cm of depth after a steep reduction from the soil surface for a similar soil (an Alfisol). The SOC levels from the grazed pasture were predictably high when compared to findings from research conducted within the same rainforest agro-ecological zone (Aruleba, 2004; Lal, 2020). The constant addition and deposit of urine and cow dung on the plot during almost two-decade period of cattle grazing may be the cause of the elevated readings. Nonetheless, the SOC level from the cultivated plot was extremely low, often less than 1% at all three depths, and the distribution of carbon stock did not much change as one descended in depth. This low organic carbon value was also consistent with findings from comparable soils under long-term farming, which have been reported frequently for various tropical land use regimes (Aina, 1979; Awe, *et al*., 2020; Echebiri and Awe, 2022).

Under tropical agriculture, continuous arable crop production has been linked to the loss of organic matter (Aina, 1979; Adepetu *et a*l., 2014; Lal, 2021). Additionally, the distribution of SOC showed low level of variability (CV < 12%) on the cultivated plot but moderate variation (CV = 12 to 60 %) under animal grazing, according to the classification provided by Warrick and Nielsen (1980).

Table 3. Soil organic carbon distribution of grazed pasture and cultivated land

Land-Use	N	Soil Depth	Min.	Max.	Mean	Std.	CV	Skew	Kurt
Grazed	20	0-10	3.23	12.7	7.67	0.76	23.47	-1.12	0.75
		10-20	2.92	7.85	5.11	0.44	8.71	2.32	3.12
		20-40	2.55	3.22	2.53	0.25	10.12	1.44	1.76
Cultivated	20	0-10	0.45	1.15	0.78	0.04	5.63	0.55	1.09
		10-20	0.52	1.14	0.82	0.05	6.54	0.48	0.48
		20-40	0.49	0.92	0.81	0.03	3.88	0.76	1.12

Key: N = no of soil samples. Soil depth in cm, soil organic carbon in %, CV %= coefficient of variability.

Table 4 displays the soil organic carbon stocks for the two soils. The top 0–10 cm of the soil, which had been grazed by cattle for seventeen years, naturally had the greatest carbon store, measuring 126.55 kg C/ha. At a depth of 20 to 40 cm, the carbon stock value considerably dropped ($p < 0.05$) down the profile to 78.93 kg C/ha. However, the greatest carbon stock was found in the ungrazed plot, with a value of 36.8 kg C/ha at a depth of 20 to 40 cm. No statistically significant variation ($p < 0.05$) was seen in the carbon stock levels of the uppermost 10 and 20 cm of soil. According to Lal (2021), the three main causes of the depletion of the organic carbon store on continuously farmed tropical soils are leaching, water erosion, and organic matter decomposition.

Table 4. Soil organic carbon stocks under grazed and ungrazed pastures

Soil Depth (cm)	SOC Stocks (kg C/ha)	
	Grazed Pasture	Ungrazed Pasture
0-10	136.5a	14.1a
10-20	80.7b	13.7a
20-40	78.9b	36.8b
LSD	21.2	11.7

Key: Values followed by same superscript a or b are not significantly different at $p < 0.05$.

Kome *et al*. (2021) stated that in a comparable study carried out in Cameroun, SOC Stocks varied from 27.1 to 87.3 tonnes/ha at the top 10 cm and 41.1 to 114.9 tonnes/ha for the 20–40 cm soil depth. Franzleubbers (2021) found that SOC under pastures was much higher in the top 12.5 cm depth than under conventionally tilled farmland in another similar study and elsewhere. Franzleubbers (2021) further postulated that approximately half of the maximum SOC accumulation will occur during the first ten years of pasture establishment, while apoo0proximately 80 percent of maximum storage could be expected within 25 years of management. This suggests that the majority of the SOC stock reported in this study may have occurred within the almost two decades of the grazed pasture's existence.

Soil Organic Carbon Sequestration under Grazed and Cultivated Fields

For agricultural soils to be more resilient to the effects of climate change, declining biodiversity, deteriorating water quality, and increased demand for food and fiber production, organic carbon must be sequestered in the soil (Franzeleubbers, 2021). According to several experts, the soil has been shown as the highest sink of organic carbon (Lal, 2021). Table 5 shows how much organic carbon is stored in cultivated and grazed soils. The grazed pasture's soil sequestered 208.81 Mg/ha of organic carbon at the top 10 cm level, while the ungrazed but long-cultivated pasture's soil sequestered 24.11 Mg/ha.

These carbon sequestration values are consistent with those reported by Lal (2021) and Franzleubbers *et a*l. (2021) and declined significantly ($p < 0.05$) down the profile.

Table 5 also showed that the soil that had been grazed by animals for almost two decades had sequestered a total of 455.54 Mg C/ha at the three depths. The quantity of organic carbon sequestered by the soil of the ungrazed pasture, which is 108.35 mg C/ha, is significantly lower ($p < 0.05$) than this value. According to Franzleubbers (2021), there was no difference in soil organic carbon (SOC) between pasture and cropped land below a depth of 12.5 cm. SOC sequestration was highest near the soil surface and decreased with depth. Additionally, it was reported that expectedly effective SOC sequestration will decline over longer time periods, particularly after 25 years. This might not match the data that could be obtained in a tropical climate, where there is a high rate of organic matter leaching and mineralization due to the hot weather and frequent rainfall (Ayoade, 2008; and Lal, 2021).

Table 5. Soil organic carbon sequestration of grazed and ungrazed pastures

Soil Depth (cm)	Grazed Pasture (Mg C/ha)	Ungrazed Pasture (Mg C/ha)	LSD (Mg C/ha)
0-10	208.81^{aa}	24.11^{a}	76.8
10-20	127.55^{b}	23.15^{a}	49.2

20-40	119.18[b]	61.08[b]	28.5
LSD	32.4	11.3	-
Total	455.54	108.35	-

Key: Values followed by same superscript a or b are not significantly different at $p < 0.05$.

Effects of Grazing on Maize Performance

Table 6 provides an overview of how maize crop responded to cattle grazing. Grazing caused a substantial change ($p < 0.05$) in all the parameters (leaf number, leaf area index, plant height, and crop production) in the two cropping years (2021 and 2022). For instance, it was noted that although there was a notable drop in maize yield from 4.3 to 3.1 tons/ha in just one cropping year (2021–2022), this may be explained by elements like crop uptake of nutrients and organic matter (Adepetu, 2014 and Bisrat, 2015) but the yield was still significantly higher than on the cultivated soil which was 0.3 ton/ha. Conservation tillage practices involving minimal disturbance of the soil and mulching holds a good promise of soil restoration for this grazed soil under a long-term continuous cropping and the vulnerability to weather extremes.

Table 6. Effects of grazing on crop performance in the cropping year 2021 and 2022

Crop performance parameters	2021		2022		2021	2022
	GP	CL	GP	CL	LSD	LSD
Leaf Number at 6 WAP	12	8	12	9	2	2
Leaf area index at 6 WAP	4500	620	3420	1005	700	445
Plant height (cm) at 10 WAP	205	68	200	80	44	64
Crop yield tons/ha	4.3	0.3	3.1	0.3	1.6	1.4

SUMMARY AND CONCLUSIONS

This study has highlighted the differences in soil properties obtained from two land use systems: cattle grazing and continuous cultivation. On the grazed pasture, significantly higher bulk density and cone index, both indicators of soil compaction, were recorded than on the cultivated soil. Infiltration rates and saturated hydraulic conductivity were higher on the grazed pasture thus resulting in higher soil moisture retention.

Expectedly, organic carbon stocks and the amount of SOC sequestered on the grazed soils were significantly higher than on the cultivated plot. This improved soil health resulted in higher yield of maize (4.3 tons/ha) on the grazed soil.

This study, going by the heavy addition of organic carbon into the grazed soil and the attendant improvements in water retention and flow plus the expectedly enhanced nutrient level and soil health, has further pointed out the benefits that can accrue from integrating moderate animal grazing into crop cultivation in a tropical environment. Therefore, to achieve a climate smart agriculture, animal grazing at moderate intensity plus conservation tillage should be incorporated into crop farming as such will enhance sustainable crop production.

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