Soil texture and organic carbon stock as influenced by land use in parts of Katsina State, Nigeria

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Abstract

Soil texture and organic carbon content are very important in determining the fertility and health through their impact on structure, drainage and nutrient content. This study estimated organic carbon stock of soils in Katsina State with a view to providing information for improving land management in the area. Five sampling plots were selected on each land use type: farms and parklands in each of the five Locations namely Baure, Sandamu, Zango, Daura and Mai'adua. A total of 5 representative soil core samples were randomly collected at depths of 0-20 and 20-40 cm each in the two land use types. The following soil properties; bulk density, texture, organic carbon (OC) and pH, Organic carbon stock of the bulked soils were determined Findings of the study revealed that sandy loam constitute the major soil textural class of the area. It further revealed that both the highest and lowest organic carbon of bulked soil (0.68 gkg^{-1}) and (0.26 gkg^{-1}) are found on parkland at 0-20 cm depth and 20-40 cm respectively. The study also revealed that the highest carbon stock of the soils is 164.56 g/m^2 (0-20 cm depth) and 235.81 g/m^2 (20-40 cm depth) while the lowest is 67.58 g/m^2 (0-20 cm depth) and 120.52 g/m^2 (20-40 cm depth). The study concluded that carbon stock of the bulked soils is influenced by both land use types and sampling depths. The study recommended the use of deep-rooted crops on agricultural fields to increase carbon storage in soil.

Keywords: Organic carbon, soil fertility, sustainable agriculture, dryland

Introduction

Soil is a fundamental natural resource that plays a vital role in supporting plant growth and sustaining ecosystems. Soil texture and organic carbon are key properties which determine the health and fertility of a given soil. They play a crucial role in agricultural productivity and the overall sustainability of our ecosystems (Zeng *et al.,* 2021). It also influenced the soil's ability to retain and transfer water, nutrients and gases. Soil texture influences its organic carbon storage capacity hence understanding the properties is crucial for sustainable agriculture and land management (Towett *et al.,* 2015; Elbasiouny and Elbehiry, 2020). It also helps in determining which crop thrive in specific soils hence making informed decisions about cropping systems and climate change mitigation depends largely on the knowledge of the properties (Nwite and Alu, 2017; Elbasiouny and Elbehiry, 2020). Increasing carbon stocks in the soil increases soil fertility, workability, water holding capacity, and reduces erosion risk and can thus reduce the vulnerability of managed soils to future global warming (Smith, 2008). It can also significantly improve climate mitigation activities (Zeng *et al.,* 2021). Soil organic carbon enhances activity and species diversity of soil biota and improve soil stability hence an intricate relation with texture is widely studied (Lal, 2015). More so, the two variables vary widely and even rapidly across the globe hence are increasingly studied being important drivers of agricultural sustainability (Lal., 1998; Agrulera *et al.,* 2013).

According to Lal (2016) soil texture and organic carbon are indispensable tools for sustainability of dryland soils hence studying both properties is a practical necessity. It is also vital for effective management of the agro-ecosystem and reducing soil degradation risks and reversing its trends in the dryland. A study by FAO (2017) noted that the dryland soils accounts for more than one third of the global carbon stockand that is a reason whya plethora of works has been carried out on texture and organic carbon of soils in the area. Examples include Lal (2001) had estimated that the dryland can sequester up to 0.4–0.6 gigaton (Gt) of carbon a year if eroded and degraded dryland soils were restored and their further degradation were stopped. Li *et al.* (2017), have indicated that while dryland soils are mostly sandy and have low organic carbon stock, they generally can contain an average of 15-30 tons of carbon per annum the top 30 cm of soil. However, carbon stock in dryland can be highly variable, ranging from less than 10 tons/ha in degraded or desert prone areas to more than 50 tons/ha in well-managed, productive ecosystem (Lal, 2015). However, the soils are facing greater risks from both human and natural factors especially where unregulated land use activities, harsh climate and desertification are eminent (Sarah, 2006; Schlesinger *et al.,*2009). Those factors are expected to influence the rate at which C can be sequestered in these regions to be low (usually less than 1 tonne per ha per year) (Steinfeld and Wassenaar, 2007).

Generally, the aforementioned studies have noted that the soil texture and carbon stock of drylands has undergone changes from farming activities and other land uses. Many soil types have turned carbon emitters rather than sinkers and loses their structure also. Lal (2002) noted that land use change has influence emission from soils to an estimated 0.23 and 0.29 Gt C per year which is around 3 % of all global emissions. In Nigeria, deforestation, overgrazing, nutrient mining, soil erosion, and loss of biodiversity have greatly influenced soil carbon stock of many soil types particularly across the North (Raji and Ogunwole, 2006; Stephen *et al.,* 2016). Sani *et al.* (2019) has also revealed that soil carbon stock and texture under local farming conditions in Northern Nigeria have also changed negatively as a result of loss of vegetation cover, soil erosion and poor land management.

Given the importance of soils to smallholder farming communities in dryland of Northern Nigeria and coupled with the reported high variability and loss of SOC over time in the area, a study of this nature is imperative for understanding the dynamics of soil types and sustainable agriculture in the area. Unlike most studies that used discrete data, this focused on an entire region and different land use types under homogenous management practices and ecological settings. The aim is to assess the texture and SOC at various spatial scales to determine the variability of the two properties across land use types using reliable evidence based data.

Materials and Methods

Study area

The study area comprises five Local Government Areas of Katsina State namely Baure, Sandamu, Zango, Daura and Mai'adua. The area is bordered to the north by Niger Republic to the south and east by Jigawa Stateand to the west by Mashi and Dutsi Local Government Area(Figure 1). The LGAs exhibit similar biophysical attributes and soil management practices which both have impact on SOC stock. The area is a dryland hence her soil is categorised as low class in terms of productivity (Harris, 2000). The major physical characteristics of the study area thatinfluences carbon stock are climate, vegetation, soil types as well as agricultural practices.

Climate of the area is the tropical wet and dry types which are caused by the fluctuations of the Intertropical Discontinuity (ITD) along the apparent movement of the sun (northwards in April – July and southwards in September – October). Rainfall in the area is largely erratic, unpredictable and highly variable. The mean annual rainfall ranges from about 450 mm to about 600mm (Usman *et al.*, 2014). The season lasts for four months from June to September. The onset and cessation periods of the rain are usually associated with violent storm.

Soil in the dryland of northern Nigeria is described as reddish brown ferruginous tropical soils (lithosols). Soils in the area are derived from the Aeolian parent materials overlying quartz-rich geological formations such as crystalline rocks of the basement complex. They are characterized as having sandy texture, covering large areas of land with very low water-holding capacity and low organic matter, nitrogen phosphorus content, neutral or moderately acidic in pH and also having a low cation exchange capacity (Jones and Wild, 1975). They are inherently fragile, low in carbon and poor in plants nutrients and predominantly sandy with low water holding capacity and usually less than 150cm deep (Harris, 2000). The soils have poorly developed weak structure which deteriorates with cropping and compaction (Harris, 2000).

The vegetation type of the study area is Sudan

Savanna which is distinguished by large expanse of grasslands with widely spaced trees of varying heights and diversity. As a result of low rainfall and poor soil fertility, the natural vegetation of the area comprises mainly of thorny shrubs and trees dominated such as Acacias, Euphorbias and short grasses which grow spontaneously during rainy season and hardly reach 0.5 m (Danjuma and Yakubu, 2017). Some of the most frequent species found in the area include *Hyphaenethebaica, Faidherbia albida, Borassus aethiopum, Ziziphus mauitania, Ziziphusspina-christii, Balanite aegyptiaca, Acacia nilotica* and *Azadirachta indica* (Danjuma and Yakubu, 2017).

Procedures

This study involved survey of soil on parkland and farms in Katsina State hence employed free traverse in selection of the two land use types. Reconnaissance survey was first carried out to examine the farming history, management practices as well as variability among the identified systems. A total of 5 representative soil core samples were randomly collected at depths of 0-20 cm and 20-40 cm each in the two land use type sand fifty fields using auger to avoid contamination. The samples were gently placed on a polythene for aeration, packaged on a cotton bag and assigned unique laboratory numbers for identification.Some in situ soil information was taken on a sheet. The samples were taken to laboratory for analysis. At the laboratory, the samples were air-dried, crushed gently with a wooden pestle and mortar to avoid breaking down of the particles. The soils were bulked to form a composite sample.Organic carbon and bulk density were analyzed using Walkley-Black and core sampler methods respectively. Soil pH was determined from saturated pastes at 1:2.5 soils to water ratiousing a glass electrode meterwhile Soil texture was determined using hydrometer method which involved suspending soil particles in water and measuring their settling rate in line with Stoke's Law. The density of suspension is determined atthe centre of buoyancy of the hydrometer (Bouyoucos hydrometer measurements) (Gee and Bauder, 1986). Organic carbon stock of bulked soil was calculated using the following formula:

SOC stock =H xBDxOCx10 ....Eq. 1 in line with Zeng *et al.* (2021).

Where,

H is the soil depth (cm), BD is the bulk density (gcm^3), OC is the soil organic carbon concentration in bulk soil (gkg^1) and 10 is a constant.

Results and discussion

Texture of the Soils

Findings of the study revealed that the main soil textural classes on both land use types are sandy loam and loamy sand. However, those are not fix as variations occur in terms of the textural class among the study locations and across the land use types. For instance, soils obtained from farms in Mai'adua and Daura which arethe northernmost locations have the highest percentage of sand while that of Baure has the least (Table 1). The parkland has relatively low sand except in Mai'adua (which is high) hence the textural class is sandy loam.

This is in line with Jones and Wild (1975) and Obalum *et al.* (2012), who reported that soils of savannah are predominantly sandy and often low in organic matter content. This finding suggests that low rainfall and poor vegetation growth are responsible for the sandy nature of the soils as suggested in Sufardi *et al.* (2021). The implication of this findings is that the soils may have high drainage and aeration potential and low water retention capacity and low ability to hold nutrients which pose challenges to plant growth. Thus, the soil types requires higher fertilization and more frequent applications of amendments.

Organic Carbon Stock of the Soils

The findings of the study revealed that both the highest and lowest organic carbon of soils (0.68 gkg^{1}) and (0.26 gkg^{1}) are found on parkland at 0-20 cm depth and 20-40 cm respectively. There is significant variation in organic carbon content of the soil between land use types and sampling depths across the study locations. All the study locations showed relatively lower SOC stocks at both top (0-20 cm) and subsoil (20-40 cm). The study revealed that the highest carbon stock of the soils is 164.56 g/m^2 (0-20 cm depth) and 235.81 g/m^2 (20-40 cm depth) while the lowest is 67.58 g/m^2 (0-20 cm depth) and 120.52 g/m^2 (20-40 cm depth). Further revealed was that the agricultural lands have low organic carbon resulting from depletion of soils nutrients and minimal vegetation cover while the parklands have relatively high organic carbon in except in Mai'adua which is at the northernmost owing to the depletion of such ecosystems. However, the topsoil has higher soil organic carbon despite high agricultural pressure on lands as indicated by the prevalence of cultivable lands.

The SOC pool in both lands are beyond the recommended threshold of 15-20 g kg-1 which indicated that the soil quality needs restoration and maintenance. In line with many studies (Tondoh *et al.*, 2016; Lal, 2015; Kanye *et al.*, 2019), high pressure on lands from both farming and livestock activities reduces biomass accumulate, which in turn affects organic carbon content at both top and sub-soils in drylands.

Conclusion

This study highlight the variability of soil texture and carbon stock on different land use types and sampling depths. The study indicated that soil texture is not consistent among the land use types while organic matter is low in the study area. The study concluded that carbon stock of the bulked soils is influenced by both land use types and sampling depths. Soils obtained from the farms have the least organic carbon stock at both sampling depths except in Mai'adua which is more arid and susceptible to depletion of top soil. The soils are fragile, low in carbon and poor in plants nutrients. The study thus provided insights for promoting sustainable agricultural practices.Being crucial to water retention and infiltration in dryland soils, organic carbon if maintained can put both land use types to use and reduce their water scarcity and buffer erosion hazard in the study area.

Recommendations

1. The study recommended that farmers should avoid excessive tillage as it can break up the soil particles and increase evaporation with a view to preserving the soil structure.
2. This study recommended the use of deep-rooted crops as well as manure (cow dung and crop residues) in combination with synthetic fertilizers on agricultural fields to increase soil carbon stock.

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Table 1: Textural Classes of Soil obtained from two land use types

Study Location	Land use type	%Sand	%Clay	%Silt	Texture
Baure	Farm	75.24	12.76	12.0	Sandy Loam
	Parkland	63.24	20.76	16.0	Sandy Clay Loam
Sandamu	Farm	83.24	8.76	8.0	Sandy Loam
	Parkland	78.77	11.52	9.71	Sandy Loam
Zango	Farm	85.24	8.76	6.0	Loamy sand
	Parkland	57.26	12.76	29.98	Loam
Daura	Farm	88.62	7.56	3.81	Loamy sand
	Parkland	78.44	12.76	8.8	Sandy Loam
Mai'adua	Farm	89.72	8.28	2.0	Loamy sand
	Parkland	79.24	12.76	8.0	Sandy Loam

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Table 2: Bulk Density and Organic Carbon Stock of Soil

Study Location	Land Use Type	Organic Carbon of Bulk Soil (gkg^{1})		Bulk Density (g/cm^3) of Soil		Soil Carbon Stock g/m^2	
		0-20	20-40	0-20	20-40	0-20	20-40
Baure	Farm	0.34	0.31	1.16	1.31	78.88	162.44
	Parkland	0.56	0.42	1.11	1.28	124.32	215.04
Sandamu	Farm	0.46	0.32	1.19	1.36	109.48	174.08
	Parkland	0.68	0.45	1.21	1.31	164.56	235.81
Zango	Farm	0.31	0.28	1.09	1.33	67.58	148.96
	Parkland	0.44	0.31	1.25	1.22	110.00	151.28
Daura	Farm	0.43	0.26	1.13	1.36	97.18	141.44
	Parkland	0.56	0.33	1.22	1.32	136.64	174.24
Mai'adua	Farm	0.43	0.32	1.06	1.27	91.16	162.56
	Parkland	0.35	0.23	1.14	1.31	79.80	120.52