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Assessing soil carbon sequestration potential by measuring clay, sand, and silt content in agroforestry parkland systems along a rainfall gradient in Burkina Faso, West Africa

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Soil texture and precipitation influence soil organic carbon sequestration. This research measured soil texture to assess the potential for organic carbon sequestration in soils within agroforestry parklands, considering a gradient of rainfall levels. The study aims to provide site-specific recommendations to promote agroforestry as a strategy for mitigating climate change in Burkina Faso. Soil samples were collected from depths of 0-10 cm, 10-20 cm, and 20-30 cm within agroforestry parklands containing Vitellaria paradoxa C. F Gaertn (Karite) and Parkia biglobosa (Jacq.) Benth (Nere) trees. These parklands are located in Tougouri, Nobere, and Sokouraba, which correspond to the Sahelian, Sudano-Sahelian savanna, and Sudano-Guinean savanna zones, respectively. The clay, silt, and sand content in the soil were measured using the spectrophotometry infrared method. The soils from all sites exhibited a balanced texture. Clay content emerged as a key factor influencing soil organic carbon sequestration, with higher percentages found at Sokouraba (30.499 ± 0.456%) and Tougouri (30.980 ± 0.451%). This trend was also observed in the 10-20 cm (27.861 ± 0.474%) and 20-30 cm (31.759 ± 0.498%) soil layers at both Sokouraba and Tougouri. Given that precipitation plays a crucial role in soil organic carbon sequestration, the findings suggest that Sokouraba is a suitable candidate for promoting agroforestry as a climate change mitigation strategy.

Key words: Texture, mitigation, ecophysiology, agriculture, climate.

INTRODUCTION

The contribution of Burkina Faso, like many other African countries, to the emission of greenhouse gases that cause climate change is relatively low (Diop, 2015; Lacour et al., 2020). However, climate change's impact on Burkina Faso is evident through the increase in extreme climatic events, such as droughts and floods, which are becoming more frequent and severe (Traore and Owiyo, 2013). These events are anticipated to have significant adverse effects on agricultural sector productivity due to its heavy reliance on rainfall (Doso-

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Jnr, 2014). Mitigation is one of the strategies employed to address the effects of climate change. It involves implementing actions aimed at reducing greenhouse gas emissions, primarily carbon dioxide, or capturing and removing these gases from the atmosphere (Fawzy et al., 2020). Carbon sequestration, which entails the removal of carbon from the atmosphere and its storage in carbon pools, plays a crucial role in climate change mitigation (Dhanwantri et al., 2014). Soil serves as a vital reservoir for sequestering atmospheric carbon, effectively transforming it into a stable solid form through direct or indirect fixation of carbon dioxide (Olson, 2014).

Direct fixation involves the natural conversion of carbon dioxide into inorganic components in the soil, such as calcium and magnesium carbonates. On the other hand, indirect fixation occurs through the production of plant biomass via photosynthesis (Lal, 2008). This biomass, generated by plants, eventually makes its way into the soil, leading to the indirect sequestration of carbon in the form of soil organic carbon during and after the decomposition process (Lal, 2008). The practice of agroforestry, therefore, contributes to climate change mitigation in several ways, including carbon sequestration in the soil through organic matter (Lorenz and Lal, 2014). Carbon sequestration in soils is influenced by various factors, including soil texture, such as clay (Kahle et al., 2003; Konen et al., 2003), silt (Six et al., 2002; Christopher and Lary, 2016; Zhang et al., 2022), and climatic factors, primarily temperature and rainfall (Zhang et al., 2022). Agroforestry parkland systems have seen significant expansion in Burkina Faso. However, only a limited amount of research has measured the sequestration potential of soils within these systems along a climatic gradient.

For Burkina Faso, which is actively involved in the process of reducing emissions from deforestation and degradation (REDD+), studies of this nature hold significance. They provide valuable information to policy makers, technical experts, and financial partners, guiding their future investments in climate change mitigation. The objective of this research was to assess the soil texture and organic carbon sequestration potential within agroforestry parkland systems, considering a gradient of rainfall levels. The findings aim to offer site-specific recommendations for promoting agroforestry as a strategy to mitigate climate change in Burkina Faso.

MATERIALS AND METHODS

Site description

The soil survey was conducted at three distinct sites along an increasing rainfall gradient: Tougouri (with the lowest studied rainfall level), situated at 13˚ 18' 59'' latitude North and -3˚ 12' 1'' longitude West within the Sahelian zone (northern part); Nobere (with the middle studied rainfall level), located at 11˚ 33' 29'' latitude North and -1˚ 12' 16'' longitude West within the Sudano-Sahelian savanna (central part); and Sokouraba (with the highest studied rainfall level), positioned at 10˚ 51' 00'' latitude North and -5˚ 11' 00'' longitude West within the Sudano-Guinean savanna (southern part). The average annual rainfall and temperature (for the years 1980-2013) were 557 mm and 26.6°C in Tougouri, 859 mm and 25.7°C in Nobere, and 1061 mm and 25.1°C in Sokouraba, according to data from DGM (2013). The average annual rainfall amounted to 620 mm in Tougouri, 775 mm in Nobere, and 927 mm in Sokouraba.

Experimental design

The studied parklands systems consisted of a parkland system with two native tree species: Karite and Nere. The area around each of the sampled trees was split into three concentric tree influence zones and was:

Zone A - from tree trunk to half of the crown radius of the tree;
Zone B - from half of the crown radius of the tree up to the edge of the crown;
Zone C - from the edge of the tree crown up to 3 m away.

This design was replicated eight times for each tree species at each site to give a total of forty-eight (= 8 reps × 2 species × 3 zones) sampling positions in Sokouraba, Nobere and Tougouri.

Data collection

Soil sampling was conducted in a randomized manner at two distinct points within each concentric zone, with depth intervals of 10 cm, reaching up to a depth of 30 cm (0-10; 10-20; 20-30 cm). An auger with a diameter of 5 cm and a volume of 250 cm^3 was utilized for this purpose. The selection of a maximum sampling depth of 30 cm was based on the fact that the soil interval of 0-30 cm encompasses the majority of root activities and variations in soil organic matter (Christopher and Lary, 2016). To create a composite sample for soil analysis, the two soil samples from the same depth and zone were mixed, resulting in a total volume of 500 cm^3. The spectrophotometry infrared method, as described by Shepherd and Walsh (2002) and Du and Zhou (2009), was employed to measure the clay, sand, and silt content in the soil. This method operates on the principle that distinct soil components absorb near rays to varying degrees based on their prevalence within the sample.

The composite soil samples were air-dried, sieved using a mesh with a 2 mm aperture, and subjected to scanning using both Near Infrared (NIR) and middle infrared (MIR) spectrophotometry. The spectrophotometer used for these scans was the "Bruker Fourier-Transform MultiPurpose Analyzer spectrometers (MPA)" from Bruker Optik GmbH, Germany, equipped with software capable of predicting clay, sand, and silt content in soil. For scanning purposes, soil subsamples of approximately 20 g were extracted from each composite dried soil sample and placed into petri dishes. Additionally, a subset comprising 10% of the entire soil samples was chosen for more detailed analysis. Clay, sand, and silt content in this subset were determined using a wet chemistry approach in a laboratory setting. The results obtained from the laboratory's wet chemistry analysis were used to assess the accuracy of the predictions made by the software integrated into the spectrophotometer, achieved through calibration processes.

Statistical analysis

The textural classes of the soil in the different sites were estimated using the mean for the different textural components calculated with Excel software and using the triangle of textures. The effect of sites, soil layers and their interaction on clay, sand and silt content in soil were tested using the general model of ANOVA. When the differences among the means were significant with ANOVA, they were separated by the test of Student-Newman Keuils at 5%. The analyses have been done using the software XLSTAT 2022.

RESULTS

The textural classes determined at each of the study sites are clay-sandy silt. The percentage of the textural components of the soils at each site is presented in Table 1. The results of the ANOVA test revealed a highly significant effect of sites and layers on clay content in soil (Table 2). The clay content in soil was significantly higher at the Sokouraba and Tougouri sites compared to the Nobere site (Figure 1a). The clay content in soil increased with the soil depth and it was significantly higher in the layer 20-30 cm compared to the layers 0-10 cm and 10-20 cm (Figure 1b). The results of the ANOVA test showed a very significant interaction between sites and layers on the clay content in soil (Table 2). The clay content in soil increased with soil depth and it was significantly higher in the layer 20-30 cm at each study sites (Figure 1c). The clay content in soil was significantly higher for the layer 0-10 cm at the site of Tougouri (Figure 1c). The clay content in soil was significantly higher for the layers 10-20 cm and 20-30 cm at the site of Sokouraba and Tougouri (Figure 1c).

The results of the ANOVA test showed a highly significant effect of sites and layers on the soil content in sand (Table 2). The results of ANOVA test did not show a significant interaction between sites and layers on sand content in soil (Table 2).

The sand content in soil was significantly higher at Nobere site compared to Sokouraba and Tougouri sites (Figure 2a). The sand content in soil decreased with soil depth and it was significantly higher in the layer 0-10 cm compared to the layers 10-20 cm and 20-30 cm (Figure 2b).The results of the ANOVA test showed a highly significant effect of sites, layers and their interaction on silt content in soil (Table 2). The silt content in soil was significantly higher at Nobere site compared to Sokouraba and Tougouri sites (Figure 3a). The silt content in soil decreased with the soil depth and it was significantly higher at the layer 0-10 cm compared to the layers 10-20 cm and 20-30 cm (Figure 3b). The silt content in soil was significantly higher in the layer 0-10 cm compared to the layers 10-20 cm and 20-30 cm at Nobere site while it was not statistically different between the layers at Sokouraba and Tougouri sites (Figure 3c). The silt content in soil was significantly higher for the layers 0-10, 10-20 and 20-30 cm at Nobere site (Figure 3c).

DISCUSSION

Soil texture plays a crucial role in determining the availability of water and nutrients for plants, primarily due to its impact on infiltration and moisture retention (Sperry and Hacke, 2002). Additionally, soil texture influences the depth of root development, as it affects moisture retention in the soil (Jackson et al., 2000). The soil at the three study sites exhibited a clay-sandy silt texture, characterized by a mixture of clay, sand, and silt, commonly referred to as loamy soil. Sperry and Hacke (2002) noted that this particular soil texture may not be conducive to optimal plant growth during dry periods due to its negative effects on gas exchange and deep root development. This physical trait of the soil could be one of the factors constraining agricultural productivity in Burkina Faso, a region located in the Sahel characterized by an extended dry season and frequent droughts throughout the agricultural period (Coulibaly, 2005). While the textural classes were consistent across all study sites, the content of textural components varied based on the sites and the depths of soil sampling. Specifically, clay content in the soil was notably higher at the Sokouraba and Tougouri sites, with Tougouri exhibiting a greater significance of clay content. The elevated clay content at these sites enhances their capacity to sequester carbon in the soil, aligning with previous findings that identify clay as a soil texture that positively influences the accumulation and fixation of organic carbon (Kahle et al., 2003; Konen et al., 2003). These high clay content sites experience differing levels of rainfall, and rainfall has been identified as a factor impacting carbon sequestration in the soil (Zhang et al., 2022). Increased rainfall contributes to greater carbon sequestration through the substantial accumulation of organic matter in the soil (Zhang et al., 2022). Studies by Coulibaly et al. (2014, 2020) revealed that agroforestry parkland systems with Karite and Nere trees at the Sokouraba site exhibited higher soil total carbon compared to Tougouri and Nobere sites. Increased precipitation was linked to significant aboveground tree biomass accumulation in agroforestry parkland systems, as demonstrated by Coulibaly et al. (2014), further supported by Panwar et al. (2022), who reported that heightened plant biomass leads to increased carbon sequestration in the soil. The clay content in the soil exhibited an increase with soil depth, with the highest values recorded in the 20-30 cm layer. This trend was consistent across all sites, and the Sokouraba and Tougouri sites consistently displayed higher clay content at every depth layer. These findings present promising opportunities for enhanced carbon sequestration at greater depths within the soils of agroforestry parkland systems at these two sites. Previous research conducted by various authors (Rumpel and Kogel-Knabner, 2011; Mathieu et al., 2015; Shi et al., 2020; Miko et al., 2021) has indicated that deeper carbon sequestration leads to a more stable retention of the sequestered carbon. Carbon stabilization in soil, defined as the reduction in potential carbon loss due to microbial respiration, erosion, or

Table 1. Percentage of the soil textural components at Nobere, Sokouraba and Tougouri sites.

Site	Sand (%)	Clay (%)	Silt (%)
Nobere	53.02	22.31	22.90
Sokouraba	48.02	30.50	20.12
Tougouri	47.31	30.98	18.95

Table 2. Results of the ANOVA test of the effect of sites, layers and their interaction on clay, sand and silt content in soil.

Soil parameter	Source	DDL	Sum of squares	Mean of squares	F	Pr> F
Clay	Sites	2,000	6839,708	3419,854	218,220	<0.0001
	Layers	2,000	4148,560	2074,280	132,359	<0.0001
	Sites×Layers	4,000	223,041	55,760	3,558	0.007
Sand	Sites	2,000	2784,246	1392,123	78,451	<0.0001
	Layers	2,000	3847,187	1923,593	108,402	<0.0001
	Sites×Layers	4,000	139,347	34,837	1,963	0.099
Silt	Sites	2,000	1185,764	592,882	812,147	<0.0001
	Layers	2,000	67,834	33,917	46,460	<0.0001
	Sites×Layers	4,000	37,217	9,304	12,745	<0.0001

Significant = P < 0.05; very significant = P < 0.01; highly significant = P < 0.001.

leaching (Sollins et al., 1996), has been recognized as a crucial factor in climate change mitigation through soil carbon sequestration (Miko et al., 2021). Considering the limited rainfall observed at the Tougouri site, it may be more appropriate to promote agroforestry practices at this location for climate change adaptation, rather than mitigation. Indeed, the contribution of agroforestry to climate change adaptation, particularly in enhancing crop productivity in arid regions, has been highlighted by Bayala et al. (2006).

While several authors have attributed a positive influence on soil carbon sequestration to clay as a soil textural component, recent research has suggested that silt or a combination of silt and clay may exert a more significant impact on the potential for carbon sequestration in soil (Six et al., 2002; Christopher and Lary, 2016; Zhang et al., 2022). Christopher and Lary (2016) and Zhang et al. (2022) have further emphasized that the influence of soil textural components on soil carbon sequestration capacity is contingent upon the geographical context of the soils. This underscores the need for site-specific climate change mitigation prediction models based on soil carbon sequestration.

The Nobere site exhibited higher silt content in the soil, while simultaneously possessing lower clay content. Moreover, the silt content decreased with increasing soil depth, mirroring this trend across all sites. Nobere site consistently displayed higher silt content for all depth layers. Despite the recognized positive influence of silt content as a soil textural component on soil carbon sequestration (Christopher and Lary, 2016; Zhang et al., 2022), Coulibaly et al. (2020) reported a low soil total carbon at the Nobere site. This observation aligns with Christopher and Lary (2016), who emphasized the necessity of site-specific measurements for evaluating the carbon sequestration capacity of soil textural components. At the Nobere site, the sand content in the soil was notably higher, particularly in the 0-10 cm layer. This prevalence of sand content likely diminished the impact of the substantial silt content on carbon sequestration, which could help explain the low soil total carbon reported by Coulibaly et al. (2020). Sandy soils are generally more aerated, possess limited adsorption capacity, and retain lower amounts of organic carbon (Yost and Hartemink, 2019). This combination of factors could have contributed to the observed pattern. The complexities of soil texture, as demonstrated in your study, underscore the importance of considering various soil properties when assessing carbon sequestration potential and its implications for climate change mitigation.

Conclusion

The clay and silt content in the soil represent crucial parameters for evaluating the potential of soil carbon sequestration. This research aimed to gauge soil texture's impact on the carbon sequestration potential of soils within agroforestry parkland systems, considering a

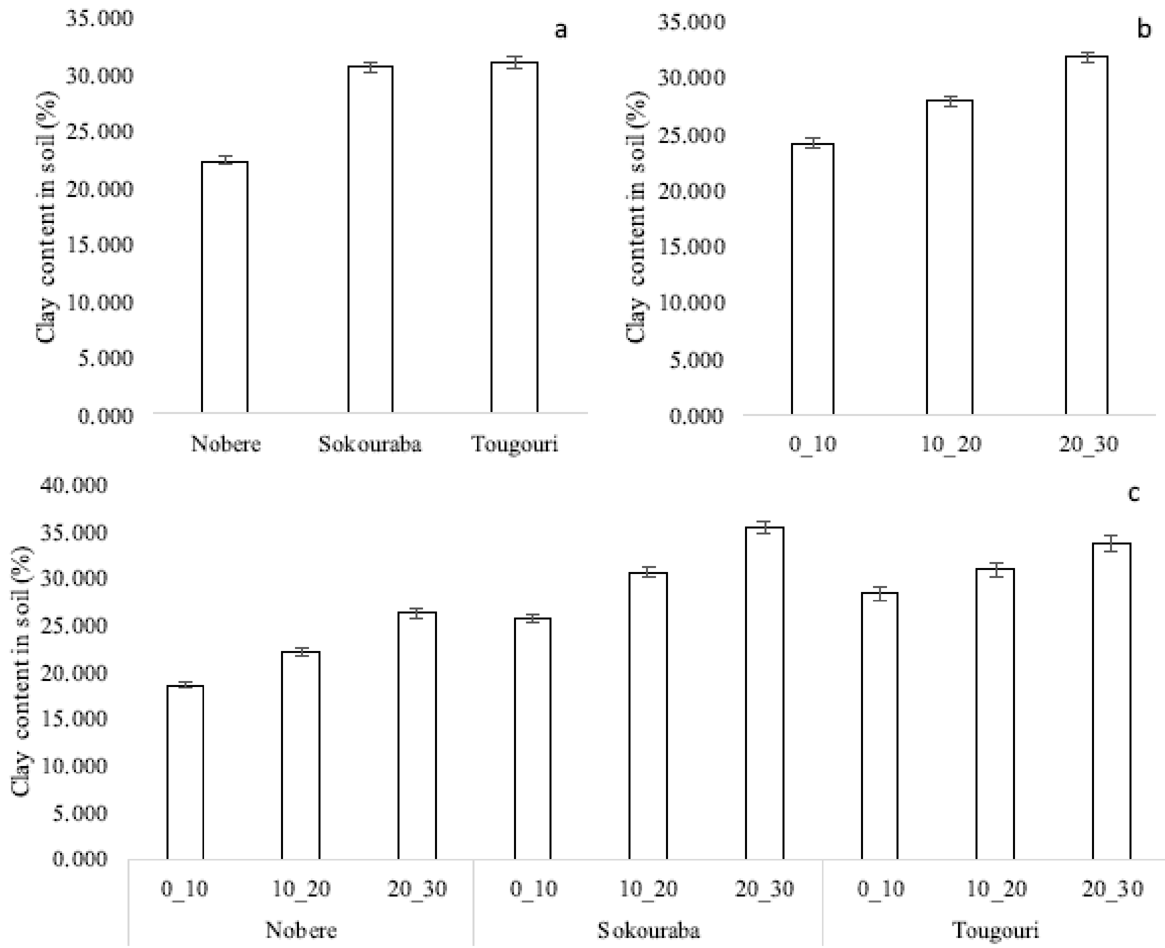

Figure 1. a-variation of the clay content in soil according to the sites, b-variation of the clay content in soil according to the soil layers and c-variation of the clay content in soil between soil layers according to the sites.

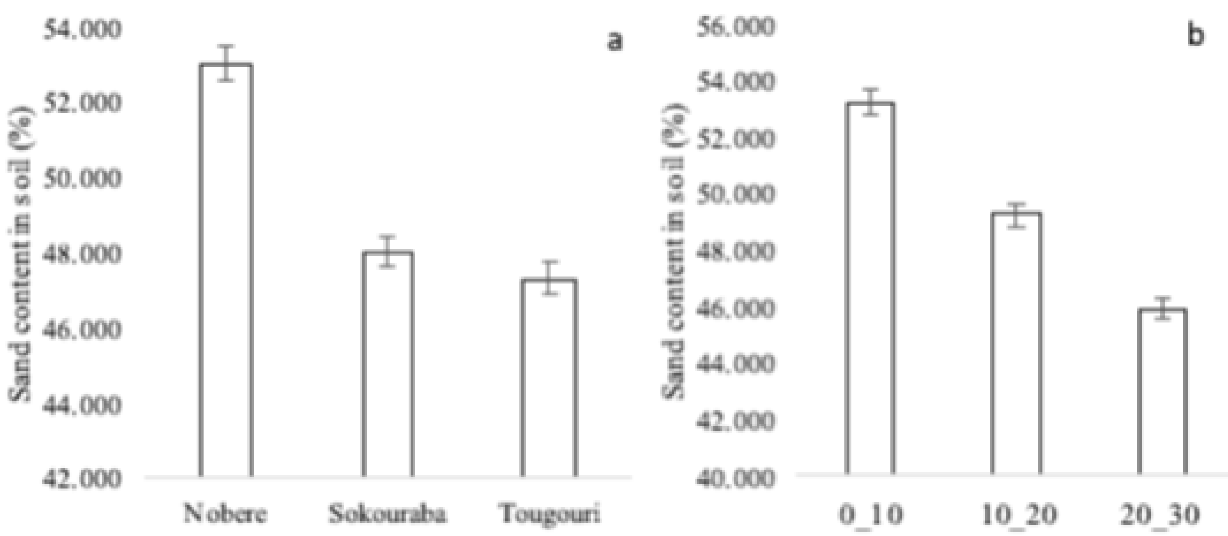

Figure 2. a-variation of the sand content in soil according to the sites, b-variation of the sand content in soil according to the soil layers.

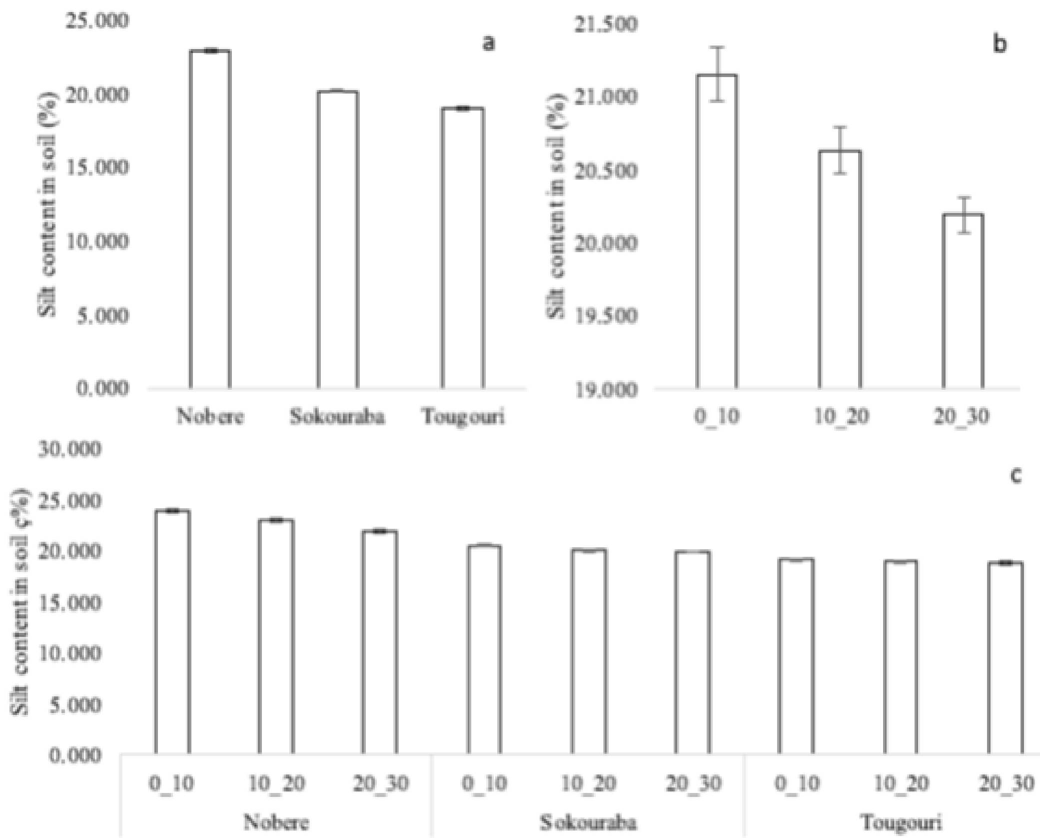

Figure 3. a-variation of the silt content in soil according to the sites, b-variation of the silt content in soil according to the soil layers and c-variation of the silt content in soil between soil layers according to the sites.

gradient of rainfall levels. Across all study sites, the soils exhibited a well-balanced texture that is conducive to crop development. Among the soil textural components, clay content emerges as a significant factor influencing soil carbon sequestration. Notably, higher clay content was observed at deeper levels in the Sudano-Guinean savanna zone's Sokouraba site and the Sahelian zone's Tougouri site. Rainfall, a pivotal factor in soil carbon sequestration, drives the accumulation of both aboveground and below ground plant biomass, subsequently contributing to the organic matter content in the soil. Given these considerations, the Sokouraba site in the Sudano-Guinean savanna zone is well-positioned for agroforestry promotion as a climate change mitigation strategy.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Bayala J, Balesdent J, Marol C, Zapata F, Teklehaimanot Z, Ouedraogo SJ (2006). Relative contribution of trees and crops to soil carbon content in a parkland system in Burkina Faso using variations in natural 13C abundance. Nutrient Cycling in Agroecosystems 76:193-201.

Christopher A, Larry JC (2016). Relationships between soil carbon and soil texture in the northern great plains. Soil Sciences 181:386-392.

Coulibaly YN (2005). Recherche de paramètres de tolérance et de sensibilité à la sécheresse chez le sorgho (*Sorghum bicolor* (L.) Moench) au jeune âge. Available at: http://bibnum.ucad.sn/viewer.php?c=mmoires&d=MemS_3082

Coulibaly YN, Mulia R, Sanou J, Zombré G, Bayala J, Kalinganire A, van Noordwijk M (2014). Crop production under different rainfall and management conditions in agroforestry parkland systems in Burkina Faso: observations and simulation with WaNuLCAS model. Agroforestry Systems 88:13-28.

Coulibaly YN, Bayala J, Gaiser T, Zombré G (2020). Assessing tree effect on total soil carbon in agroforestry parklands systems along a rainfall gradient in Burkina Faso (West Africa). International Journal of Biological and Chemical Sciences 14(9):3030-3046.

Dhanwantri K, Sharma P, Mehta S, Prakash P (2014). Carbon sequestration, its methods and significance. Environmental Sustainability Concepts Principles Evidences Innovations 151(2):56-61.

Diop M (2015). COP21: une chance à saisir pour l'Afrique. Géoéconomie 5(77):63-71.

Direction Générale de la Météorologie (DGM) du Burkina Faso (2013). Base de données climatiques du Burkina Faso, Ouagadougou, Burkina Faso.

Doso-Jnr S (2014). Land degradation and agriculture in the Sahel of Africa: Causes, impacts and recommendations. Journal of Agricultural Science and Applications 3:67-73.

Du C, Zhou J (2009). Evaluation of soil fertility using infrared

spectroscopy: a review. Environmental Chemistry Letter 7: 97-113.
Fawzy S, Osman AI, Doran J, Rooney DW (2020). Strategies for mitigation of climate change: a review. Environmental Chemistry Letters 18:2069-2094.
Jackson RB, Sperry JS, Dawson TE (2000). Root water uptake and transport: using physiological processes in global predictions. Trends in Plant Science 5:482-488.
Kahle M, Kleber M, Torn MS, Jahn R (2003). Carbon storage in coarse and fine clay fractions of ilitic soil. Soil Science Society of American Journal 67:1732-1739.
Konen ME, Burras CL, Sandor JA (2003). Organic carbon, texture and quantitative color measurement relationships for cultivated soils in North Central Iowa. Soil Science Society of American Journal 67:1823-1830.
Lacour MA, Steven JD, Benis NE (2020). Trends and drivers of African fossil fuel CO2 emissions 1990-2017. Environmental Research Letters 15(12):124039.
Lal R (2008). Carbon sequestration. Philosophical Transactions of the Royal Society B. Biological Sciences, 363:815–830.
Lorenz K, Lal R (2014). Soil organic carbon sequestration in agroforestry systems. A review. Agronomy for Sustainable Development 34:443-454.
Mathieu JA, Hatté C, Balesdent J, Parent É (2015). Deep soil carbon dynamics are driven more by soil type than by climate: a worldwide meta-analysis of radiocarbon profiles. Global Change Biology 21:4278-4292.
Miko UFK, Don A, Michael HB, Mike JH, Roberto CP, Denis C, Sam RM, Erin JLS (2021). Sequestration of soil carbon by burying it deeper within the profile: A theoretical exploration of three possible mechanisms. Soil Biology and Biochemistry 163:108432.
Olson KR (2014). Soil organic carbon sequestration, storage, retention and loss in U.S. croplands: Issues paper for protocol development. Geoderma, 196:201-206.
Panwar P, Mahalingappa DG, Kaushal R, Bhardwaj DR, Chakravarty S, Shukla G, Thakur NS, Chavan SB, Pal S, Nayak BG, Srinivasaiah HT, Dharmaraj R, Veerabhadraswany N, Apshahana K, Suresh CP, Kumar D, Sharma P, Kakade V, Nagaraja MS, Singh M, Das S, Kanchan MT, Roy AD, Gurung T (2022). Biomass production and carbon sequestration potential of different agroforestry systems in India: A critical Review. Forests 13(8):1274.
Rumpel C, Kogel-Knabner I (2011). Deep soil organic matter-a key but poorly understood component of terrestrial C cycle. Plant and Soil 338:143-158.
Shepherd KD, Walsh MG (2002). Development of reflectance spectral libraries for characterization of soil properties. Soil Science Society of America Journal 66:988-998.
Shi SD, Allison YJH, Levine PA, Hoyt AM, BeemMiller QZ, Wieder WR, Trumbore S, Randerson JT (2020). The age distribution of global soil carbon inferred from radiocarbon measurements. Nature Geoscience 13:555-559.
Six J, Conant RT, Paul EA, Paustian K (2002). Stabilisation mechanisms of soil organic matter: implication for C-saturation of soils. Plant and Soil 241:155-176.
Sollins P, Homann P, Caldwell BA (1996). Stabilization and destabilization of soil organic matter: mechanisms and controls. Geoderma 74(1-2):65-105.
Sperry JS, Hacke UG (2002). Desert shrub water relations with respect to soil characteristics and plant functional type. Functional Ecology 16:367-378.
Traore S, Owiyo T (2013). Dirty droughts causing loss and damage in Northern Burkina Faso. International Journal of Global Warming 5:498-513.
Yost JL, Hartemink AE (2019). Soil organic carbon in sandy soils: A review. Advances in Agronomy 158:217-310.
Zhang Y, Li P, Liu X, Xiao L, Li T, Wang D (2022). The response of soil organic carbon to climate and soil texture in China. Frontiers of Earth Science 16:835-845. \\192.168.1.30\all operations 2023\AGRIC SCIENCES DATA\AJAR\DOWNLOAD\2023\6.June\AJAR-16.06.23-16426\Review\From Author