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Carbon Sequestration Potential of Cashew (*Anacardium occidentale* L.) Plantations Across Climatic Gradients in Togo

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The current study seeks to estimate the carbon sequestration capability of a cashew plantation in Togo as a function of climate gradient. The research was conducted in the Guinean and Sudanian climatic zones, on farmers' cashew plantations. The study was run from March to October 2023.

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This study was carried out in ten (10) cashew farms (five per climatic zone) which have ten years old. Cashew trees were classed based on their diameter at breast height (0-5 cm, 5-10 cm, 10-15 cm, and > 15 cm). To measure carbon stock in the biomass, allometric equations were utilized, and soil carbon stock was assessed using laboratory analysis**.** The Guinean zone has a higher soil carbon stock (86.89 ± 4.06 t C/ha) compared to the Sudanian zone (80.23 ± 3.78 t). The same trend can be observed in the various cashew tree components (trunk, branches and leaves). In general, the tree trunk had 79% of the carbon supply, compared to 19% and 2% in the branches and leaves, respectively. Carbon sequestration in the soil varies depending on the climatic zone and the soil depth (0-25 cm; 25-50 cm). Cashew-based cropping systems might be deemed carbon-efficient.

Keywords: Carbon sequestration; biomass; cashew tree (Anacardium occidentale L.).

1. INTRODUCTION

Human activity is currently altering the natural exchanges of carbon (C) between the atmosphere, the oceans, and terrestrial ecosystems. The combustion of fossil fuels in the northern hemisphere and the conversion of tropical forests to agricultural land are the causes of these changes (Paustian et al., 2000). Carbon dioxide (CO_2) levels in the atmosphere hit 400 parts per million (ppm) in early May 2013 (Ralph, 2013). Due to shifts in land use and management practices, the African continent is responsible for 17% of global carbon emissions (Canadell et al., 2009). A total of 48% of Africa's carbon emissions are attributable to changes in land use patterns. At a rate of roughly 2 parts per million annually, this level has most likely not been reached in the last 20 million years (Hansein, 2004). Since the savanna is cultivated and wood is taken for electricity and coal extraction, tropical habitats are generally seen as sources of CO_2 rather than sinks (Tinlot, 2010). Three significant climate threats in West Africa are highlighted as drought, late rains, severe and poorly distributed rains, and floods (Agossou et al., 2012). Ago (2016) asserts that forest ecosystems and resources are critical to climate resilience because they preserve water supplies, produce food, lessen the effects of natural disasters, and supply organic matter that enhances soil fertility, stores carbon, and supports farmers' livelihoods. Soil quality will be directly impacted by carbon sequestration and an increase in soil organic matter. According to Peichl et al. (2006), agroforestry systems store carbon in the aerial and root biomass of trees.

Biomass: Plant biomass may store a significant quantity of carbon. Forest plantations and the preservation of old forests are crucial for regulating the amount of the total terrestrial carbon sink since forests store almost 90% of the world's terrestrial carbon. For instance, it has been calculated that forests in the Northern Hemisphere may store up to 0.7 GT of carbon (C) per year, or over 10% of the world's current carbon emissions from fossil fuels (Goodale et al. 2002). Living biomass accounted for 0.2 GT annually, dead wood for 0.15 GT annually, and soil and forest floor carbon for 0.13 GT annually. Forest goods accounted for the remaining.

Soil carbon derived from roots: The majority of carbon (C) entering the soil carbon pool is primarily transported by roots. The amount of carbon (C) stored in the soil in temperate and boreal forests is roughly four times that of the vegetation and 33% greater than the total amount of C stored in tropical forests (IPCC 2000). Another significant environment for soil carbon sequestration is grasslands, which make up 50% of the Earth's surface, or over 1.2 billion hectares (ha), and are often characterized here as ecosystems with a preponderance of herbaceous vegetation. 98% of the total C stored in grasslands is stored underground in the soil and roots. An estimated 194 GT of carbon are stored in grassland soils worldwide, making up around 8% of all soil carbon. The whole soil carbon pool has a potential sequestration capability that is at least equal to the amount lost to soil erosion and deterioration in the preindustrial and industrial periods (Ipinmoroti and Ojo Akanbi, 2014; Victor et al., 2021). The amount of this loss is unknown; estimates range from 44 to 537 GT for the soil organic carbon portion (Lal, 2004). By implementing land-management modifications such as afforestation, reforestation, and improved farming techniques, it has been proposed that 80 to 130 GT might be sequestered as SOC over a 50- to 100-year period (Thomson et al., 2008).

As C sinks, plants can fulfill two essentially distinct functions. Plants store a significant amount of organic carbon in their above- and belowground biomass by using photosynthesis to absorb atmospheric CO_2. This is especially important for herbaceous plants with large root systems and perennial trees. A very short-term (decades to centuries) sequestration of carbon occurs when it is stored in living biomass; as the plants decompose, the carbon is released back into the atmosphere. However, plants in an ecosystem can continue to function as a C sink for several centuries if they are kept in good condition and are not disturbed. Although plant biomass can also be gathered and transformed into long-lasting plant products like fiber-cement materials and composites, the C storing capacity is again just temporary. When carbon from aboveground biomass moves to the roots and into the pool of SOC (Soil Organic Carbon), it can be sequestered for a long time (millennia). It can also be added to the soil in various ways, such as phytoliths or biochar. In addition to photo assimilation CO_2, plants can also act as C sinks by being used as bioenergy crops, which will replace greenhouse gas emissions from fossil fuels.

Among other tree species, cashew (*Anacardium occidentale* L.) plantations are unique due to their growing significance in terms of land area and as a substitute for reforestation. With 7 million hectares of plantations, it is one of the most important nut export crops in the world (FAO, 2015). Three significant and related development issues economic, social, and environmental are resolved by the cashew-based agroforestry system (Tandjiékpon et al., 2003). Therefore, cashew tree cultivation is a business venture that protects and revitalizes the environment. A sustainable way to counteract human impact on tree species is to use cashew farms (Tandjiékpon et al., 2003). Boillereau and Adam (2007) claim that these plantings made a positive contribution to carbon sequestration. Numerous forest species in numerous regions have been the subject of studies on the carbon stock in terrestrial ecosystems in the context of climate change. For instance, research in Cameroon has shown that carbon sequestration in tree-based systems, like cocoa agroforests, is double that of typical fallows. Accordingly, 72 tons of carbon might be produced from the conversion of one hectare of short-term cocoa-based agroforestry fallow (Durot, 2013).

In Benin, Bello et al. (2017) assessed the carbon sequestration potential of cashew plantations. But in Togo, there are almost no scientific studies evaluating the carbon sequestration potential of cashew plantations. We decided to conduct this scientific research. The overall objective of the present study is to assess the organic carbon stock in the cashew plantations (*Anacardium occidentale* L.), in Togo regarding the climate gradient. Specifically, it aims:

- To determine the structural characterization of cashew tree stands;
- To assess the aerial and underground biomass of cashew trees;
- To assess the stock of organic carbon stored in the trunks, branches and leaves of cashew trees, and in the soil and litter of cashew plantations.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

A country in West Africa, Togo covers an area of 56600 km² and is bordered by the Atlantic Ocean, Benin, Ghana, and Burkina-Faso to the South, East, West and North respectively. It is located between 6º06'N and 11º08'N latitudes and 0°09 W and 1º49 W longitudes on the coast of the Guinean Gulf. with an estimated population of 8,095,498 and a density of 143/km² (DGSCN, 2022) the country is subdivided into five administrative and economic regions: Savannahs, Kara, Central, Plateaux and Maritime. Togo is characterised by two major climate zones: The tropical Sudanian climate in the north (from the 8th parallel) has a rainy season running from May to October and a dry season, from November to April. In this zone, annual rainfall varies between 850 and 1400 mm and the temperature vary between 29 to 32°C. The plant growth period are less than 175 days. The Guinean tropical climate in the south (south of the 7th parallel) is characterised by two dry seasons and two rainy seasons of unequal duration. The annual rainfall varies from 1000 to 1600 mm. The average temperature is generally high. It can reach 28°C in the northern areas and 27°C in the coastal zone (Badameli and Dubreuil, 2015). Average relative humidity is also high in the southern areas (73 to 90%), but low in the northern regions (53 to 67%). The average wind speed is 1.93 m/s and the average sunshine duration is 6 hours 37 minutes per day. Average evapotranspiration is 1.540 mm/year (Badameli, and Dubreuil, 2015).

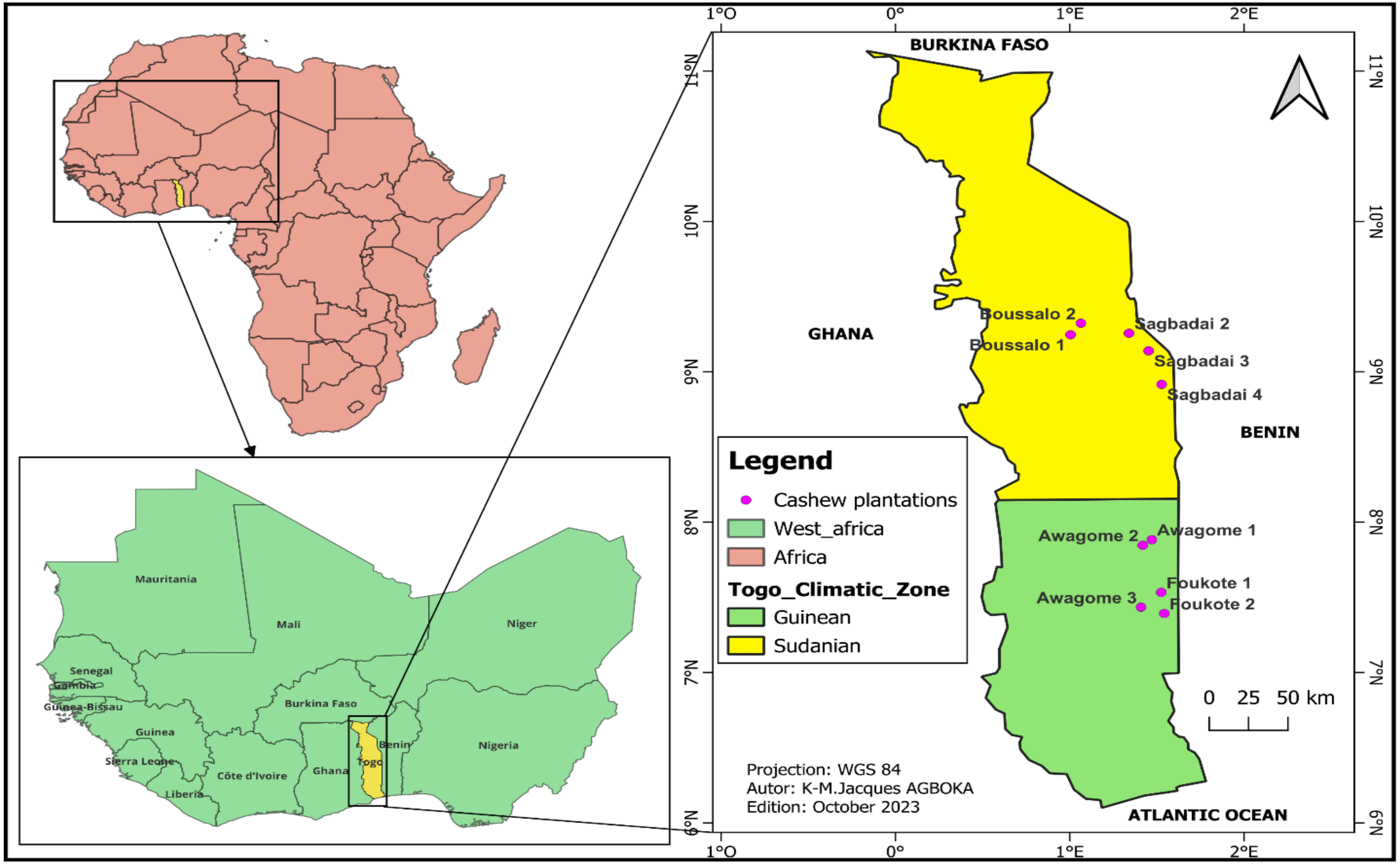

Fig. 1. Location of the study area Togo in West Africa. The circle is showing the study sites

Table 1. Characteristics of study area

Area	Season. Rainfall and Temperature (Badameli and Dubreuil, 2015)	Climate	Bulk density g/cm3	
			0-25 cm	25-50 cm
Foukotè 1	Two dry seasons and two rainy seasons	Guinean (A)	0.985	0.985
Foukotè 2			0.983	0.995
Awagomé 1	Temperature: 27 to 28°C		0.989	0.99
Awagomé 2	Rainfall: 1000 to 1600 mm		0.988	0.993
Awagomé 3			0.982	0.972
Sagbadaï 2	One dry season and one rainy season	Soudanian (B)	0.981	0.974
Sagbadaï 3	Temperature: 29 to 32°C		0.975	0.978
Sagbadaï 4	Rainfall: 850 to 1400		0.963	0.926
Boussalo 1			0.95	0.963
Boussalo 2			0.974	0.952

2.2 Biological Material

The basic biological material of this study consists of 10 years old cashew (*Anacardium occidentale* L.) tree plantations. The trees on which data were collected were in a delimited plot of 400 m² in each plantation to assess the trees' density. A total of ten cashew plantations were selected as part of our study, with five plantations selected for each climatic zone.

2.3 Methods of Data Collection and Statistical Analysis

The synoptic stations of Atakpame and Sokode were used to gather meteorological data, including mean temperatures (°C) and precipitation (mm). As a result, these data were gathered during a ten-year period (2014–2023).

Measurements of biomass were made on each 400 m² plot. Rectangular plots are thought to be more reflective of the stand and more heterogeneous (Hairiah et al., 2011). As a transect, the plot offers a typical perspective of the plantations. We take into account four DBH classes (0–5,5–10, 10-15 and > 15) in each plot. A SUUNTO clinometer was then used to measure each tree's height. The Ruban pi was used to calculate the diameter at breast height (DBH).

Two sightings were used to calculate the trees' height (H).

First at the shaft's top (V1) and second at the shaft's base (V2). The proportion of the distance (L) between the operator and the tree is represented by these two observations. The relationship established by Rondeux (1999) is used to determine the measured tree's total height:

$$H = [(V2 - V1) * L]/100 \quad (1)$$

The cylinder method was used to calculate the bulk density of the soil. A hollow metal cylinder with a volume of 100 cm³ is used to collect a sample of soil. At the end, the clod that was removed from the cylinder is shaved. The amount of soil removed is equivalent to the cylinder's volume. After that, the soil is taken out and dried in the Institut Togolais de Recherche Agronomiques' (ITRA) Soil and Plant Laboratory at 105°C. The approach used to estimate sequestered carbon is based on the suggestions made by MacDiken (1997), Valentini (2007), and the IPCC (2003) in the "Good Practice Guidance for Land Use, Land-use Change and Forestry" (LULUCF). It involved calculating the amount of organic matter in the soil and assessing the biomass of the tree's various subsurface and aerial sections. Estimating the total organic carbon at various soil depths or globally for one or more horizons and transforming the data while accounting for soil bulk density allowed for the determination of soil carbon. Using Equation 2, the organic carbon stock was calculated. The total amount of carbon at the designated depths, represented in tons of carbon per hectare, was the outcome (FAO, 2002). Equation (2).

$$SOC = C/100 \times \rho \times D \times (1\text{-}Frag) \times 100 \quad \text{(Equation 2)}$$

Where:

SOC = soil organic carbon stock (t C ha-1)
C = soil organic carbon concentration of soil fines (fraction < 2 mm) determined in the laboratory (%, g kg-1)
ρ = soil bulk density (g cm-3)
D = depth of the sampled soil layer (cm)

frag = % volume of coarse fragments/100
100 is used to convert the unit to convert the unit to t C ha-1

Note: SOC is determined on the fine soil fraction (< 2 mm) and the bulk density should be corrected for the proportion of the soil volume occupied by coarse fragments (> 2 mm).

To create composite samples, soil samples were taken at four separate locations in the 400 m² corner of each plot at depths of 0–25 cm and 25–50 cm. Forty soil samples in all were gathered. To separate the fine and coarse components, the soil samples were first allowed to dry at ambient temperature before being sieved through a 2 mm screen. The chemical analysis was conducted using these small soil samples.

Three quadrats with a surface area of one meter square were used to measure the quantity of carbon in the litter and herbaceous vegetation at each main plot. The amount per hectare was then calculated. After all of the vegetation in each quadrat was removed, the litter was gathered and weighed on-site. After that, samples of the vegetation and litter were collected and sent to the lab for chemical analysis. By oxidizing soil organic matter with potassium dichromate (K2Cr2O7 1N) in an acidic medium with a sol/K2Cr2O7 ratio of 0.25/10, the Walkley and Black (1934) method was used to quantify the amount of organic carbon in the soil. After adding the diphenylamine indicator, the carbon content is ascertained by titrating with a 0.5 N iron sulphate solution. To increase the trustworthiness of the results, several publications suggested using certain regression equations for the most common species for the evaluation of carbon stock in the above and root biomass (MacDiken, 1997; IPCC, 2003). The FAO (1997) created equations 3 and 4 for arid zones (less than 1500 mm annually), and cashew was regarded as a large tree (height > 7 m). The determination of areal biomass and root biomass stock has been done using equations 3 and 4.

Equation (3): AB = $exp^{(-1,996+2,32 lnD);}$ With AB = Aerial Biomass, D = Diameter of the tree (D in cm)

Equation (4) = RB = $exp^{\ (-1,0587+0,8836*\ln\ (AB))}$ With RB = Root Biomass.

The allometric equations created by FAO (1997) and modified by Boulmane et al. (2013) based on the carbon stock models for the various tree components were used to determine the amount of carbon in the various tree sections in each plantation (Table 2).

After being dried for 72 hours at 65 °C in an oven, the samples of herbaceous plants and litter were crushed, and the dry ashing method was used to measure the amount of organic carbon. Equation 5 was used to calculate the herbaceous vegetation's proportion of dry matter, and Equation 6 was used to calculate the biomass (Valentini, 2007). The average herbaceous biomass was then converted to ton per hectare. Equation (5): DM = (PSE/PHE)*100 where DM = percentage of dry matter (%); PSE = dry weight of the sample after three days in the oven at 65°C (g); PHE = wet weight of the sample measured in the field (g). Equation (6): B = (PHT*DM)/100; where: B = biomass (g); PHT = total wet weight in measured in the field (g); DM = percentage of dry matter (%).

Cashew stand structure analysis consisted of the determination of keys structure parameters as tree density, mean diameter, mean heigh and basal area (Curtis and McIntosh, 1951). Diameter size class distribution was established for each site and in order to determine the variation of different parameters according to tree classes. For each parameter determined, Students T-test was performed to compare mean values of each zone. All analysis was done using R software version 4.3.3. The following Table 3 presents main parameter determined.

Table 2. Allometric equations to assess carbon stocks in the various components of the trees

Component of the tree	Adjusted model of carbon stock Estimation (Kg/tree)	R^2
Trunk	SCTr = 191 x (D^2H)	0.97
Branches	SCBr = 46 x (D^2H)	0.95
Leaves	SCL = 5.4 x (D^2H)	0.96

Note: D = diameter at 1.30 m, H = height of the tree (in meter), D and H are in meter (m). SCTr = carbon stock in the trunk, SCBr = carbon stock in the branches, SCL = carbon stock in the leaves

Table 3. Diversity and structure metrics to be computed for the structural analysis

Parameters	Formula	Formula details	Interpretation	References
Density, *D*	$RD = \frac{N}{TN}$	*N is the number of individuals of a species and TN is the total number of individuals considering all species*	Measures abundance of a species relative to abundance of all species	Cintron and Schaeffer-Novelli (1984)
Basal area, *G* ($m^2.ha^{-1}$)	$G=\frac{10000\ \pi}{4s}\sum_{i=1}^{n_g} d_i^2$	d_i is the diameter of the tree i^{th} of the plot	Dendrometric parameter which inform to basal area distribution	Cintron and Schaeffer-Novelli (1984)
Mean diameter, *D* (cm)	$D=\sqrt{\frac{1}{n}\sum_{i=1}^{n} d_i^2}$	d_i is the diameter (in cm) of the tree i^{th} of the plot	Measures horizontal growth of a species	Cintron and Schaeffer-Novelli (1984)

3. RESULTS

3.1 Structural Characterization of Cashew Tree Stands

The Table 4 and Fig. 2 present the structural parameters of cashew tree stands based on main parameters such as density of individuals, diameter, height and basal area. Considering the density of individuals, at the scale of the two climatic zones, a high value was observed for the Guinean climate (255±73.06 individuals/ha) and then the Soudanian climate (155±65.38 individuals/ha). A comparison of the density of the two climate zones shows that the lowest density value was observed in the Soudanian climate zone (37.5±12.5 individuals/ha) while the highest value was observed in the Guinean climate zone (445±178.96/ha).

As for the diameter of individuals, considering the two climatic zones, the highest average value is observed for the Guinean climate (5.37±0.56 cm) followed by the Soudanian climate (4.82±0.44 cm). The lowest mean diameter value is 3.48±0.76 cm and is obtained in cashew trees stands located in the Guinean climate zones. Considering the cashew stands located in the Soudanian climate zones, the high mean diameter value was (17.60±1.04 cm) while the low value was (4, 38±0.13 cm). In the Guinean climate zone, the highest mean value was (19.37±1.48 cm) followed by (12.42±0.54 cm). The lowest mean diameter value was 3.48±0.76 cm.

Considering the height, on the scale of the two climatic zones, we observe that the average height of cashew tree stands increases with the cashew tree classes. The highest mean height was 6.67±0.52 m for the cashew stand located in the Guinean climatic zone, whereas the lowest height is observed in the Sudanian climatic zone and was 3.88±0.88 m.

Considering the two climatic zones, the basal areas of cashew tree populations increase when the tree classes increase. 15.22±2.25 m^2/ha was the mean basal area for the Guinean climate zones, while 10.51±1.99 m^2/ha was the mean basal area for the cashew stands located in the Soudanian climate zones.

Table 4. Structural characterization of cashew tree stands

Structural parameters	Cashew population	Zone A	Zone B	P
Average diameter (Cm)				
[0-5[	3.74±0.55	3.48±0.76	4. 38±0.13	0.048
[5-10[	6.86±0.22	6.80±0.40	6.91±0.022	0.799
[10-15[	12.22±0.29	12.42±0.54	12.02±0.24	0.522
>15	18.49±0.90	19.37±1.48	17.60±1.04	0.357
Overall	5.09±0.35	5.37±0.56	4.82±0.44	0.508
Height (Cm)				
[0-5[	4.48±0.69	4.72±0.93	3.88±0.88	0.224
[5-10[	4.35±0.24	4.66±0.33	4.03±0.31	0.197
[10-15[	5.3±0.35	5.53±0.58	5.06±0.44	0.544
>15	6.15±0.42	6.67±0.52	5.63±0.62	0.241
Overall	11.52±0.82	12.12±1.52	10.94±0.77	0.463
Basal area (m^2/ha)				
[0-5[	0.17±0.08	0.22±0.11	0.06±0.01	0.122
[5-10[	1.76±0.41	1.76±0.69	1.76±0.52	0.255
[10-15[	4.25±0.75	3.81±1.39	4.69±0.71	0.477
>15	6.73±2.08	9.42±3.63	4.04±1.62	0.221
Overall	12.86±1.62	15.22±2.25	10.51±1.99	0.156
Density (individuals/Ha)				
[0-5[	142.86±77.4816	185±105.06	37.5±12.5	0.245
[5-10[	435±100.014	445±178.96	425±113.74	0.225
[10-15[	375±70.71	335±129.08	415±70.98	0.624
>15	205±49.13	255±73.06	155±65.38	0.104
Overall	205±49.13	255±73.06	155±65.38	0.174

Zone A: Guinean climate; Zone B : Soudanian climate

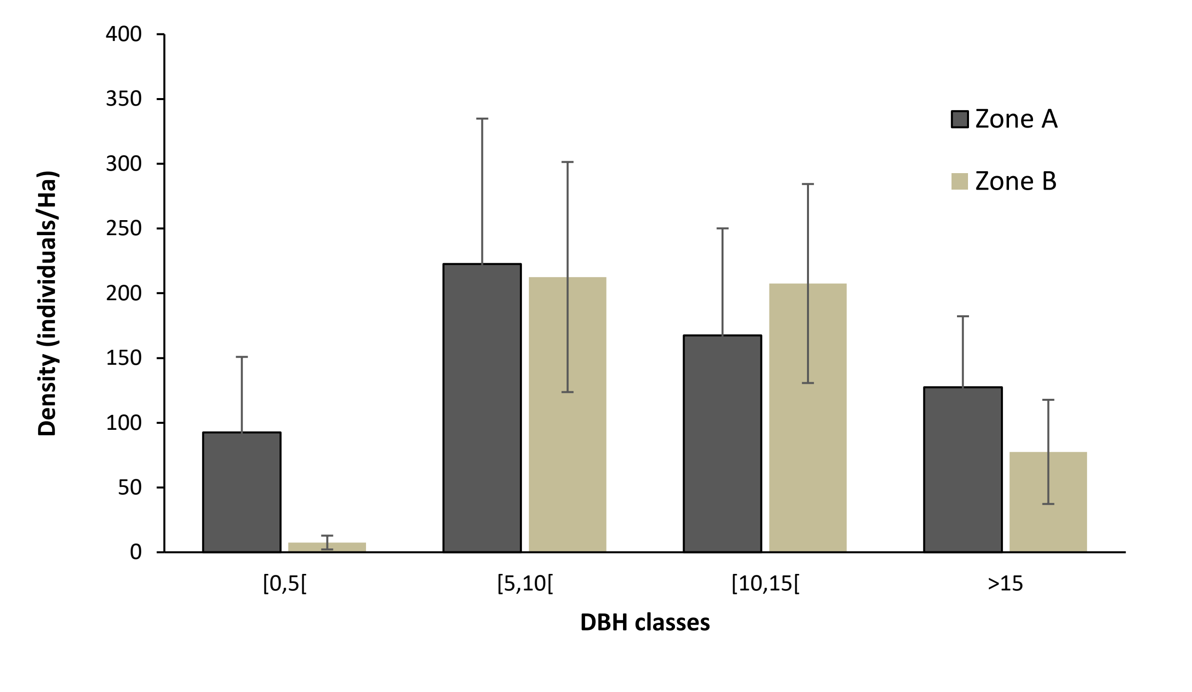

Fig. 2. Density of cashew trees as a function of DBH classes and climatic gradient. (Zone A: Guinean climate; Zone B: Soudanian climate)

3.2 Assessment of the Aerial and Underground Biomass of Cashew Trees

The variation of aerial and underground biomass according to the two climatic zones (Guinean and Soudaninan climate zones) was assessed and the observed averages are recorded in the Table 3 below. The analysis of these results shows that the biomass (aerial and underground) varies from one climatic zone to another. Considering the two climatic zones, the highest aerial and root biomass was observed in the Guinean climate zone: 30.93±5.89 kg/individual for the aerial biomass and 0.82±0.15 kg/individual for the root biomass. An analysis of Table 5 below shows that biomass (aerial and root) increases slightly on average as a function of changes in tree classes, for both climatic zones (Guinean and Sudanian).

3.3 Stock of Organic Carbon in the Different Compartments of Cashew Trees in Litter and Soil

Table 6 below shows the amount of carbon stored in the cashew tree's different compartments (trunks, branches, and leaves) as a function of climatic zone and tree classes, as well as the carbon stored in the soil and the litter as a function of the climatic zone. Generally, trunks (79%) store more carbon than other compartments (branches (19%) and leaves (2%)). On the other hand, the cashew tree compartment that stores on average less tonnes of carbon per hectare is the leaf (Fig. 4), and this is observed in the case of the two climatic zones (Guinean and Sudanian climate). Furthermore, the average carbon stored in the trunk by cashew trees in the Guinean zone (23.17±4.80 kg C/individual) is greater than that stored by cashew trees's trunk in the Sudanian zone 13.69±3.20 kg C/individual. The trend remains the same if we compare the average carbon stored in the two climatic zones' other compartments (branches and leaves). The Soil in the Guinean climate zone sequesters more carbon per hectare than the soil in the Soudanian climate zone (Table 6), the opposite trend is observed for the average amount of carbon stored in litter per hectare. What's more, the amount of carbon sequestered increases with the depth (from 0-25 cm to 25-50 cm).

The Fig. 3 below shows the cumulative carbon stock as a function of DBH classes and the climate zones. In the Guinean climatic zone, cashew trees with a DBH greater than 15 cm store 68% organic carbon. On the other hand, in the Sudanian climatic zone, cashew trees with a

DBH greater than 15 and those with a DBH between 10 and 15 cm store almost the same amount of carbon, 46% and 42% respectively. Fig. 4 shows that whatever the climatic zone (Guinean or Sudanian) and the cashew tree compartment (stems, branches and leaves), the cumulative percentage of organic carbon stored remains the same.

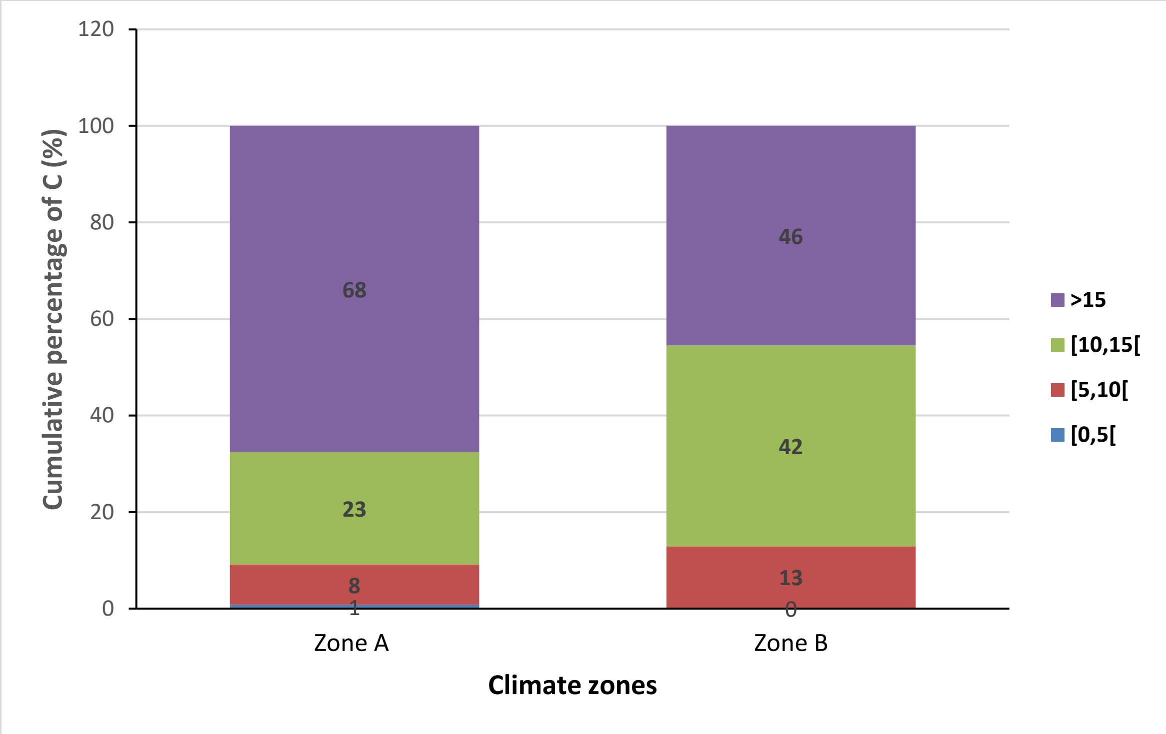

Fig. 3. Cumulative carbon stock as a function of DBH classes and climatic gradient. (Zone A: Guinean climate; Zone B: Soudanian climate)

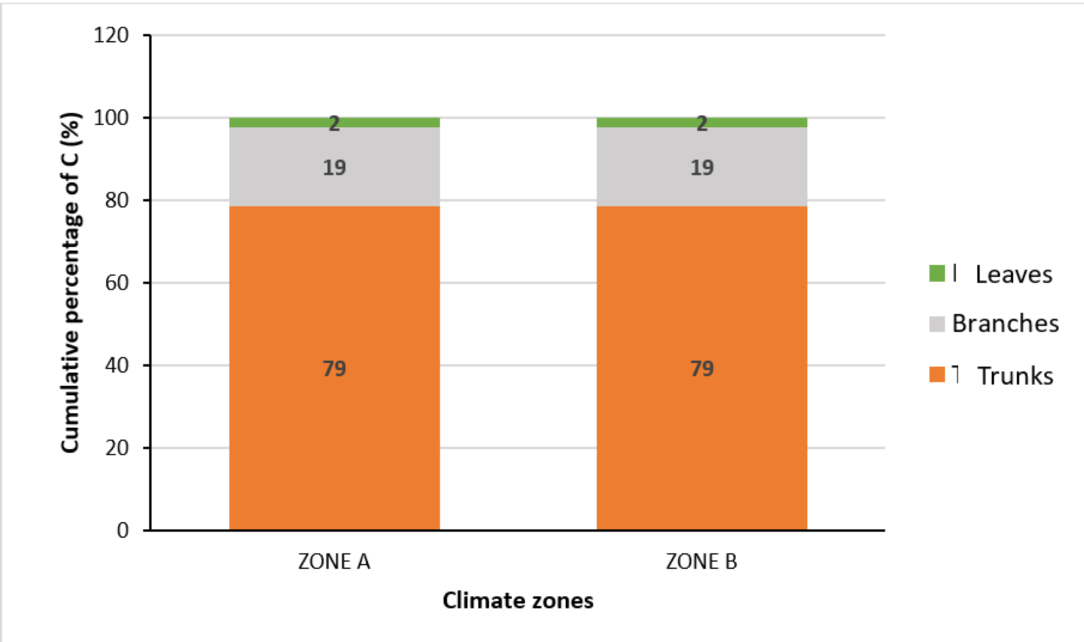

Fig. 4. Cumulative organic carbon stock in the different compartments (leaves, branches and trunks) of cashew trees regarding the climatic gradient

Table 5. Aerial and underground biomass of cashew trees

Structural parameters	Cashew population	Zone A	Zone B	P
Aboveground biomass (kg/individual)				
[0-5[	0.22±0.10	0.28±0.14	0.07±0.02	0.160
[5-10[	2.73±0.63	2.72±1.07	2.74±0.82	0.774
[10-15[	7.7±1.35	6.91±2.50	8.48±1.27	0.590
>15	14.72±4.77	21.04±8.42	8.42±3.39	0.203
Overall	25.30±4.77	30.93±5.89	19.68±3.90	0.139
Underground biomass (kg/individual)				
[0-5[	0.07±0.03	0.09±0.04	0.02±0.01	0.117
[5-10[	0.25±0.05	0.27±0.09	0.23±0.06	0.987
[10-15[	0.27±0.06	0.25±0.11	0.276±0.05	0.878
>15	0.17±0.04	0.21±0.07	0.12±0.05	0.307
Overall	0.73±0.04	0.82±0.15	0.64±0.11	0.139

Zone A: Guinean climate; Zone B : Soudanian climate

Table 6. Stock of organic carbon stored in the trunks, branches and leaves of cashew trees, and in the soil and litter of cashew plantations

Structural parameters	Cashew population	Zone A	Zone B	P
Trunk (kg C/individual)				
[0-5[	0.14±0.05	0.18±0.07	0.05±0.025	0.100
[5-10[	1.84±0.4	1.93±0.68	1.74±0.50	0.953
[10-15[	5.55±1.18	5.41±2.33	5.70±0.90	0.910
>15	10.94±3.69	15.65±6.56	6.23±2.65	0.220
Overall	18.43±3.14	23.17±4.80	13.69±3.20	0.149
Branch (kg C/individual)				
[0-5[	0.03±0.01	0.04±0.01688	0.01±0.006	0.100
[5-10[	0.44±0.096	0.47±0.16	0.42±0.12	0.953
[10-15[	1.34±0.28	1.30±0.56	1.37±0.22	0.910
>15	2.63±0.89	3.77±1.58	1.50±0.64	0.220
Overall	4.43±0.76	5.58±1.15	1±0.77	0.384
Leaf (Kg C/individual)				
[0-5[	0.004±0.002	0.01±0.001	0.001±0.00	0.100
[5-10[	0.05±0.01	0.05±0.02	0.05±0.01	0.953
[10-15[	0.16±0.033	0.15±0.07	0.16±0.03	0.910
>15	0.31±0.10	0.44±0.19	0.18±0.07	0.220
Overall	0.52±0.09	0.93±0.14	0.38±0.09	0.156
Litter (t C/ha)				
	0.49±0.01	0.47±0.02	0.50±01	2.11
Soil (t C/ha)				
0 – 25 cm	29.89±11.14	18.49±1.13	20.97±1.56	2.445
25 – 50 cm	30.31±11.13	38.72±2.43	43.92±3.17	1.251
Total	83.58	86.89	80.23	-

Zone A: Guinean climate; Zone B : Soudanian climate

4. DISCUSSION

4.1 Carbon Sequestration in the Different Climatic Zones in Togo

The carbon storage in each compartment varies by location (cashew production areas) and tree DBH in different climatic zones. Of course, trees with a high DBH store more carbon. This conclusion supports Thompson et al. (2004)'s prior findings that the longer a tree grows, the more carbon it sequesters. Soil organic carbon reserves vary by location, ranging from 18.49±1.13 t C/ha to 43.92±3.17 t C/ha, which do not fall within the 11 to 33 t C/ha range determined by Volkoff et al. (1999) in Benin. The fluctuations in soil carbon stock are determined by soil depth and climate gradient. Soil carbon reserves are higher than the IPCC's (2003) estimate of 31 t C/ha for the dry tropics and close to the 42 t C/ha obtained by Tinlot (2010) and Sonwa (2004) in a cocoa-based agroforestry system. The low carbon content of the soil in cashew farms could be attributed to increased organic matter decomposition caused by greater temperatures in the research location, which is located in the Sudanian climate zone. Our investigation found that carbon stock in litter ranged from 0.47±0.02 t C/ha to 0.50±01 t C/ha. This finding differs from the 2.8 t C/ha determined by the IPCC (2003). The low carbon rate could be attributed to the poor quality of litter. In India, Rupa et al. (2013) found that 7-year-old cashew farms with 156 to 600 trees per hectare stored between 32.25 and 59.22 t C/ha. According to Albrecht and Kandji (2003), the carbon storage capacity of an agroforestry system ranges from 12 to 228 t C/ha, with an average of 95 t C/ha. Our study's computed values fall within this range. The difference in C stock between zones might thus be attributed to variations in planting density. The quantity of carbon trapped by the agroforestry system varies according to the tree species and plantation density. Montagnini and Nair (2004) found that the quantity of carbon sequestered varies by tree species, geographic region (climate, soil), planting density, and system management. Lawal et al. (2010) found that a 20-year agroforest yielded less than 60 and 90 t C/ha. The plantation soil's carbon stock exceeds the agricultural system's expected worth. This allows us to argue that the agroforestry system is a carbon sink in comparison to the agricultural system. As a result of the quick regeneration and abundance of litter, natural forests have a higher carbon stock than agroforestry systems. Montagnini and Nair (2004) observed that agroforestry systems had an indirect influence on carbon capture by lessening strain on wild forests.

4.2 Influence of Climatic Gradient on Carbon Sequestration

Rainfall, temperature, and wind are the most essential climatic characteristics of agricultural production, with a specific climatic gradient (Yabi et al., 2013). The effect of climatic conditions on carbon stock reveals that temperature has a negative and substantial association with carbon stock in cashew plantations (Bello et al., 2017). Reichstein (2007) and Jayathilaka et al. (2012) explain that high temperatures resulted in a high CO_2 content, which contributed to low carbon sequestration. According to our findings, the Sudanian climatic zone is more exposed to high mean temperatures (29 to 32°C), which explains why cashew farms in this zone store less carbon than those in Guinea. Carbon storage or release is determined by both organic matter degradation processes and biomass behavior in response to climatic change. The high temperature stimulates microbe activity (Fissore et al., 2008), resulting in the oxidation of organic matter, which influences atmospheric CO_2 levels. Furthermore, high rainfall promotes high primary productivity, both aerial and root, resulting in large CO_2 emissions (Reichstein, 2007). This explains why cashew plants in the Guinean zone (with annual rainfall ranging from 1000 to 1600 mm) have more aerial and root biomass than cashew trees in the Sudanian climatic zone. In general, stimulating plant growth with higher temperatures would increase carbon in litter (Reichstein, 2007), which has an influence on the environment because of a greater release of CO_2 into the atmosphere (Lawal et al., 2010). As a result, in our study, litter from the Sudanian zone (high average temperature) retains more carbon than litter from plantations in the Guinean climate zone. Rising temperatures and variable precipitation can lead to a rise in water deficit. Litter breakdown would consequently be minimized and retarded, allowing for large carbon storage in forest soils (Kurz-Besson et al., 2006). The investigation of carbon stock variation along the climatic gradient found that cashew plants in the Guinean climate zone sequestered more carbon. This finding could be explained by the fact that the temperature in this zone promotes canopy growth, which can trap CO_2 in the atmosphere while simultaneously slowing the mineralization of organic materials for carbon storage in soils. The low carbon stock found in the Sudanese zone could be linked to the reported high temperatures. According to Jayathilaka et al. (2012), an increase in temperature causes a release of carbon stock in soil.

5. CONCLUSION

The current study demonstrated that cashew plantations are agroforestry systems that store differing amounts of carbon, based on climate zones (Guinean and Soudanian), soil depth, and the various compartments (trunks, branches, and leaves) of the cashew tree. Climate-related variables influence this fluctuation. In terms of climatic zones, the Guinean climate has the most biomass, whereas the Soudanian climate has the least. According to the several compartments to be considered in the cashew plantation, the soil and trunk biomass store a higher quantity of carbon. Herbaceous biomass contains little carbon, yet it contributes to soil carbon sequestration capacity. Given the results of this study, cashew producers may gain income from the global carbon market, increasing their financial flow. As a result, policies must be developed to promote sustainable agroforestry systems through the implementation of climate change-related carbon sequestration initiatives on cashew. In this regard, investigations on greenhouse gas (GHG) emissions on cashew plantations should be considered in order to compare emission and sequestration rates. Furthermore, it would be interesting to carry out a study to examine changes in total organic carbon stored in cashew tree plantations as a function of the climatic gradient in Togo.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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