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Biomass and carbon stocks of woody vegetation across urban land-use units in the city of Kétou

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Abstract
In urban environments, vegetation contributes to the maintenance of ecological functions, but it is progressively degraded due to population growth and spatial expansion. In this context, a study was conducted to assess the carbon stock sequestered by woody vegetation across different land-use units in the city of Kétou. A systematic inventory was carried out to measure tree dendrometric parameters within each unit, while allometric equations were used to estimate biomass and sequestered carbon. The results show that the mean diameter varies according to land-use units: 27.36 cm in agglomerations, 28.61 cm in crop-fallow mosaics, 39.64 cm in woody and shrubby savannahs, and 41.63 cm in the crop-fallow mosaic under palms. Biomass is very low in agglomerations (11.03 ± 16.34 t/ha), intermediate in crop-fallow mosaics (82.13 ± 119.64 t/ha), and high in woody and shrubby savannahs (312.73 ± 578.08 t/ha) as well as in crop-fallow mosaic under palms (147.63 ± 223.32 t/ha). This pattern is reflected in carbon stocks, which are low in agglomerations (5.18 ± 7.67 tC/ha) and in crop-fallow mosaics (38.60 ± 56.23 tC/ha), but higher in woody and shrubby savannahs (146.98 ± 271.69 tC/ha) and in crop-fallow mosaic under palms (69.38 ± 104.96 tC/ha). The differences observed between land-use units are statistically significant ($p < 0.000$***), highlighting the influence of land-use types on carbon sequestration capacity. These findings call for improved management and conservation strategies for woody vegetation in Kétou.
Keywords: Total woody biomass, carbon stock, land-use units, urban environment, Kétou

Résumé
En milieu urbain, la végétation contribue au maintien des fonctions écologiques, mais elle subit une dégradation progressive liée à la croissance démographique et à l'expansion spatiale. Dans ce contexte, une étude a été conduite afin d'évaluer le stock de carbone séquestré par la végétation ligneuse au sein des différentes unités d'occupation du sol de la ville de Kétou. Un inventaire systématique a permis de mesurer les paramètres dendrométriques des arbres dans chaque unité, tandis que des équations allométriques ont été mobilisées pour estimer la biomasse et le carbone séquestré. Les résultats montrent que le diamètre moyen varie selon les unités d'occupation du sol : 27,36 cm en agglomérations, 28,61 cm en mosaïque de cultures et jachères, 39,64 cm en savanes arborées et arbustives, et 41,63 cm en mosaïque de cultures et jachères sous palmiers. La biomasse est très faible en agglomérations (11,03 ± 16.34 t/ha), intermédiaire en mosaïque de cultures et jachères (82,13 ± 119.64 t/ha), et élevée en savanes arborées et arbustives (312,73 ± 578.08 t/ha) ainsi qu'en mosaïque de cultures et jachères sous palmiers (147,63 ± 223.32 t/ha). Cette dynamique se reflète sur les stocks du carbone, faibles en agglomérations (5,18 ± 7.67 tC/ha) et dans la mosaïque de cultures et jachères (38,60 ± 56.23 tC/ha) et plus élevés dans la savane arborée et arbustive (146,98 ± 271.69 tC/ha) et la mosaïque de cultures et jachères sous palmiers (69,38 ± 104.96 tC/ha). Les différences observées entre les unités sont statistiquement significatives ($p < 0,000$***), traduisant l'influence du mode d'occupation du sol sur la capacité de séquestration du carbone. Ces résultats appellent à des stratégies de gestion et de conservation de la végétation ligneuse à Kétou.
Mots-clés : Biomasse ligneuse complète, stock du carbone, unités d'occupation du sol, milieu urbain, Kétou

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1. Introduction

Urban vegetation plays a key role in landscape structuring and in maintaining the ecological functions of cities (Khalid *et al.,* 2019; Marinšek *et al.,* 2022). According to the WWF (2022), it contributes to an annual reduction of 160,787 kg of CO_2 and an average temperature decrease of 3°C. However, this carbon storage function, which is part of ecosystem regulation services and is essential in urban environments, is declining due to the reduction of urban vegetation cover, mainly driven by urban expansion and population growth.

Indeed, rapid population growth in many cities leads to unplanned urban expansion, often occurring without adequate consideration for the natural environment (Kouagou *et al.,* 2018; Geoffroy *et al.,* 2020). This represents a major threat to ecosystems in general and to vegetation cover in particular (Jiagho, 2018; WWF, 2022). This situation is evident in Benin, particularly in the city of Kétou, where the expansion of agglomerations and agricultural land to meet the demands of population growth has occurred at the expense of natural vegetation. As a result, natural vegetation decreased from 739 to 562 km², representing a reduction of 7.97% over a period of ten (10) years (SDAC Kétou, 2024).

Yet, urban vegetation provides essential provisioning and regulating services, such as the storage of fine particulate matter and greenhouse gases like CO_2 (Me-Mba *et al.,* 2022; Marinšek *et al.,* 2022). Even in small amounts, sequestered carbon contributes significantly to reducing air pollution and mitigating the effects of climate change (Gomgnimbou *et al.,* 2019; Folega *et al.,* 2020).

However, scientific studies often estimate carbon stocks at the city scale or along urban gradients without a detailed distinction between land-use units (Flégeau, 2020). In reality, cities and urban gradients are characterized by the coexistence and superposition of heterogeneous land-use units. Estimating carbon stocks by land-use unit would allow for a more detailed analysis that reflects the diversity of urban forms, enabling better identification of areas to be protected and those requiring urban greening for improved city planning (Agbelade *et al.,* 2017; Folega *et al.,* 2020; N'ganmo and Priso, 2022).

Furthermore, very few studies estimate both aboveground and belowground biomass (carbon stack above and below the soil) when assessing carbon stocks (Gomgnimbou *et al.,* 2019; Kouadio *et al.,* 2020). Yet, several authors emphasize the importance of including both components for a more comprehensive evaluation of total carbon storage (Folega *et al.,* 2020; N'ganmo and Priso, 2022). These aspects are essential for accurately assessing the total carbon stock of woody vegetation across land-use units in the city of Kétou and for proposing effective improvement measures.

In this context, the present study was conducted to evaluate the carbon sequestration potential of woody vegetation resources, with the aim of supporting sustainable urban management in the city of Kétou, Benin.

2. Materials and methods

2.1. Study area

Located in southeastern Benin, the city of Kétou is one of the six (06) districts and the administrative capital of the municipality of Kétou. It lies between 7°10′ and 7°41′17″ North latitude and between 2°24′24″ and 2°47′40″ East longitude (Figure 1). Kétou is classified as an intermediate-status city and encompasses major urban centers covering an area of 2,072.78 hectares. The city experiences a tropical climate with a bimodal rainfall regime and an average annual temperature of approximately 25 °C. The soils are predominantly tropical ferruginous and ferralitic, slightly weathered, and the natural vegetation consists mainly of wooded savannahs and forest formations. However, within the city of Kétou, vegetation is primarily composed of green spaces and roadside plantations, with only a few remaining natural formations. The population is estimated at approximately 57,704 inhabitants and has grown rapidly, increasing from 25,102 inhabitants in 2002 to 39,626 in 2013, with projections of 64,592 inhabitants by 2026 and potentially 101,406 inhabitants by 2038. The population is mainly composed of Yoruba (77.7%) and Fon (19.6%) ethnic groups. The predominant economic activities include agriculture (50%), trade (30%), and, to a lesser extent, crafts, livestock farming, and forestry (20%) (INSAE, 2016; MECPD, 2019; SDAC Kétou, 2024).

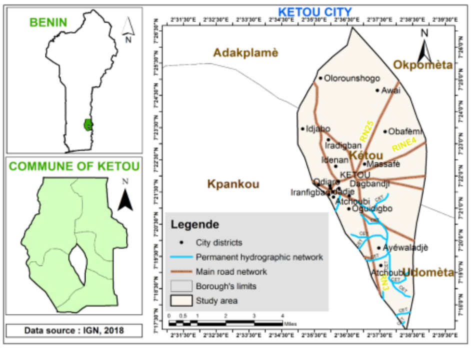

Figure 1 : Location map of the city of Kétou-Carte de situation de la ville de Kétou

2.2. Sampling and data collection methods

2.2.1. Sampling method

To carry out the floristic inventory, the grid-based sampling method used by Tuo *et al.* (2017) and Orou Wari *et al.* (2021) was adopted. A network of 2 km × 2 km square grids was established across the entire city, covering the different land-use units of Kétou defined by Idakou *et al.* (2025) in their study on the dynamics of tree vegetation in the city (Figure 2). This approach made it possible to select seventeen (17) sampling points according to the area of each land-use unit: two (02) points in the palm-based crop-fallow mosaic (MCJP), four (04) points in agglomerations (AGGL), five (05) points in woody and shrubby savannahs (SASA), and six (06) points in the crop-fallow mosaic (MCJ). Within each land-use unit, vegetated spaces were identified, including roadside trees, cemeteries, managed natural areas, green spaces associated with public buildings, green spaces within social and educational institutions, and private green spaces (such as home gardens and residential areas), following the typology proposed by the Association of City Engineers of France (AIVF) (Bouge, 2009).

2.2.2. Data collection method

Sampling points were located in the field using a GPS. Due to the large size of vegetated areas within the land-use units, plots of 1,500 m² (50 m × 30 m) were established following the method of Assalé *et al.* (2021)

and Jiagho (2018). This plot size is considered appropriate for facilitating inventory in large vegetated areas. At each sampling point, two (02) plots were installed within a radius of 250 m and spaced 100 m apart (Figure 2). A systematic inventory of woody plants was then conducted within each plot. This resulted in a total of 268 individuals over an area of 18,000 m^2 in the crop-fallow mosaic units (MCJ), 130 individuals over 6,000 m^2 in the palm-based crop-fallow mosaic units (MCJP), and 198 individuals over 15,000 m^2 in the woody and shrubby savannah units (SASA) (Table 1). In contrast, in agglomerations (AGGL), due to the limited size of vegetated spaces, a systematic inventory of woody plants was carried out in public buildings, social and educational institutions, cemeteries, and private green spaces containing at least four trees, within a 250 m radius of each sampling point. This resulted in a total of 387 individuals over an area of 167,545 m^2 (Table 1). Roadside trees were inventoried along a length of 100 m on each side of primary and secondary roads (paved or asphalted). Tree circumference at breast height and tree height were measured and recorded using a digital database designed in KoboCollect. Circumference was measured at 1.30 m above ground using a diameter tape, and tree height was measured using a clinometer through top and bottom sighting (Figure 3). Geographic coordinates and the areas of sampled sites were recorded using a GPS, and photographs were taken during the field survey using a digital camera. The PlantNet application (https://www.lesnumeriques.com/telecharger/plantnet-identification-plante-32962) was used for in-field identification of plant species and subsequently validated at the National Herbarium of the University of Abomey-Calavi (Benin) using collected specimens of woody plant organs.

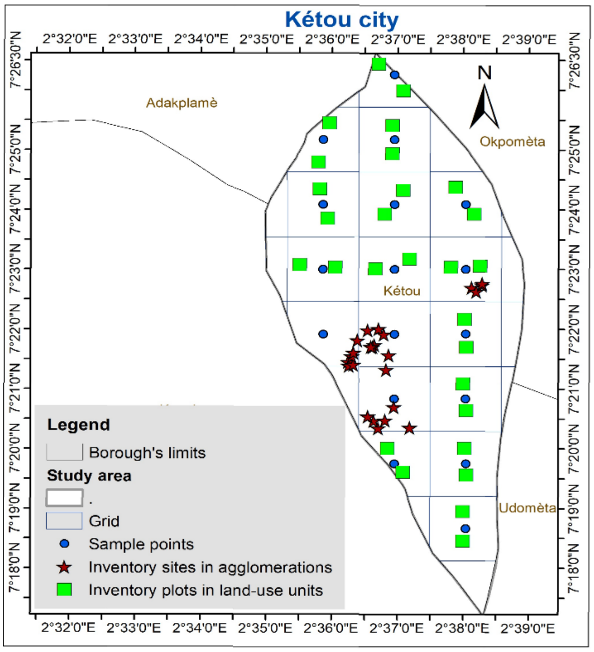

Figure 2: Map of sample points in study area - Carte des points arborea d'échantillon dans le milieu d'étude

Figure 3: Measurement of circumference at breast height of Gmelina Roxb - Mesure de la circonférence à hauteur de poitrine d'un pied de Gmelina arborea Roxb

Table 1: Trees number and inventoried area per site/plot within each land-use unit - Nombre d'arbre et superficie inventoriées par site/placeau dans chaque unité d'occupation du sol.

Sampling points	Land-Use Type	Site/Plot	Area (m²)	Number of trees (individuals)
1	Agglomerations (AGGL)	House 1	620	5
		House 2	1692	5
		House 3	887	4
		Céline Hotel	9023	6
		House 4	950	4
		House 5	500	4
		House 6	600	13
		Primary School	8910	8
2		Calvaire Douane Street	1200	12
		Youth Center	7392	25
		House 7	450	9
		Youth Center near City Hall	1000	9
		Centenary School	8927	8
3		Centenary Square	17503	49
		Customs Office	15176	23
		Idi Square	6100	27
		Hospital	9053	33
		CEG 1 Kétou	60218	33
		Catholic Cemetery	8633	17
4		Alakétou Radio	4008	40
		Radio Mosque	2153	9
		House 8	900	13
		House 9	1000	21
		House 10	650	10
5	Crop-fallow mosaic (MCJ)	Plot 1	1500	35
		Plot 2	1500	38
6		Plot 3	1500	58
		Plot 4	1500	5
7		Plot 5	1500	44
		Plot 6	1500	8
8		Plot 7	1500	15
		Plot 8	1500	0
9		Plot 9	1500	12
		Plot 10	1500	1
10		Plot 11	1500	27
		Plot 12	1500	25
11	Palm-based crop-fallow mosaic (MCJP)	Plot 1	1500	30
		Plot 2	1500	22
12		Plot 3	1500	57
		Plot 4	1500	21
13	Woody and shrubby savannahs (SASA)	Plot 1	1500	38
		Plot 2	1500	12
14		Plot 3	1500	29
		Plot 4	1500	1
15		Plot 5	1500	21
		Plot 6	1500	2
16		Plot 7	1500	30
		Plot 8	1500	1
17		Plot 9	1500	22
		Plot 10	1500	42

2.3. Data analysis method

Tree circumferences measured at breast height ($C_{1.30}$ m) were converted into diameter at breast height (DBH). Only trees with a DBH greater than or equal to 10 cm were retained. To analyze the structure of urban vegetation in Kétou, DBH values of woody species were grouped into classes with an interval of ten (10) cm.

- ***Biomass assessment (aboveground and belowground)***

Biomass was estimated using general allometric equations for urban trees (Aguaron and McPherson, 2012; Kouadio *et al.,* 2020), which account for both aboveground and belowground biomass, as well as tree types (broadleaf, palms, and conifers). These equations allow for rapid and accurate estimation of woody biomass over large areas, both in urban environments and in tropical forests (Valentini, 2007; Jiagho, 2018; Gomgnimbou *et al.,* 2019).

In the present study, the following formulae were used:

Let $Bt_{broadleaf}$ represents the biomass of broadleaf trees, calculated as:

$$Bt_{broadleaf} = 0{,}161555 \times DBH^{2{,}310647}$$

where $Bt_{broadleaf}$ is the total biomass (aboveground and belowground) of broadleaf trees expressed in kilograms (kg), and *DBH* is the diameter at breast height measured in centimeters (cm).

Then, Bt_{Palm} represents the biomass of palm trees, calculated as:

$$Bt_{Palm} = 1{,}282 \times (7{,}7 \times HT + 4{,}5)$$

Where Bt_{Palm} is the total biomass (aboveground and belowground) of palms expressed in kilograms (kg), and *HT* is the tree height measured in meters (m)

Similarly, $\mathbf{Bt_{conifer}}$, the biomass of coniferous trees, was calculated using the following equation:

$$Bt_{Conifer} = 0{,}035702 \times DBH^{2{,}580671}$$

where *Bt_conifer* is the total biomass (aboveground and belowground) of coniferous trees expressed in kilograms (kg), and *DBH* is the diameter at breast height measured in centimeters (cm).

The biomass values obtained in kilograms (kg) for the inventoried areas within each land-use unit were extrapolated and expressed in tons per hectare (t/ha) before estimating the sequestered carbon.

- ***Carbon stock estimation***

To determine carbon stock (tC/ha), the amount of biomass (t/ha) was multiplied by the conversion factor recommended by the GIEC (2003), which is 0.47, according to the following formula:

$$\text{Carbon stock} = \text{Amount of biomass x } 0{,}47 \text{ (Conversion factor)}$$

The non-parametric Kruskal-Wallis test was performed on carbon stock values using R software (version 4.3.3) to assess significant differences at the 5% level among land-use units in the city of Kétou. A post-hoc analysis was then conducted using pairwise comparisons of carbon stock values between land-use units with the Tukey test ('pairwise' function).

Finally, scatter plots and regression lines were generated to examine the relationships between biomass, tree diameter, and tree density, in order to assess their correlations.

3. Results and Discussion

3.1. Results

Tree density and mean diameter vary across land-use units. The lowest values are observed in agglomerations (AGGL), while the highest occur in the crop-fallow mosaic under palms (MCJP) and in woody and shrubby savannahs (SASA) (Table 2). In AGGL, density is 23 stems/ha with a mean diameter of 27.36 cm, whereas in the crop-fallow mosaic (MCJ), it reaches 148 stems/ha with a mean diameter of 28.61 cm, indicating relatively young tree stands. In contrast, in the crop-fallow mosaic under palms (MCJP), density is 216 stems/ha with a mean diameter of 41.63 cm, and in woody and shrubby savannahs (SASA), it is 132 stems/ha with a mean diameter of 39.64 cm. These values indicate more or less mature tree stands. The total number of trees is strongly influenced by the sampled area. Agglomerations show the highest number of trees (387 stems), which is related to their large area (16.7545 ha). Conversely, the palm-based mosaic, despite its high density, contains fewer trees (130 stems) due to its small area (0.6 ha).

Table 2 : Tree density, mean diameter, and number of inventoried trees by sampled area - Densité, diamètre moyen et nombre d'arbre inventorié par superficie échantillonnée.

Land-use units	Density (stems/ha)	Mean diameter (cm)	Number of trees (stems)	Area (ha)
Agglomerations (AGGL)	23	27.36	387	16.7545
Crop-fallow mosaic (MCJ)	148	28.61	268	1.8
Crop-fallow mosaic under palms (MCJP)	216	41.63	130	0.6
Woody and shrubby savannahs (SASA)	132	39.64	198	1.5

Diameter distribution shows an "L-shaped" structure in agglomerations (AGGL) and in the crop-fallow mosaic (MCJ), and a "bell-shaped" structure in the crop-fallow mosaic under palms (MCJP) and in woody and shrubby savannahs (SASA) (Figure 4). The L-shaped distribution is characterized by a higher number of trees in the]20-30 cm] class in AGGL and in the]10-20 cm] class in MCJ, suggesting young stands subjected to frequent disturbances. In contrast, the bell-shaped distribution in MCJP shows a higher number of trees in the]20-30 cm] to]30-40 cm] classes, while in SASA, more trees are found in the]20-30 cm] to]40-50 cm] classes. This indicates a structure in a maturation phase, likely less disturbed. Polynomial curves show high coefficients of determination ($R^2 \approx 0.86$ to 0.96), indicating a good statistical fit of the models to the observed data and confirming the consistency of the described trends.

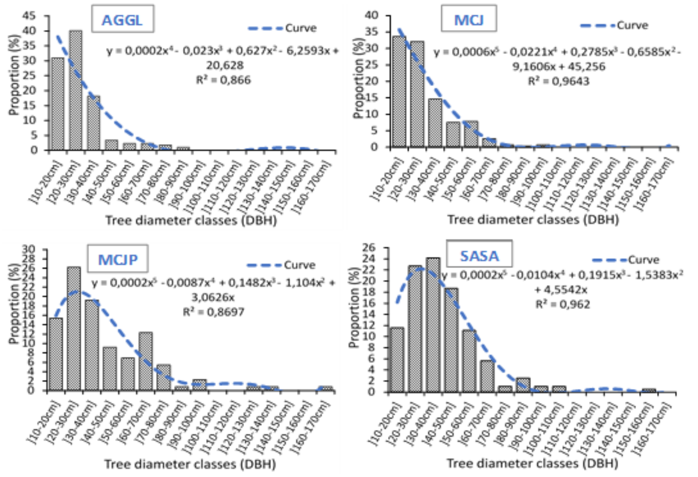

Figure 4 : Diameter class (DBH) distribution across land-use units - Distribution des classes de diamètre (DBH) de chaque unité d'occupation du sol.

Woody biomass values vary across land-use units. This trend is also reflected in the estimated carbon stocks (Table 3). The lowest values are observed in agglomerations (AGGL) (11.03 ± 16.34 t/ha; 5.18 ± 7.67 tC/ha) and in the crop-fallow mosaic (MCJ) (82.13 ± 119.64 t/ha; 38.60 ± 56.23 tC/ha). The highest values are recorded in the crop-fallow mosaic under palms (MCJP) and in woody and shrubby savannahs (SASA), which exhibit biomass and carbon stocks approximately twice as high as those in AGGL and MCJ. The Kruskal-Wallis test indicates a highly significant difference at the 5% level ($p < 0.000$***) among carbon stock values across land-use units. The Tukey post hoc test shows very significant differences ($p < 0.002$***) between AGGL and all other units (MCJ, MCJP, SASA), indicating that settlements are clearly distinguished by their low biomass and carbon stock levels. Comparisons between MCJ and MCJP ($p < 0.002$***), as well as between MCJ and SASA ($p < 0.007$***), are also highly significant, indicating differing carbon storage capacities among these units. In contrast, the difference between MCJP and SASA ($p < 0.21$) is not significant, suggesting that these two land-use types have broadly similar biomass and carbon stock levels (Table 4). Furthermore, Figure 5 shows a positive correlation between biomass, diameter, and woody plant density within each land-use unit. This implies that biomass increases as a function of both tree density and diameter.

Tableau 3: Distribution of woody biomass and carbon stock across urban land-use units -Biomasse et stocks de carbone des ligneux par unité d'occupation du sol urbain.

Land-use units	Biomass (t/ha)	Carbon stock (tC/ha)	Kruskal-Wallis test statistics	
			Chi²	Pr(>F)
Agglomerations (AGGL)	11.03 ± 16.34	5.18 ± 7.67	982	0,000***
Crop-fallow mosaic (MCJ)	82.13 ± 119.64	38.60 ± 56.23		
Crop-fallow mosaic under palms (MCJP)	312.73 ± 578.08	146.98 ± 271.69		
Woody and shrubby savannahs (SASA)	147.63 ± 223.32	69.38 ± 104.96		

Tableau 4 : Pairwise comparison p-values (Tukey test) for carbon stock across land-use units-Probabilités (p-value) de comparaison deux à deux du test de Tukey entre les taux de stock du carbone des unités d'occupation du sol.

Land-use units	Agglomerations (AGGL)	Crop-fallow mosaic (MCJ)	Crop-fallow mosaic under palms (MCJP)
Crop-fallow mosaic (MCJ)	0.002***	-	-
Crop-fallow mosaic under palms (MCJP)	0.002***	0.002***	-
Woody and shrubby savannahs (SASA)	0.002***	0.007***	0.21

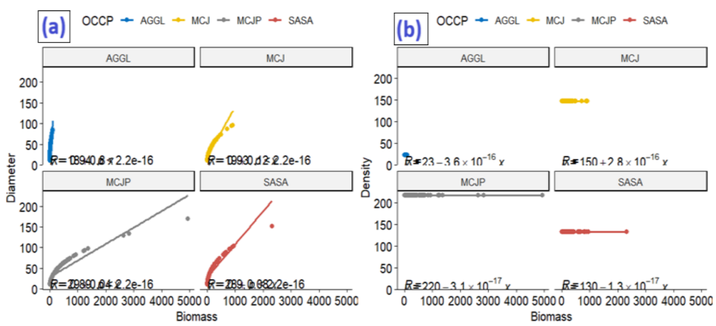

Figure 5 : Scatter plots and regression lines showing the relationships between biomass and tree diameter (a), and between biomass and tree density (b) across different land-use units - Nuages de points et de droites de régression entre la biomasse et les diamètres (a), et entre la biomasse et la densité (b) des arbres des différentes unités d'occupation du sol.

3.2. Discussion

The results show a variation in mean tree diameter and density across land-use units, from agglomerations (27.36 cm; 23 stems/ha) to the crop-fallow mosaic (28.61 cm; 148 stems/ha), woody and shrubby savannahs (39.64 cm; 132 stems/ha), and reaching a maximum in the crop-fallow mosaic under palms (41.63 cm; 216 stems/ha). These diameters are higher than the range of 24.66 cm to 28.38 cm reported by Folega *et al.* (2020) in Dapaong (Togo). However, the densities remain lower than those reported by Kombaté *et al.* (2019) in cities of Togo (191 to 276 stems/ha) and by Moussa *et al.* (2019) in Niger (51.06 to 198.38 stems/ha) across land-use units. These differences may be due to the inclusion, in the present study, of only trees with DBH ≥ 10 cm, or to the high anthropogenic pressure in the study area. The values obtained in agglomerations (AGGL) and in the crop-fallow mosaic (MCJ) indicate that tree stands are dominated by young individuals. This observation is supported by the "L-shaped" diameter class distribution (Figure 4), which is characteristic of vegetation formations subjected to frequent disturbances. In contrast, the values recorded in the crop-fallow mosaic under palms (MCJP) and in woody and shrubby savannahs (SASA) reflect more mature and relatively stable stands. The "bell-shaped" diameter distribution observed in these units (Figure 4) indicates structural balance and less disturbed environments. These findings are consistent with those of Jiagho (2018) and Folega *et al.* (2020), who reported that L-shaped distributions are typical of highly disturbed environments dominated by young trees, whereas bell-shaped distributions reflect stable environments with mature trees. However, the values remain very low in AGGL, intermediate in MCJ, and high in MCJP and SASA. This suggests that disturbances are more intense in AGGL, mainly due to activities such as urbanization, wood harvesting, and soil sealing, which limit tree growth and maturation. This explains the low density and the predominance of small-diameter (young) trees observed in these areas. The intermediate pattern observed in MCJ reflects a transitional environment between highly anthropized areas and more natural formations. It indicates a system subjected to agricultural disturbances, mainly due to tree clearing for crop establishment, while still retaining some regeneration potential. The high values recorded in MCJP and SASA indicate that these environments are less disturbed and tend to accumulate trees, often planted for commercial purposes. Similarly, biomass remains very low in AGGL (11.03 ± 16.34 t/ha), intermediate in MCJ (82.13 ± 119.64 t/ha), and high in SASA (147.63 ± 223.32 t/ha) and MCJP (312.73 ± 578.08 t/ha). These values are lower than those reported by Gomgnimbou *et al.* (2019) in Bobo-Dioulasso (Burkina Faso), which ranged from 6.44 t/ha to 713.97 t/ha. Carbon stock is also low in AGGL (5.18 ± 7.67 tC/ha) and higher in MCJ (38.60 ± 56.23 tC/ha), followed by SASA (69.38 ± 104.96 tC/ha) and MCJP (146.98 ± 271.69 tC/ha). These values are lower than the range of 19.1 tC/ha to 440 tC/ha estimated by Ifo and Binsangou (2019) in Congo. The low biomass and carbon stock values observed in agglomerations (AGGL) and in the crop-fallow mosaic (MCJ) further confirm the low tree densities and mean diameters recorded, highlighting environments subjected to strong anthropogenic pressures. This is because, in densely urbanized areas, spatial constraints and repeated human disturbances limit tree growth and longevity, resulting in reduced diameters, low biomass, and a limited carbon storage potential (Binsangou *et al.,* 2017; Folega *et al.,* 2020). In general, only a few ornamental tree species such as *Cordia sebestena* and fruit trees such as *Citrus sinensis, Mangifera indica* are found in wealthy households and public spaces. However, these are mostly exotic species with low carbon storage capacity, which would need to be complemented in large numbers by native species. In contrast, the crop-fallow mosaic under palms (MCJP) and woody and shrubby savannahs (SASA) exhibit higher mean diameters, indicating a more mature and better-preserved woody structure. These environments are dominated by individuals planted for commercial purposes, such as *Anacardium occidentale*, *Gmelina arborea*, and *Tectona grandis*. These species form semi-natural stands that increase in diameter over time and contribute significantly to biomass and carbon stocks (Tschora and Cherubini, 2020). Biomass and carbon storage levels vary significantly across land-use units (p-value = 0.000**), which is consistent with the findings of Ifo and Binsangou (2019), who reported high variability among different environments. The Tukey post hoc test reveals a highly significant difference between agglomerations (AGGL) and other land-use units ($p < 0.002$***), confirming the negative impact of urban pressure on biomass and carbon storage. Similarly, significant differences ($p < 0.007$***) between MCJ and the MCJP and SASA units indicate that agricultural practices strongly influence ecosystem structure and functioning. In contrast, the absence of a significant difference between MCJP and SASA ($p < 0.21$) suggests that palm-based agroforestry systems may exhibit ecological performance comparable to that of natural formations, particularly in terms of carbon storage. These observations are also supported by Tschora and Cherubini (2020), who showed that urbanization and agricultural intensification are associated with substantial losses of vegetation carbon, whereas semi-natural landscapes maintain higher and more stable carbon stocks over time. Furthermore, the positive correlation observed between biomass, diameter, and woody plant density (Figure 5) confirms that increases in carbon stock depend on stand structure. This relationship highlights the importance of conserving trees in MCJP and SASA, as well as implementing reforestation strategies to maintain sufficient tree density in MCJ and especially in AGGL in order to optimize carbon sequestration. It is therefore necessary to promote management strategies adapted to each land-use type, while supporting sustainable conservation and enhancement of woody vegetation in the land-use units of Kétou, for a healthier urban environment.

4. Conclusion

This study shows that biomass and carbon stocks vary considerably across land-use units, with very low values in Agglomerations (11.03 ± 16.34 t/ha; 5.18 ± 7.67 tC/ha) and markedly higher values in woody and shrubby savannahs (147.63 ± 223.32 t/ha; 69.38 ± 104.96 tC/ha), followed by the crop-fallow mosaic under palms (312.73 ± 578.08 t/ha; 146.98 ± 271.69 tC/ha). These results confirm the major role of these units in biomass accumulation and carbon storage. Agglomerations, characterized by low values, reflect the impact of anthropogenic pressures and spatial constraints typical of urban environments. In contrast, crop-fallow mosaics under palms and woody and shrubby savannahs are distinguished by more mature woody structures, associated with higher biomass levels and greater carbon sequestration capacity, although they are undergoing gradual changes. Biomass production and carbon storage vary significantly among land-use units. Although carbon stock levels remain relatively high in the crop-fallow mosaic under palms and woody and shrubby savannahs, no significant difference is observed between these two units, and their values remain lower than those reported in some large cities. This highlights the need to strengthen carbon storage through reforestation programs using perennial species, particularly in agglomerations. These findings call for the implementation of sustainable management and conservation strategies for woody vegetation, including the protection of mature trees, in order to enhance ecological resilience and environmental quality in urban and peri-urban areas.

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