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Phytodiversity, structure and carbon sequestered by avenue trees in the Municipality of Sèmè-Podji, Southern Benin

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ABSTRACT

The importance of plants in the urban environment is sufficiently demonstrated by their potential and the ecosystem services they generate for the environment and populations. The present work aimed at assessing the contribution of avenue trees to carbon sequestration in the municipality of Sèmè-Podji in Benin. The methodological approach used has allowed making the inventory of trees along 26 kilometers of managed roadways. The diversity and structure parameters were computed to assess the floristic potential, the diameter and height structure of the trees, then the sequestered carbon from the allometric equations established for urban environments. The results revealed 19 species grouped into 12 families and 17 genus along the explored streets. Shannon's average diversity index (3.25±0.13 bits) and Pielou's equitability (0.76±0.04) explain the dominance of a few species, among which the most representative are *Terminalia catappa* (33.79%), *Delonix regia* (12.5%), and *Khaya senegalensis* (9.72%). The diameter and height structures are irregular, with average of 46.75 ± 33.46 cm and 10.35 ± 5.33 m respectively. The aerial biomass for the inventoried streets is 756.16 t/ha, corresponding to a carbon stock of 378.17 t/ha, that is the equivalent of 102.09 t of CO_2 per hectare. It appeared from this study that the floristic procession and the structural characteristics of the avenue trees are limited to ensure the socio-ecological functions in the municipality of Sèmè-Podji. However, this information could encourage decision-makers to take reforestation measures to increase the vegetation cover of the streets and for better management of the city's urban forestry.

Keywords: Avenue Trees; Diversity; carbon Sequestration; Urban Planning; Sèmè-Podji; Benin.

INTRODUCTION

Fast population growth is causing rapid and uncontrolled urbanization in some cities, sometimes leading to artificial lands in place of plant formations (Charahabil, 2018). However, the maintenance of plants in urban environments is the basis for the conservation of biodiversity and the availability of

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ecosystem services, which the importance no longer needs to be demonstrated for the well-being of populations (Bolund and Hunhammar, 1999). Generally, this involves improving the living environment through the sequestration of carbon in the atmosphere (Kouadio et al., 2016; Vroh et al., 2014), the renewal of oxygen in the air and humidity regulation (McPherson 2006; Kenney et al., 2011), control of soil water erosion (Fuwape and Onyekwelu, 2011) and improvement of thermal comfort (Livesley et al., 2016). It is therefore necessary to promote urban forestry in order to increase the supply and demand of socio-ecological benefits (Beichler, 2015), and the economic value of the benefits provided by urban trees (Fisher et al., 2008; Gómez- Baggethun et al., 2010) to hope for the well-being of populations and the sustainability of cities.

Being aware of these challenges, local governance actions are initiated by urban managers through the development of urban green spaces, including avenue trees or shade rows. In West Africa, the specific objectives pursued by streets tree reforestation are multiple and are often expressed in terms of supply, regulation and socio-cultural services provided by urban trees to communities (Amontcha et al., 2015; Lougbégnon, 2013). This demonstrates the usefulness of the tree in daily practices through the relationships between the plant diversity of cities and the forms of use by urban populations. Moreover, even if the production of regulation services is not visible, or poorly perceived by city dwellers (Osséni et al., 2020a), the contribution of the floristic diversity of avenue plantations to increase in biomass and by therefore the stock of sequestered carbon is widely proven (McHale et al., 2007 ; Kouassi et al., 2018 ; Nomel et al., 2019).

In Benin, avenue trees contribute to attractiveness of the landscape and their promotion is done during reforestation campaigns, where adapted species are used. However, the failure of management methods, in particular the lack of maintenance and monitoring of planted trees, leads to their degradation and gives the impression that they are neglected. These practices affect the socio-ecological dimension of their importance, and therefore compromise their production function in goods and services at the municipal scale (Calaza et al., 2018). This is the case of the commune of Sèmè-Podji, which is a border area with Nigeria, then a territory of transition between two large towns of Benin: Cotonou, which is the largest economic center, and Porto-Novo that is the political capital of the country. With this geographical position, the municipality of Sèmè-Podji has experienced in recent years a considerable increase in its population due to the advantages it offers in terms of dormitory town, economic activities, and industrial and transit space (PDC of Sèmè-Podji, 2005).

Despite these assets, which promote human settlement, tourism, and transit, less attention is paid to the landscaping of the urban agglomeration of this city and particularly to the enhancement of its public spaces by both the urban managers and the people. This observation is illustrated by the scarcity of public green spaces, and more specifically roadway avenue trees, the abundance of which could help to mitigate the effects of climate change (Gomgnimbou et al., 2019) and to identify other contemporary challenges such as landscape attractiveness, ecological connectivity, as well as the conservation of biodiversity in the city. Globally, terrestrial ecosystems help reduce the effects of climate change because they absorb nearly 50% of carbon dioxide emissions emitted into the atmosphere (Folega et al.) Quoted by Adjonou et al., 2010. Specifically, it has been shown that carbon stock is higher in aboveground biomass than in root biomass (Diatta et al., 2016 ; Kooke et al., 2019). These considerations allowed to confirm that the magnitude of the benefits provided by urban trees depends on their abundance and growth in the urban landscape (Sehoun et al., 2021). Thus, the aim of this study is to assess the contribution of avenue trees to ecosystem services of regulation, in particular the carbon sequestered by the biomass of avenue trees in the municipality of Sèmè-Podji through analyzing their floristic diversity and structures parameters.

MATERIALS AND METHODS

Study area

Located in the department of Ouémé, in the south-east of the Republic of Benin and on the Atlantic coast, the commune of Sèmè-Podji is positioned between 6°19'59" and 6°27'34' ' North latitude and between 2°27'42" and 2°42'34" East longitude (Figure 1). It is limited to the north by the communes of Porto-Novo, Aguégués, Sô-Ava, and Adjarra; to the south by the Atlantic Ocean; to the east by the Federal Republic of Nigeria and to the west by the Atlantic Division (city of Cotonou). According to the latest territorial division, it is subdivided into six districts (Agblangandan, Aholouyèmè, Tohouè, Sèmè-podji, Djèrègbé and Ekpè) and covers an area of 250 km². From a demographic point of view, at the last population census, the municipality of Sèmè-Podji had 222.701 inhabitants, including 113.107 women (INSAE, 2016). Due to its geographical location, the municipality of Sèmè-Podji enjoys a Sudano-Guinean type climate with two dry and two rainy seasons. The average temperature is around 27°C with high relative humidity. The annual rainfall is 1100 mm, due to cyclical disturbances under the influence of the coastal wind, which also makes this town one of the wettest areas in southern Benin. The hydrographic network of the Commune is well supplied and defined as a continuum between the Atlantic Ocean, the lagoon of Porto-Novo, the Ouémé River, and Nokoué Lake. The plant landscape of the study area belongs to the coastal Guinean phytogeographical sector consisting of shrubs, which are endangered due to the pressure exerted by riparian populations. As a result, natural species have given way to imported species such as (*Casuarina equiseltifolia*, *Eucalyptus camaldulensis*, *Borassus aethiopum*). The biophysical conditions described are thus favorable to the development of urban plants, including the avenue trees. These trees are planted on 26.169 linear kilometers of roads, distributed as follows:

- Boulevard: Roadways from CimBénin to Djrègbé, a distance of 22921.52 meters;
- Street 1: Paved road going from the Sinka Hongbodji intersection to the Sèmè-Podji's Central hospital, a distance of 2072.705 meters;
- Street 2: Houdégbé paved road, going from Pk10 to the beach over, a distance of 1174.56 meters.

Sampling and data collection methods

Data collection was based on a floristic inventory that was carried out along all developed roads and provided with avenue trees according to the itinerant survey method. In total, 03 homogeneous road axes from structural point of view and with a total length of 26 km were explored in this study. Thus, the species of avenue trees were recorded with the associated numbers, on both sides of the roads if necessary, on an inventory sheet. Then, variables such as height and diameter at breast height (DBH ≥ 10 cm) of the trees were also measured. The taxonomic identification of the plant species collected was confirmed from the analytical flora of Benin (Akoègninou et al., 2006).

Data processing and analysis methods

The data entered on the inventory sheets were transferred to a database to be processed using the Microsoft Office Excel spreadsheet. The identification consisted in determining the scientific name of each plant, its botanical family, as well as its genus.

To inform about the floristic diversity of the roads studied, the specific richness, the Shannon diversity index, the Pielou equitability and the relative frequency were calculated and adapted to the urban context. The various calculated parameters are described as follows:

The specific richness (S) is the number of species present along a studied street axis.

The Shannon diversity index (H) is the most commonly used in the literature

$$H = -\sum \text{pi} \log_2 \text{pi}$$

H varie both according to the number of species present and according to the relative proportion of individuals of the various species. It generally varies between 0 and Hmax ≈ 5 bits, and sometimes beyond. The value pi (between 0 and 1) is the relative proportion of individual numbers of a specie i in all the individuals of all the species concerned; pi = ni /∑ ni; with ni as the number of individuals of species i and ∑ni as the set of individuals of all species.

Pielou's equitability (R) often accompanies the Shannon diversity index to assess the even distribution of species. It reflects the degree of diversity achieved by a plantation, and corresponds to the ratio between the effective diversity (H) and the theoretical maximum diversity (H max).

$R = H/(\log_2 S)$

The equitability varies between 0 and 1. It tends towards 0 when almost all of the numbers correspond to a single species in the stand, and tends towards 1 when each of the species is represented by the same number of individuals.

The relative frequency (FR) is calculated to report the ratio of the number of individuals of a species or observation (n) compared to the total number of species listed or total observation for a variable (N) :

$FR = (n \times 100)/N$

To provide the structural characteristics of the avenue trees of the municipality of Sèmè-Podji, the diagrams in sticks was used to present the diametrical structures and height of the trees. Thus, the diameters are grouped by 10 cm amplitude class, and the heights by 2 m amplitude class. As the urban environment is heavily disturbed, trees are under enormous pressure, which could affect their growth. Thus, to analyze the influence of anthropogenic pressures on trees, a linear regression was established to assess the concordance between diameter and height.

To estimate the above-ground biomass of roadside trees in the town of Sèmè-Podji, urban equations known as UGES (Urban General Equations) were used according to the type of species (Aguaron and McPherson 2012). These equations presented in the literature are the most suitable for the urban context, given their specificity (Nomel et al. 2019). Thus, two allometric equations were retained according to the type of species inventoried (trees and palms):

For trees, the equation is on the form: $Biom = 0.16155 \times DBH^{2.310647}$

For Palms, the equation is of the form $Biom = 1.282 \times (7.7H+4.5)$

In these formulas, Biom designates the total biomass expressed in kg/stem; DBH is the diameter at breast height at 1.30 m from the ground expressed in cm; H is the height of the palm trees in meters. The carbon stock is obtained by multiplying the biomass by 0.5. The corresponding carbon equivalent or CO_2 was determined by multiplying the carbon stock by 0.27 (IPCC, 2003).

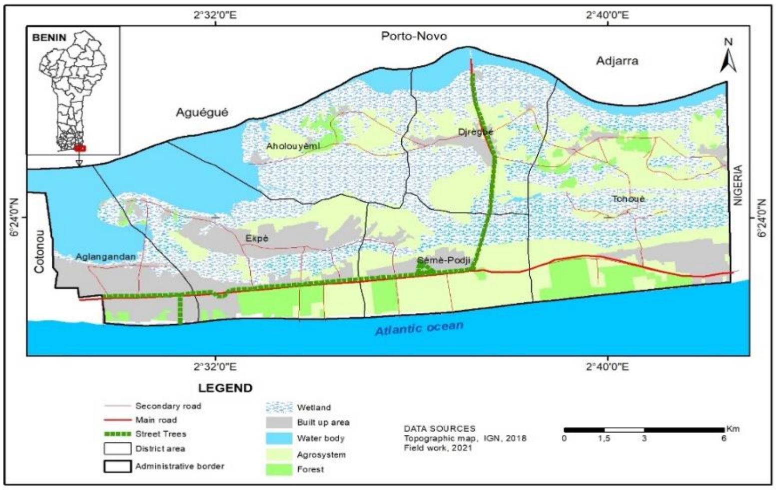

Figure 1: Geographical location of the commune of Sèmè-Podji.

RESULTS

Floristic diversity of avenue trees in the municipality of Sèmè-Podji

The avenue trees counted in the managed roadways of the municipality of Sèmè-Podji are composed of 216 individuals divided into 19 species, grouped into 12 families and 17 genus. Most of these species are introduced into the facilities during reforestation campaigns or by the populations according to their preferences. The list of species and their frequency of occurrence are presented in Table 1.

We retain from this table that four (4) species are representative with 64.8% of individuals (Figure 2). These are *Terminalia catappa* (33.79%), *Delonix regia* (12.5%), *Khaya senegalensis* (9.72%), and *Coccoloba uvifera* (8.79%). Among the 12 families identified (figure 2), most representative are: Combretaceae (43.51%), Arecaceae (16.20%), Caesalpiniodeae (12.96%) and Meliaceae (12.5%).

As for the specific diversity, it varied from one street to another and for the whole city. Examination of Table 2 indicates that the Shannon index calculated for all the avenue trees of the Sèmè-Podji municipality was 3.25 ± 0.13 bits and the equitability of Pielou is 0.76±0.04. These values are above the average and confirm a phenomenon of dominance of a few species along the main roads of the city. Similarly, the values of the Shannon diversity index of boulevard and street 1 are 2.61±0.21 and 2.87±0.2 bits respectively, while that of equitability are 0.72±0.01 and 0.77±0.05 respectively. This explains both a dominance and an absence of even distribution of certain species in these avenue trees. On the other hand, street 2 had a low diversity index (1.78±0.2 bits) and an evenness value of 0.77±0.3. We also noted that the specific richness of street 2 is relatively low, compared to that of the other two roads.

Structural characteristics and carbon sequestered by avenue trees in the municipality of Sèmè-Podji

Diameter and height structures

The Figure 3 presents the structure of the diameter of the inventoried avenue trees in the municipality of Sèmè-Podji. The average diameters of the avenue trees was 46.75 ± 33.46 cm. It is an irregular saw-tooth structure that shows an accumulation of a large number of individuals in the class interval [10-20[, with 29.62% of individuals. It is followed by the classes [20-30[, [40-50[and [100 and more[, each of which accounts for 12.03% of individuals. This Similar tendency was observed for the structure of height (Figure 4). Thus, the average height calculated for the avenue trees was 10.35 ± 5.33 m. The height class interval that accumulated the greatest number of individuals was [4-6[, with 16.2% of individuals. It was followed by the classes [8-10[with 13.42% of the individuals, then the classes of [10-12[and [14-16[, each with 12.03% of the individuals. According to the investigations, this irregularity in the structures in diameter and in height is linked to the mutilations suffered by the trees and the renewal of certain feet.

The relationship between the diameter and the height of the avenue trees of Sèmè-Podji's municipality is presented in Figure 5. We note from this figure, a strong dispersion of the points around the line of adjustment, which shows that most diameter measurements do not agree with measured heights. This observation is confirmed by the coefficient of determination R^2 that is 0.014 ($P < 0.001$). The low probability values resulting from the analysis of variance ($F = 25.89$; $P < 0.001$) also expresses independence between these two parameters. On the one hand, it appears from these analyses that the trees counted within these plantations are of different generations. On the other hand, the growth in height of the trees is disturbed by other factors of the urban environment, which could be explained by the pruning and repeated sizes to maintain the overhead electricity network.

Areal biomass and carbon stored by avenue trees

The biomass value estimated for all the street trees inventoried was 756.16 t/ha. This biomass value corresponds to a sequestered carbon stock of 378.17 t/ha, which is equivalent to a value of 102.09 tons of CO_2 per hectare (Table 3). If we consider the roads separately, the boulevard has a higher quantity of biomass (489.27 t/ha) than streets 1 (111.32 t/ha) and street 2 (155.57 t/ha)). It is the same for their sequestered carbon values and CO_2 equivalent. However, the biomass and carbon values of street 2 are higher than those of street 1, while the latter is superior in terms of linear distance, species richness and number of individuals. This implies that the carbon values depend more on the type of species and the density of the crown in the avenue.

Table 1: List of these species and their frequency of appearance in the avenue trees of Sèmè-Podji.

Specy	Family	Genus	Frequency (%)
***Azadirachta indica* Juss.**	Meliaceae	Azadirachta A.Juss.	3.24
***Calotropis procera* Brow.**	Apocynaceae	Calotropis R.Br.	0.46
***Coccoloba uvifera* Linn.**	Polygonaceae	Coccoloba L.	8.79
***Cocos nucifera* Linn.**	Arecaceae	Cocos L.	0.46
***Cordia sebestena* Linn.**	Boraginaceae	Cordia L.	2.77
***Delonix regia* Boje. et Rafi**	Caesalpiniodeae	Delonix Raf	12.5
***Elaeis guineensis* Von.**	Arecaceae	Elaeis Jacq.	1.38
***Eucalyptus camaldulensis* Debn.**	Myrtaceae	Eucalyptus L.	0.92
***Ficus polita* Vahl.**	Moraceae	Ficus L	3.24
***Gmelina arborea* Roxb.**	Verbenaceae	Gmelina L.	2.31
***Haematoxylon campechianum* Linn.**	Fabaceae	Haematoxylom L.	0.46
***Khaya senegalensis* Desr. et Juss.**	Meliaceae	Khaya A. Juss.	9.72
***Parkia bicolor* A. Chev.**	Fabaceae	Parkia A. Chev.	0.46
***Polyalthia longifolia* Sonn.**	Annonaceae	Polyalthia Blume.	6.01
***Roystonea regia* Kunt.**	Arecaceae	Roystonea O.F.Cook	3.7
***Tamarindus indica* Linn.**	Caesalpiniodeae	Tamarindus L.	0.46
***Terminalia catappa* Linn.**	Combretaceae	Terminalia L.	33.79
***Terminalia mentaly* Perr.**	Combretaceae	Terminalia L.	7.87
***Terminalia superba* Engl. et Diels.**	Combretaceae	Terminalia L.	1.38

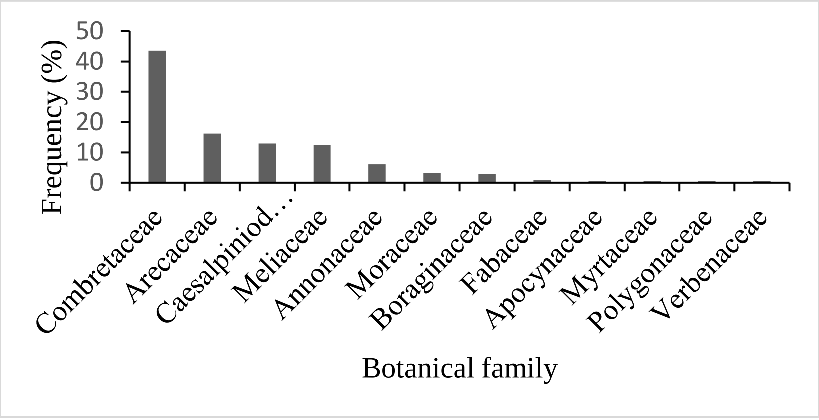

Figure 2: Repartition of species number by botanical family.

Table 2: Species diversity of avenue trees planted along managed roadways of Sèmè-Podji.

Indices	Boulevard	Street 1	Street 2	Ensemble
Specific richness	12	13	5	19
Shannon index	2.61±0.21	2.87±0.2	1.78±0.2	3.25±0.13
Pielou's Equitability	0.72±0.1	0.77±0.05	0.77±0.03	0.76±0.04

Boulevard: Tarred road from CimBénin to Djrègbé; Street 1: Paved road from the Sinka Hongbodji intersection to the zone hospital; Street 2: Paved Houdégbé road, going from Pk 10 to the beach.

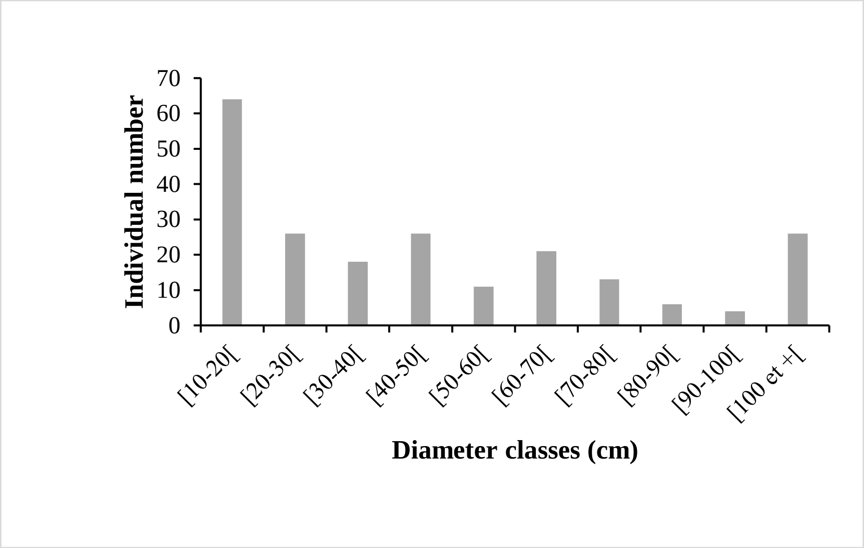

Figure 3: Diametric structure of alignment trees.

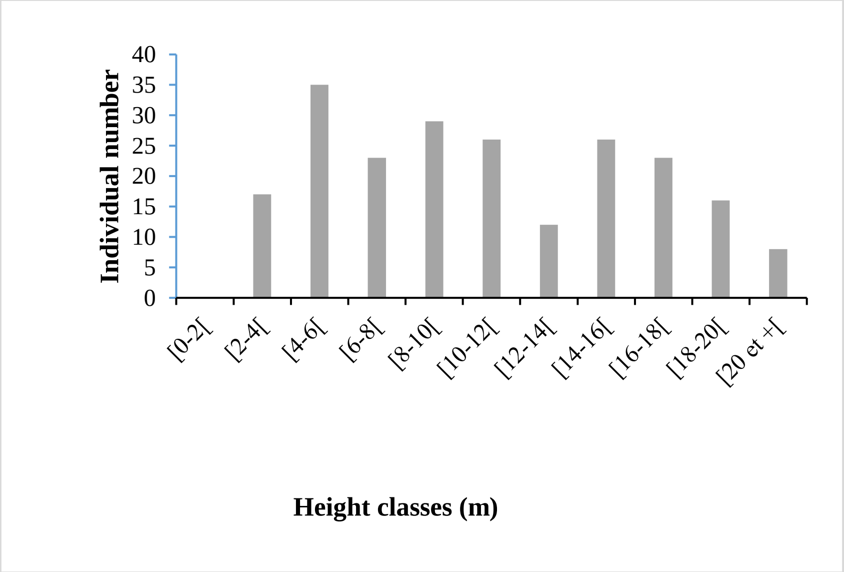

Figure 4: Structure in height of the alignment trees.

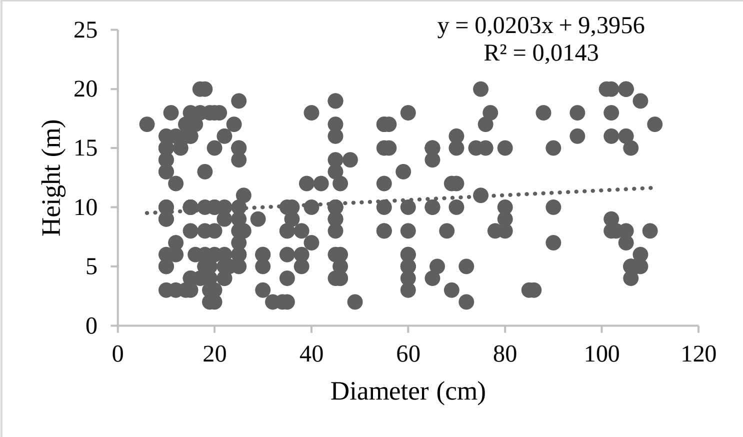

Figure 5: Correlation between diameter and height of avenue trees in Sèmè-Podji.

Table 3: Parameters of areal biomass and stored carbon.

Parameters	Boulevard	Street 1	Street 2	Total
Aerial Biomass (t/ha)	489.27	111.32	155.57	756.16
Sequestered carbon (t /ha)	244.63	55.66	77.88	378.17
CO_2 équivalent (t/ha)	66.05	15.02	21.02	102.09

Boulevard: Tarred road from CimBénin to Djrègbé; Street 1: Paved road from the Sinka Hongbodji intersection to the zone hospital; Street 2: Paved Houdégbé road, going from Pk 10 to the beach.

DISCUSSION

Diversity of avenue trees in the municipality of Sèmè-Podji

The mains species that characterize the avenue trees in the city of Sèmè-Podji are *Terminalia catappa*, *Delonix regia*, *Khaya senegalensis* and *Coccoloba uvifera*. The abundance of these species has been favored by their promotion during reforestation campaigns as fast-growing species adapted to the environment. This implies the presence in majority of families such as Combretaceae, Arecaceae, Caesalpiniodeae and Meliaceae on this city's roadways. These same group of families are observed for the street trees of the city of Cotonou (Amontcha et al., 2017), in the city of Allada (Sehoun et al., 2021) and in other West African sub-region cities (Radji and Kokou, 2013; Kouadio et al., 2016). As required the methodological approach, taking into account diameter at breast height greater than 10 cm considerably reduced the number of trees considered in this study. As a result, the floristic heritage of the avenue trees of the city of Sèmè-Podji presents relatively low diversity parameters, resulting in the dominance of a few species within them. However, we noted that the species vary according to the typology of the road network. Indeed, the species found on street 1, which crosses the central agglomeration of the town of Sèmè-Podji, are more numerous than those on the Boulevard and street 2. The investigations revealed that the populations introduced over successive years, species of their choice in order to benefit from goods and services such as shade, fruits, and organs for domestic uses. This practice, which seems to be specific to street trees, is observable in most cities where the implementation of landscaping plans is not supported (Kouassi et al., 2018). In addition, for the most part, the introduced species are mainly of the fruit type (Nomel et al., 2019). As a result, some streets present a plant landscape contrasted by the floristic heterogeneity and the degraded character of the tree crown, caused by anthropogenic pressures (Osséni et al., 2020b). For the successful integration of urban forestry into land use planning, the function dedicated to avenue trees must be clearly defined, in order to make sustainable plant choices along roadways.

Structures and carbon sequestered by avenue trees in the municipality of Sèmè-Podji

The diameter and height structures of the avenue trees of Sèmè-Podji present a sinusoidal evolution. In addition, tree height growth is not necessarily a function of diameter at breast height. This reflects a strong influence of the environment on the trees that make up these alignments. These results confirm the hypothesis of anthropogenic pressures linked to the sociocultural context. Thus, to strengthen the ecological functions of the city, it is important to regulate access to the material benefits of street trees, which a priori are an integral part of the development of the city and contribute to the well-being of city dwellers. This regulatory effort would increase the ecosystem services provided by the avenue trees, in particular the regulation service of carbon sequestration. Indeed, the assessment of this service for the urban environment is generally based on approaches for estimating the biomass and the carbon rate from allometric equations with a single predictor whose diameter for trees and height for Palm trees. The application of this equation for the avenue trees in the city of Sèmè-Podji has made it possible to note that in all the plantations inventoried, the equivalent of the carbon dioxide stored by the roadway plantations is low and that the average CO_2 value is estimated at 102.09 t/ha. This is the participation of trees planted in the developed streets of the city of Sèmè-Podji in the reduction of greenhouse gases including carbon dioxide, which contributes the most to global warming (IPCC, 2003). This contribution help for the sustainability of cities, because plant degradation causes carbon loss and indirectly contributes to climate change (Ouedraogo et al., 2019). But the values obtained at Sèmè-Podji are low and significantly lower than those found by Sehoun et al. (2021) for the city of Cotonou and in the sub-region (Kouadio et al., 2016; Kouassi et al. 2018), although they used the same method. However, they are close to those obtained by McPherson et al. (2002). This difference in values is certainly linked to anthropogenic pressures that do not favor the normal growth of trees. It would therefore be important to increase reforestation and improve the management methods of urban trees in order to increase the potential for carbon sequestration in the city (Gomgnimbou et al., 2019). Thus, urban managers in Sèmè-Podji can claim to a lesser extent to mitigate air pollution and access carbon credit for the city (McHale et al., 2007). In addition, it will be necessary to act on the efficiency of the equation model used by continuing to reflect on the adjustment of the methodology for estimating the biomass according to the environment, in order to refine the calculation formula on the carbon dioxide sequestration from avenue trees. For example, according to Loubota Panzou (2018), given that the urban environment is quite restrictive for trees, it would have been more interesting to integrate the environmental stress factor for more precision. This proposition confirms the thinking of Peltier et al. (2007) for whom the specificities of the environment are decisive for the measurements taken in the field to reflect a correct estimate of the dry biomass.

Conclusion

At the local scale of Sèmè-Podji city, the avenue trees are dominated by species that seem to be adapted to the constraints of the environment. The Combretaceae, Arecaceae, Caesalpiniodeae and Meliaceae families are the most representative for all plantations. Apart from street 2 that has low diversity, the diversity parameters are average for all the plantations. The introduction of species preferred by the populations constitutes a response to the requirements of the quality of the living environment, but compromises the functions dedicated to the street trees. In addition to this, there are anthropogenic factors that condition the linear and surface densities, the diametric and height structures, and therefore the carbon sequestration potential of street trees. Thus, the reduction of carbon dioxide in the air in the municipality of Sèmè-Podji would depend on the number and spatial distribution of trees that contribute to the maintenance of ecosystem services for the well-being of populations.

COMPETING INTERESTS

The authors of this manuscript have no competing interests.

AUTHORS' CONTRIBUTIONS

AAO and GHFG designed the study. AAO and YFA: Data collection, analysis, and the first draft of the manuscript; review and editing: GHFG and YFA. All authors read and approved the manuscript.

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