

Original Paper

Afforestation/Reforestation Based on *Gmelina Arborea* (Verbenaceae) in Tropical Africa: Floristic and Structural Analysis, Carbon Storage and Economic Value (Cameroon)

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Abstract

The study was carried out in three selected plantations. Sampling was made in five 100x20 m² plots per site. Overall, 32 species, 36 genera and 17 families were surveyed. *Hymenocardia acida*, *Combretum adenogonium*, *Daniellia oliveri*, *Entada africana*, *Terminalia macroptera*, *T. laxiflora*, *Lannea schimperi*, *Lophira lanceolata*, *Maytenus senegalensis*, *Ochna schweinfurthiana*, *Protea madiensis*, *Psorospermum senegalense*, *Piliostigma thonningii*, *Sarcocephalus latifolius* and *Securidaca longepedunculata* were the most important species. The richness index ranged from 2.53±0.05-7.74±0.03. Shannon index was 3 in all sites. Density ranged from 98±2.01-253±10.23 stems/ha. Basal area was statistically significant among the sites ($p < 0.001$). All sites were floristically similar ($k > 70\%$). The vertical structure showed three types of figures; L shape, symmetrical bell shape and unsymmetrical bell shape. These structures confirmed a good regeneration of timbers in the sites. There was a positive correlation of the species dispersal in the sites ($p < 0.001$). The amount of AGB was 23.50±0.38 t C/ha. The amount of C sequestration was 86.28±16.57 t CO_{2eq}/ha. The ecosystem service payments ranged between 258.87±24.88-8629.25±248.16 €/ha with the lowest values for CDM price and the highest for REDD+price. A financing of such projects is required in the frame of creating adaptation and attenuation measures to global warming effects.

Keywords

phytodiversity, biomass, carbon storage, tropical Africa

1. Introduction

Adaptation and mitigation are two main stakes of fighting against climate change. During the last 20 years, question relative on climate change has attracted attention of the international community which has decided to fight against the phenomena. The frame agreement of the United Nations upon climate change was adopted in 1992. The Kyoto protocol which has adopted in December 1997 imposed to all state members common duties even though these engagements are distinguished. To developed countries, the protocol imposed restrictive obligations of reduction of Greenhouse Gases (GHG). To under-developed countries, the protocol promotes and eases their participation in the climate change fighting by means of financial mechanisms on the one hand and the flexibility mechanisms based on the market as the Clean Development Mechanism (CDM) in other hand. The CDM aims at supporting developed countries to reduce the cost of implementation of their commitments of reduction by financing or realizing of emission reduction in under-developed countries. Thus, the latter must receive projects that will contribute to their sustainable development. In the under-developed countries, CDM aims at preserving the already existing carbon sinks or at creating new carbon sinks. In fact, afforestation/reforestation projects of non-wooded and/or degraded surface areas are practices to be encouraged in tropical countries where the rhythm of the biodiversity disruption is alarming. These practices represent an expansion potential of the phytodiversity which could balance an unsettled part of the floral diversity in the savannah ecosystems due to deforestations (Bosangi, 2017; Noiha *et al.*, 2018a).

So, after the Kyoto Protocol, it has become possible for Certified Emission Reduction to consider actions of Clean Development Mechanism (CDM) projects involving activities of land use, land use change and agroforestry. In the world at large, conifers are mostly used for afforestation. Thus, the afforestation/reforestation based on *Pinus* represents 32 % of the productive plantation areas and *Cunninghamia* (11 %) especially in China; as against 8 % (according to FAO) or 14 % (according to data published by GIT Forestry) for the afforestation/reforestation based on *Eucalyptus*. *Acacia* is the most used genus in Southeast Asia, whereas *Eucalyptus* is the most used genus all over the Tropics with 40 % of afforested areas in South America (FAO, 2008).

Agrosystems as reported in many works, could therefore offer a palliative solution to mitigate climate change (Albrecht & Kandji, 2003; Saint-André *et al.*, 2005; Oelbermann *et al.*, 2005; Lufafa *et al.*, 2008; Takimoto *et al.*, 2008; Prakash & Lodhiyal, 2009; Torres *et al.*, 2010; Hergoualc'h *et al.*, 2012; Kuyah *et al.*, 2012; Thangata & Hildebrand, 2012; Zapfack *et al.*, 2013; Somarriba *et al.*, 2013; Noiha *et al.*, 2017; Noiha *et al.*, 2018b). Agrosystems are refuge centres for endogenic species which are threatened by anthropogenic activities which the natural ecosystems incur (Bhagwat *et al.*, 2008; Noiha *et al.*, 2018a). A sustainable management of agricultural systems must be extolled; except for their multiple known uses which are beneficial for the population, their role in the process of climate

mitigation to our knowledge remains unknown. These practices as well, can lead to the implementation of the process of Clean Development Mechanism (CDM) of poor populations, thus contributing to the reduction of poverty; one of the sustainable development millennium goals.

Amongst the most used species in afforestation/reforestation, *Gmelina arborea* offers an important economic potential in tropical Africa (Niskanen, 1998). Many private and public dealers are interested for woodwork yield (Dupuy *et al.*, 1999). Originated from Indian tropical rain forests, its timber is most appreciated during several centuries (Louppe, 2008). Many qualities of *Gmelina*'s wood have promoted the extension of the plantations of this species in many African countries. To remedy to the increasing requirement of populations in woodwork and combustible, the introduction of exotic species of reforestation occurred as a good alternative in the majority of the countries in central Africa (Palupi *et al.*, 2010). The choice of species used in reforestation lied on its socio-economic and environmental interest.

During the past two decades, the northern part of Cameroon was confronted to accelerated and alarming biodiversity degradation due to anthropogenic and/or natural activities (Ndjidda, 2001). To palliate to the lack of woodwork and firewood, the populations of this zone have chosen for *Gmelina* cultivation which vast surface areas of plantations are kept in this part of the country. The present work aimed at evaluating the floristic composition and the sequestration potential of plantations based on *G. arborea*.

2. Material and Methods

2.1 Study Site

The study was conducted in Cameroon, Adamawa region, Vina division located between 6°-8° N and 11°-15° E (63,701 km²) which is a vast base block raised, punctuated by small volcanoes (Anonymous 2016; Figure 1). The soils of this area are ferruginous with intrusions of lateritic soils overlying basaltic rocks, granitic and sedimentary rocks. The climate is tropical with bimodal rainfall in lowland savannah of Central and Eastern and single mode (a dry season and a wet season) in the northern part. The annual rainfall varies between 900-1500 mm and decrease as one moves northward. Temperatures vary between 22° C and 24° C down to 10° C at certain times. The Adamawa plateau is the country's water castle and separates Cameroon in two separate hydrographic regions and two climatic regimes (Lienou *et al.*, 2008). Vegetation consists of low altitude and Sudanese savannahs dominated by *Daniellia oliveri* and *Lophira lanceolata* (Letouzey, 1985) corresponding to the Guinean phytogeographic unit and representing in its southern part as the transition area or buffer zone between the forest and the southern Sudano-Sahelian savannah of the north.

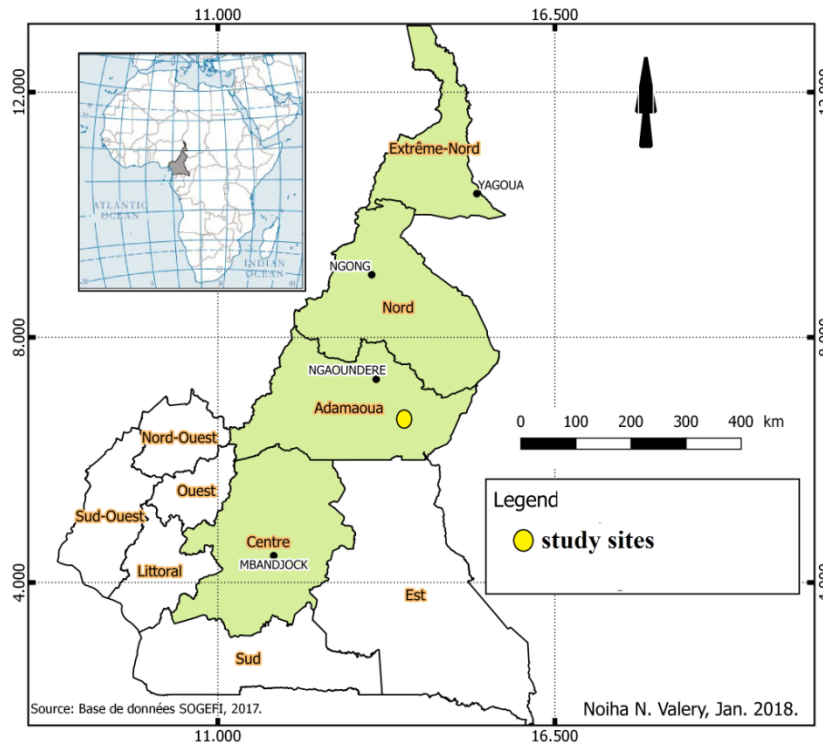


Figure 1. Site Localization

2.2 Data Collection

A Randomized Complete Block Design (RCBD) was used to collect data for statistical analysis. The RCBD is one of the most widely used experimental designs in forestry research. The design is especially suited for field experiments where the number of treatments is not large and there exists a conspicuous factor based on which homogenous sets of experimental units can be identified (Jayaraman, 1999). The primary distinguishing feature of the RCBD is the presence of blocks of equal size, each of which contains all the treatments. For this study, three treatments representing three sites of Gmelina plantations were considered. Each transect was used replication; five transects of 100 m x 20 m were established in each sites (covering 1 ha, Figure 2). This methodology was similar to that of Hu et al. (2015) even though they established nine 20 x 50 m sampling plots of five stages. Several blocks or squares (quadrates) with definite size (20 x 20 m²) were established in the stands to identify the total number of timbers. The Spatial data layers contours (altitude, slope and aspect) and vegetation types were extracted from topo sheet. Suunto Hypsometer was used to measure the height of the trees. Likewise, for measuring diameter and circumferences, instruments like Calliper and measuring tape were employed for all woody species (dbh ≥ 2 cm). GPS and compass were used to install and to locate stands. The diameter was measured at 1.30 m aboveground for trees and at 0.30 m for shrublets.

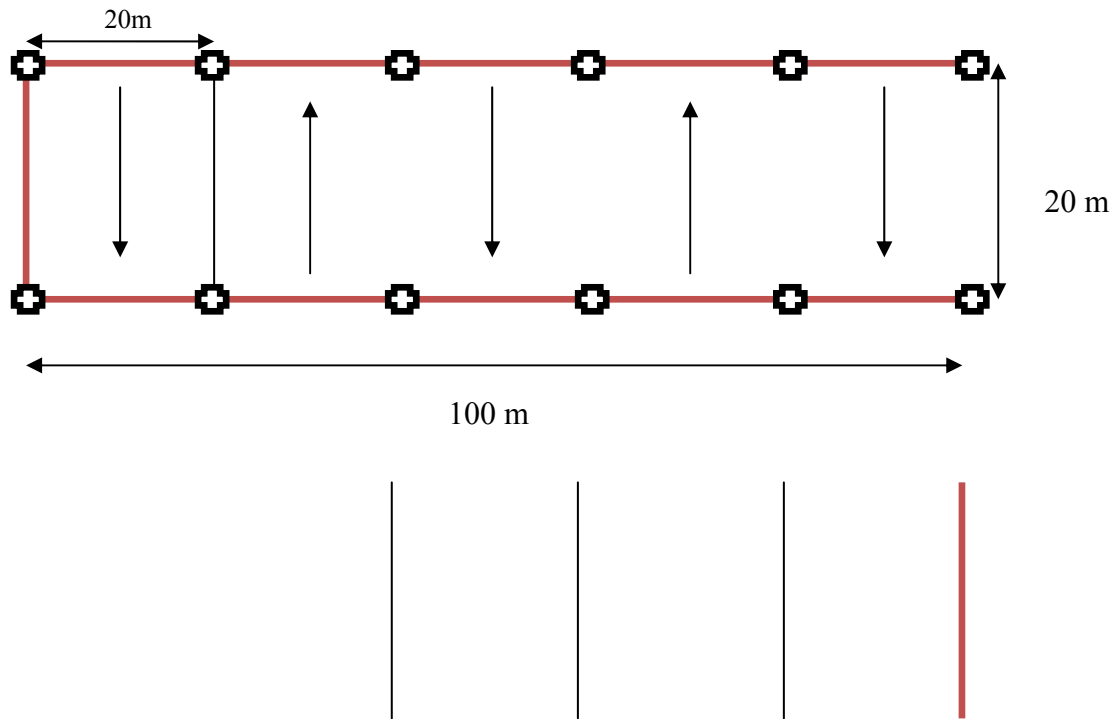


Figure 2. Illustration of a Single Sampling Unit

2.3 Vegetation Analysis

The ecological importance of each species in the studies stands was demonstrated using parameters such as relative frequency, relative abundance (%), relative dominance (%), density, basal area as well as the importance value index.

- Relative dominance is the percentage share of the basal area of a given species out of the total measured stems basal areas for all species;
- Relative abundance is the percentage of the abundance of each species out of the total stem numbers for all species;
- Relative frequency is the percentage of the frequency (the percentage of the total number of plots containing the species compared to all plots) of a species compared to the total frequencies of all the species added together;
- The Importance Value Index (IVI) of each species was computed by summing the relative frequency, relative abundance and relative dominance as follow:

$$IVI = \text{relative Dominance}_{(\text{species})} + \text{relative Abundance}_{(\text{species})} + \text{relative Frequency}_{(\text{species})}$$

- Density (D): This is the number of individuals per ha. In the plots, the density (D) is calculated based on the formula: $D = \frac{n}{S}$, D: density (stems/ha), n: number of trees present on the considered surface and S: reporting surface (ha)
- Basal area is the sum of the basal areas of all stems in the assessed area of land calculated as: BA

$$= \frac{\pi}{4} \sum_{i=1}^n d_i^2 = \frac{1}{4n} \sum_{i=1}^n C_i^2$$

with BA: basal area (m²/ha), d: diameter (m), C: (m) circumference.

- Family Importance Value: FIV=relative Dominance (species)+relative Density (species)+relative Diversity (species).

- Species richness and diversity for stand were calculated using a popular index of alpha diversity: $N = 2^H$, 2 is the basis of logarithm, H is the Shannon index and N is the effective species richness; Shannon's index: $ISH = -\sum_{i=1}^N \frac{n_i}{N} \text{LOG}_2 \left(\frac{n_i}{N} \right)$, with ni=number of the species i, N=number of all species; ISH is expressed in bit and Pielou's equitability: $EQ = \frac{ISH}{\text{LOG}_2 N}$ (Shannon, 1949; Magurran, 1988).

- Coefficient of similarity of Sorensen (K) was used to reveal floristic similarity between the stands: $K = \frac{2c}{a+b} \times 100$, with a=number of species of the statement 1, b=number of species of the statement 2, c=number of species common to the 2 statements.

- Floristic structure (size-class distribution): to catch the structure of the plantations, we used dbh and species height. For the size-class diameter distribution in the understories of the stands, timbers were grouped in class of diameters with amplitude of 10 cm. For the size-class height distribution, we adopted Letouzey's method; here individuals were grouped into class of height with amplitude 2 cm. The structure shapes have led to distinguished stems of regeneration, stems of future, mean stems and big trees. By so doing, the aspect of the evolution of species in the understories was forecasted through histograms of distribution.

2.4 Biomass and Carbon Sequestration Potential Estimates

- Above Ground Biomass (AGB) was estimated from the dbh assessed during the vegetation survey. We used existing allometric equations to evaluate biomass:

$$B = 0.066 \cdot D^{2.59}$$

B=biomass in kg; D=dbh in cm, with 8 ≤ D ≤ 48 cm (Ketterings *et al.*, 2001).

- The carbon sequestration potential (VCO_{2eq}) was estimated using the ratio 44/12 corresponding to the CO₂/C report.

- Economic values:

Many carbon markets were put in place since 2000. However, we opted for the CDM, Voluntary market and REDD+prices which the mean prices are 3€/tCO_{2eq}; 4.7€/t CO_{2eq} and 100€/t CO_{2eq} respectively (Chenost *et al.*, 2010; Ecosystems Marketplace, 2017).

2.5 Statistical Analysis

All statistical analyses were performed with STATGRAPHICS plus version 5.0 (2016) for Windows and R software. The significance and correlation tests were performed using the One-way analysis of variance (ANOVA) and Kruskal-Wallis test at 1 %.

3. Results

3.1 Floristic Composition of Gmelina Arboreastands

As a result of our fieldtrip, 4,359 timbers divided into 36 species, 32 genera and 17 families were surveyed. The table 1 below shows the taxonomic richness of the understories of the surveyed sites and the Figure 3 the most important species in the Gmelina stands. Among the surveyed species, *Hymenocardia acida*, *Piliostigma thonningii* (8.85 %), *Protea madiensis* (8.43 %), *Terminalia macroptera* (6.89 %) and *Terminalia laxiflora* (5.85 %) were the most abundant.

Table 1. Taxonomic Richness Following the Sites (ni, Number of Individuals; nE, Number of Species; nG, Number of Genera; nF, Number of Families)

| Gmelinastands | ni | nE | nG | nF |
|---------------|------|----|----|----|
| Site 1 | 1435 | 26 | 24 | 17 |
| Site 2 | 1323 | 27 | 25 | 18 |
| Site3 | 1601 | 29 | 27 | 19 |
| Total | 4359 | 32 | 36 | 16 |

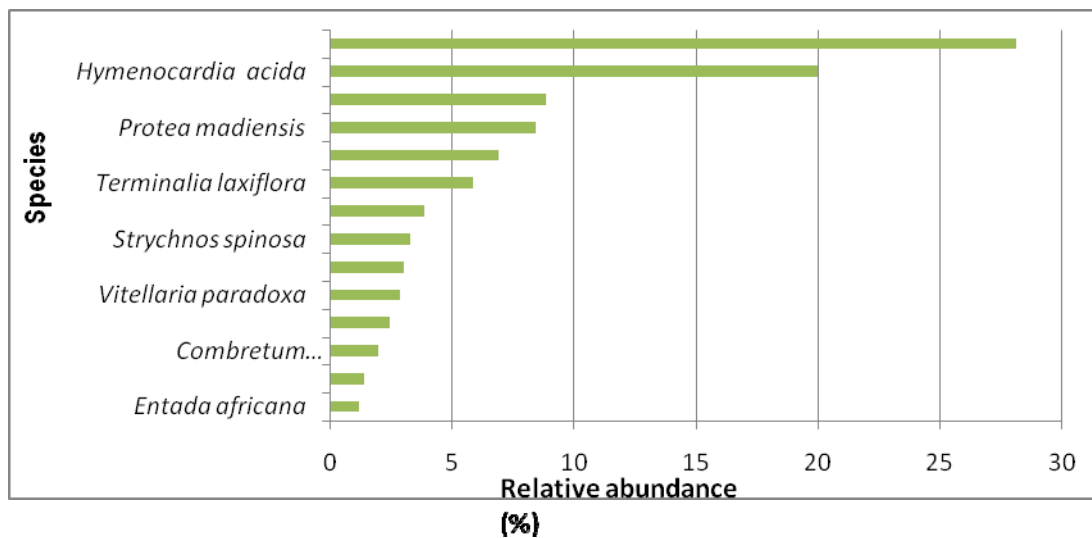


Figure 3. Relative Abundance of the Most Important Species in the Plantations

Ecologically, *Terminalia macroptera* in site 1; *Hymenocardia acida* in site 2; *Protea madiensis* and *Piliostigma thonningii* in site 3 have contributed the most to the importance value index in the Gmelina plantations (Table 2).

Table 2. Most Important Species in the Sites (FR, Relative Frequency; DR, Relative Density; DoR, Relative Dominance; IVI, Index of Importance Value)

| Sites | Species | FR (%) | DR (%) | DoR (%) | IVI (%) |
|--------|------------------------------------|--------|--------|---------|---------|
| Site 1 | <i>Combretum adenogonium</i> | 0.04 | 5.16 | 5.16 | 10.37 |
| | <i>Daniellia oliveri</i> | 1.25 | 6.87 | 8.85 | 16.98 |
| | <i>Entada africana</i> | 4.51 | 2.84 | 2.84 | 10.19 |
| | <i>Terminalia macroptera</i> | 78.78 | 20.89 | 12.87 | 114.55 |
| | <i>Terminalia laxiflora</i> | 0.04 | 5.07 | 5.07 | 10.19 |
| Site 2 | <i>Hymenocardia acida</i> | 97.13 | 45.54 | 45.54 | 188.21 |
| | <i>Lannea schimperi</i> | 0.13 | 9.73 | 9.73 | 19.61 |
| | <i>Lophira lanceolata</i> | 3.82 | 4.53 | 6.51 | 14.86 |
| | <i>Maytenus senegalensis</i> | 0.49 | 13.85 | 13.85 | 28.20 |
| | <i>Ochna schweinfurthiana</i> | 0.32 | 9.17 | 9.17 | 18.66 |
| Site 3 | <i>Piliostigma thonningii</i> | 78.78 | 10.89 | 12.87 | 104.55 |
| | <i>Protea madiensis</i> | 88.02 | 33.41 | 33.41 | 154.86 |
| | <i>Psorospermum senegalense</i> | 2.10 | 14.19 | 14.19 | 30.49 |
| | <i>Sarcocephalus latifolius</i> | 1.25 | 6.87 | 8.85 | 16.98 |
| | <i>Securidaca longepedunculata</i> | 8.78 | 10.89 | 12.87 | 31.55 |

Verbenaceae in sites 1 and 3, Combretaceae in site 2 have also contributed the most in family index value (Table 3).

Table 3. Most Important Families Following the Sites (FR, Relative Frequency; DR, Relative Density; DoR, Relative Dominance; nE, Uumber of Species; DiR, Relative Diversity; FIV, Family Index Value)

| Sites | Families | nE | DR (%) | DoR (%) | DiR (%) | FIV |
|--------|------------------|----|--------|---------|---------|--------|
| Site 1 | Anacardiaceae | 2 | 0.91 | 25.49 | 6.90 | 33.29 |
| | Verbenaceae | 5 | 78.43 | 14.41 | 15.15 | 137.99 |
| | Caesalpiniaceae | 3 | 2.33 | 7.63 | 9.38 | 19.04 |
| | Celastraceae | 2 | 1.79 | 16.27 | 6.25 | 24.31 |
| | Clusiaceae | 3 | 0.85 | 9.96 | 12.5 | 23.31 |
| Site 2 | Combretaceae | 6 | 72.24 | 0.34 | 17.24 | 89.96 |
| | Hymenocardiaceae | 1 | 50.85 | 4.41 | 25 | 80.26 |
| | Verbenaceae | 1 | 0.85 | 34.84 | 4.16 | 39.85 |
| | Mimosaceae | 1 | 0.33 | 24.36 | 3.13 | 27.81 |
| | Myrtaceae | 5 | 4.86 | 14.82 | 15.15 | 34.83 |

| | | | | | | |
|--------|--------------|---|-------|-------|-------|--------|
| | Rubiaceae | 1 | 28.57 | 6.78 | 03.03 | 38.38 |
| | Sapotaceae | 6 | 11.63 | 21.54 | 0.11 | 33.28 |
| Site 3 | Verbenaceae | 2 | 58.9 | 32.76 | 57.93 | 149.59 |
| | Ochnaceae | 1 | 12.12 | 15.71 | 4.72 | 32.55 |
| | Polygalaceae | 2 | 0.33 | 0.33 | 24.36 | 27.02 |

3.2 Species Distribution and Floristic Similarity among the Study Sites

Using STATGRAPHICS plus version 5.0, the cluster analysis (AFC) between species in relation with abundance in the study sites showed a strong correlation among the sites ((Dnl=2; F=54.34; p<0.001); Figure 4A). This correlation translates a floristic similarity among the sites (Sorensen’s coefficient of similarity, k>70 %). Some species are weekly represented in the study population; these species are accidental and form a cloud of points (Figure 4B). In contrast, *Gmelina arborea*, *Lophira lanceolata*, *Gardenia aqualla*, *Terminalia mollis*, *Sarcocephalus latifolius*, *Strychnos spinosa* are the most abundant species in the *Gmelina* stands.

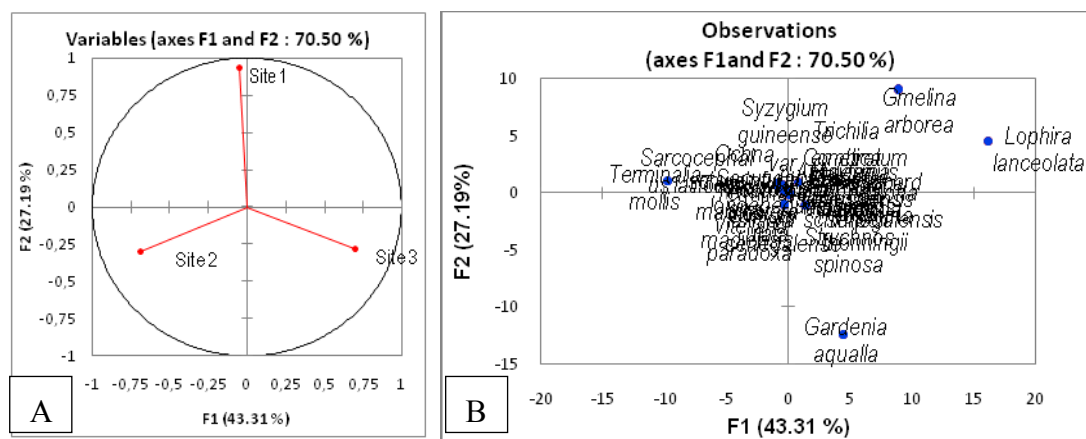


Figure 4. Principal Component Analysis Showing Correlation among Sites (A) and Species Dispersion (B)

3.3 Floristic Diversity and Structure of *Gmelina* Stands

Species richness ranged from 2.53±0.05 to 7.74±0.03 with the highest in site 3 (p<0.001). There was no significant difference of diversity among the sites according to the Kruskal-Wallis test (p>0.001); the indices of Shannon and Piéluou were about 3 and 1 respectively. L’indice de diversité de Shannon la plus élevé s’observe dans le site 3 (3,20±0,13 bits). The Piéluou’s value translates an equitable distribution of individuals amongst species. Density was significantly different among the sites (p<0.001) and ranged from 98±2.01 to 253±10.23 stem/ha with the lowest in site 2. Basal area among the sites was not significantly different (p>0.001) and was around 5 m²/ha. The synthesis of the floristic structure is given in Table 4.

Table 4. Floristic Diversity and Structure of the Gmelina Plantations

| Indices | <i>Gmelina arborea</i> sites | | |
|---------------------------------|------------------------------|---------------------------|---------------------------|
| | Site 1 | Site 2 | Site 3 |
| Species richness | 2.53 ± 0.05 ^b | 4.50 ± 0.01 ^a | 7.74 ± 0.03 ^c |
| Shannon index | 3.15 ± 0.15 ^a | 3.12 ± 0.12 ^a | 3.20 ± 0.13 ^a |
| Pielou's equitability | 1 ± 0.25 ^a | 1 ± 0.25 ^a | 1 ± 0.25 ^a |
| Simpson's index | 0.0007 ± 0.1 ^a | 0.0007 ± 0.1 ^a | 0.0007 ± 0.1 ^a |
| Density (stem/ha) | 182 ± 4.57 ^b | 98 ± 2.01 ^a | 253 ± 10.23 ^c |
| Basal area (m ² /ha) | 5.35 ± 0.47 ^a | 5 ± 0.4 ^a | 5.38 ± 0.49 ^a |
| IVI | 300 ± 23 ^a | 300 ± 23 ^a | 300 ± 23 ^a |

The size-class distributions following the height, the dbh and the circumference were significantly different amongst the study sites (<0.001). In fact, the Figure 5A showed that the floristic structure using the height presented a symmetric bell Shape; the majority of individuals being represented in size-class 8-10 m in height.

Following the size-class diameter, the analysis of Figure 5B showed that Gmelina stands exhibited a classic exponential decay distribution curve (of Shape “L” or “J” if inverted) reflecting the predominance of individuals with small diameters; this structure shows a good regeneration in the stands.

The floristic structure showed an unsymmetrical bell Shape using the circumferences; the most represented class being the size-class 70-80 cm.

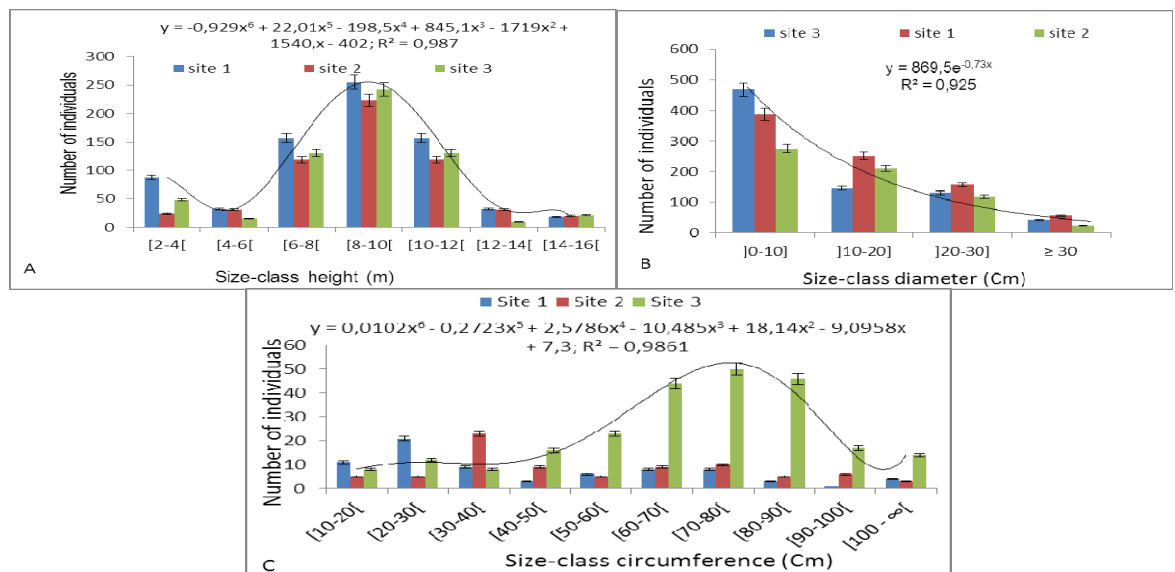


Figure 5. Size-Class Distributions Following the Height (A), the dbh (B) and the Circumference

(C)

3.4 Dendrometry Parameters, Carbon Storage and Its Economic Value

The species number, the mean density, the mean height, the mean diameter and biomass varied significantly amongst the sites (Kruskal-Wallis test; $p < 0.001$). In contrast, there was no significant difference of above ground biomass amongst the study sites (Kruskal-Wallis test; $p > 0.001$). The values of these studied parameters are given in Table 5. The lowest values of the studied parameters were found in site 2. Carbon stocks ranged from 22.72 ± 0.36 to 24.63 ± 0.47 t C/ha with the highest value in site 3.

Table 5. Dendrometry Parameters and Carbon Storage (nE, Number of Species; Dem, Mean Density; Hm, Mean Height; Dm, Mean Diameter; B, Biomass; AGB, above Ground Biomass)

| | nE | Dem (ha) | Hm (m) | Dm (cm) | B (Kg/ha) | AGB (t/ha) |
|---------------|-------------------|------------------|-------------------|--------------------|---------------------|--------------------|
| Site 1 | 2.53 ± 0.05^b | 118 ± 3.63^b | 6.19 ± 0.03^b | 14.18 ± 0.01^b | 47859 ± 10.85^b | 23.17 ± 0.31^a |
| Site 2 | 4.50 ± 0.01^a | 95 ± 2.91^a | 4.89 ± 0.01^a | 20.43 ± 0.04^a | 38350 ± 9.51^a | 22.72 ± 0.36^a |
| Site 3 | 7.74 ± 0.03^c | 185 ± 6.04^c | 9.86 ± 0.05^c | 10.25 ± 0.02^c | 52419 ± 13.42^c | 24.63 ± 0.47^a |

Overall, 23.50 ± 0.38 t C/ha were surveyed in the Gmelina plantations. This value corresponds to a sequestration potential of 86.28 ± 16.57 t CO₂/ha. From the economical point of view, this ecosystem service was estimated in three prices. The different prices in euro are given in Table 6. The highest price is that from REED+market and the lowest that from CDM market.

Table 6. Economic Value Estimate Following the Different Market (AGB, above Ground Biomass; CO_{2eq}, Equivalent of Sequestered CO₂; CDM, Clean Development Mechanism; VM, Voluntary Market)

| | AGB (t C/ha) | CO _{2eq} (t/ha) | CDM price | VM price | REED+ price |
|---------------|--------------------|--------------------------|----------------------|----------------------|------------------------|
| Site 1 | 23.17 ± 0.31^a | 85.05 ± 16.05^a | 255.17 ± 26.76^a | 399.78 ± 86.45^a | 8505.98 ± 156.65^a |
| Site 2 | 22.72 ± 0.36^a | 83.39 ± 18.65^a | 250.19 ± 26.34^a | 391.97 ± 98.56^a | 8339.93 ± 285.43^a |
| Site 3 | 24.63 ± 0.47^a | 90.41 ± 15.01^a | 271.25 ± 21.54^a | 424.96 ± 87.54^a | 9041.85 ± 302.4^a |
| Mean | 23.50 ± 0.38 | 86.28 ± 16.57 | 258.87 ± 24.88 | 405.57 ± 90.85 | 8629.25 ± 248.16 |

4. Discussion

Gmelina is known for its rapid growth rate. Several works have been dedicated in taxonomy, anatomy, wood density and usages of Gmelina (Mayowa *et al.*, 2016). There is a lack of knowledge relative to the conservation aspect and sequestration potential based on Gmelina plantation. As a result of our survey, 32 species with a dominance of *Hymenocardia acida*, *Combretum adenogonium*, *Daniellia*

oliveri, *Entada africana*, *Terminalia macroptera*, *T. laxiflora*, *Lannea schimperi*, *Lophira lanceolata*, *Maytenus senegalensis*, *Ochna schweinfurthiana*, *Protea madiensis*, *Psorospermum senegalense*, *Piliostigma thonningii*, *Sarcocephalus latifolius*, *Securidaca longepedunculata* that are native species of the study sites were harvested in the Gmelina's understory. These results confirmed many other investigations undertaken in neem, cashew, cocoa and eucalypt agrosystems which showed that afforestation sites are refuge Centre for indigenous species (Noiha *et al.*, 2018b). With an absolute abundance of 4,359 individuals surveyed in Gmelina stands, such an afforestation system offers good climatic and edaphic conditions for a best development of species. In fact, climatic factor plays an important role in the floristic structure and composition (Ousmane *et al.*, 2013). Our results were similar to the survey list of Scholte *et al.* (2000) in the periphery of the national park of Waza in Cameroon. As confirmed by the piélou's evenness, the equitable repartition of the individuals in the Gmelina stands corroborates the previous works from several agrosystems in tropical Africa (Savadogo *et al.*, 2007; Noiha *et al.*, 2015, 2017, 2018a). The values of diversity index showed that the stands are diversified and heterogeneous. The floristic structures translated a good dynamic of the understories of the study population; similar structures were noticed in Senegal and Burkina Faso in the stands of *Acacia senegalensis* and the park of *Faidherbia albida* respectively (Depommier *et al.*, 1993; Diallo *et al.*, 2012). In contrast, the structure using individual height showed a symmetrical bell Shape with a good representation of the size-class 8-12 m. This structure is different from that of Laouali (2008) and Soumana (2015) respectively in the parks of *Faidherbia albida* and *Prosopis africana*. The low density recorded in this study showed that, populations are not really very interested in afforestation based on Gmelina in the zone. We registered important densities in neem, cashew and eucalypt in the same northern part in Cameroon. The highest basal area was 5.38 ± 0.49 m²/ha; attesting that, *Gmelina arborea* is not a vigorous species. The highest mean recorded dbh was 20.43 ± 0.04 cm; this is due to the impacts of the anthropogenic activities. Since the population have selected Gmelina for woodworks, individuals are usually cut for their requirement.

The carbon stock variation in timbers following the size-class diameter showed a distribution model in "J inverted" that is well adjusted with the linear equation $y=3.460x+0.1$. The small size-class of individuals store the less. Biomass ranged from 38350 ± 9.51 to 52419 ± 13.42 Kg/ha. This value was near from that of Corley *et al.* (1971) in Malaysia; but less than the value of Brown (1997) in Burkina Faso. Carbon stock was estimated at 23.50 ± 0.38 t C/ha; this result was similar to that of Jaffré *et al.* (1983) in the palm plantations of 15-21 year-old in Ivory Coast with respectively 23.58 t/ha et 22.37t/ha. The economic value of the Gmelina ecosystem service varied from one market type to another as follow: 258.87 ± 24.88 € for the CDM market price; 405.57 ± 90.85 € for the voluntary market price and 8629.25 ± 248.16 € for the REDD+price. The best market was that of REDD+.

5. Conclusion

Gmelina is known for its rapid growth rate; one individual could reach a merchantable timber size of 5.8 m-8.3 m with 10 cm-15 cm diameter in only three years. Likewise, at this age, it is already a prolific seeder. Gmelina, as reported in previous works, is a raw material for pulp and paper making, posts, house timbers and poles, and its wood is sawn for general carpentry, joinery, and furniture components. Additionally to the goods and services supplied by this type of reforestation, our study bounced the implication of Gmelina plantations in the biodiversity conservation. In fact, our survey led to enrol the native species of the savannah in the Gmelina's understorey. These plantations offer a refuge for these species which some of them are threatened of disruption due to anthropogenic pressures which savannah ecosystems incurred. Additionally to this conservation role of the phytodiversity, afforestation based on Gmelina is carbon sinks; thus constituting a measure of adaptation to the smallholders and attenuation of climate change effects. Cameroonian state must instigate the smallholders in the frame of the fighting against climate change at least at the local scale. A financing of such projects is required in the frame of creating adaptation and attenuation measures to global warming effects on one hand, and the socio-economic development of the populations in other hand. Afforestation based on Gmelina could serve as fundament to guide all action programs that aims at conserving and managing afforested areas. It could also guide to the fight against desertification and desert installation in Africa.

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