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Assessment of Biomass and Carbon Sequestration of Millettia Laurentii De Wild (Wenge) After 76 Years in Plantation at Yangambi Biosphere Reserve

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ABSTRACT

Deforestation and forest degradation are still occurring at an alarming rate, and are contributing significantly to the current loss of biodiversity. Every year, about 13 million hectares of forest are converted to various uses. Many ecologists attest that sylviculture is one of the remedies to this problem. In this paper, we evaluate the impact of silvicultural techniques on the carbon sequestration potential of *Millettia laurentii* plantations. A carbon stock estimation study was conducted in 2016 in three silvicultural plots installed in 1940 following the Layon, Blanc etoc and Martineau techniques. Diameter at breast height of 359 *M. laurentii* individuals and wood density were used in an allometric equation to estimate biomass and sequestered carbon. In the Layonnage plot, biomass and carbon stored were 914.39 t/ha and 457.19 t/ha respectively; 695.47t/ha and 347.74t/ha in the Blanc Etoc plot; 767.67 t/ha and 383.8 t/ha in the Martineau plot. After 76 years in plantation, the Layon technique proved to be more favorable to biomass production and carbon stock by *M. laurentii*.

1. Introduction

Tropical forests are among the largest carbon dioxide sinks in the world (Aimé et al., 2015). These forests produce a large amount of aboveground plant biomass and store atmospheric carbon, removing about 15% of anthropogenic carbon dioxide emissions (Chave et al.. 2005; Hubau et al.. 2022). Furthermore, tree plantations have been assumed to increase the importance of international efforts to mitigate climate change due to their ability to sequester and store more carbon than any other terrestrial ecosystem (Vaidya et al., 2017).

In the current context, increasing carbon emissions is one of the main concerns that has been addressed in the Kyoto Protocol (Ravindranath et al., 1997). In international negotiations, especially in the framework of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism. when it comes to the management of forests and anthropized ecosystems one of the main issues is to know how to develop the sustainable strategies to store carbon (Aimé et al., 2015). Estimating and monitoring the large amount of carbon contained in tropical forests and particularly the above-ground biomass of trees is a key aspect to the successful implementation of climate change mitigation strategies (Fayole et al., 2018) . In this estimation, the use of a model equation for each species is preferable because trees of different species are different in terms of architecture and wood density (Ketterings et all., 2001). To overcome the above problem, silviculture is still a feasible solution, which can maintain biodiversity, increase carbon sequestration, reduce harvesting damage and optimize the production of quality wood (Bernard et al., 1998). However, there is still much to be learned about appropriate silvicultural practices, particularly silvicultural techniques for the establishment of forest plantations. Our study focuses on M. laurentii, a hardwood species that is highly valued in the international market for its many uses. We tested the hypothesis that silvicultural techniques have a significant impact on aboveground biomass production and carbon sequestration of M. laurentii in plantations. The main objective was to compare changes in above-ground biomass and carbon stock in M. laurentii plantations established in the Yangambi Biosphere Reserve in 1940.

2. Materials and Methods

2.1. Study site

M. laurentii forest plantations are located in the Yangambi Biosphere Reserve (RBY) (Figure 1). The RBY is located in the Tshopo province of the Democratic Republic of Congo. It covers an area of 25000 ha between 24°16'95"E and 25°08'48"E longitude. 0°38'77"N and 01°10'20"N latitude and at an average altitude of 450 m (Toirambe, 2011). RBY enjoys an Af type climate according to Köppen's classification. The average annual rainfall hovers around 1814 mm with at least 172 days of overall rainfall, on average once every two days, and the average annual temperature is 24.9°C. Soils in the Yangambi region are mostly poor with low cation exchange capacity (CEC) (2-8 meq/100g). fairly

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high acidity (pH between 3.5 and 5.5), abundant exchangeable aluminum (about 40-80% of CEC). high phosphorus retention on iron oxides and fairly low nitrogen and phosphate contents (Mikwa et al., 2016). The vegetation of the RBY is part of the Guinean-Congolese Regional Center of Endemism. The Yangambi Forest Region is covered by two main types of major vegetation formations, dense moist forests on dry land grouping evergreen forests and semi-caducious forests, and dense moist forests on hydromorphic soils (Djiofack, 2018).

2.2 Materials

The biological materials for our study consisted of 359 individuals of 76-year-old *M. laurentii* inventoried in 2016 in the forest plantations of the National Institute for Agronomic Study and Research (INERA), located in the buffer zone of the Yangambi Biosphere Reserve.

2.3 Method

2.3.1 Installation of plantations

The techniques described below were used during the installation of *M. laurentii* plantations in 1940 : The Layon Technique, also called an extensive method, consists of opening parallel and equidistant layons in the forest and introducing, at regular intervals, commercial species raised in nurseries. The Martineau Technique, also known as "planting under the canopy", is a careful introduction of noble species under a canopy that is gradually destroyed. It consists of completely replacing the heterogeneous stand with a regular stand by a tight planting under the forest canopy. The Blanc etoc technique is intensive and consists of radically changing the heterogeneous stand into a pure stand (Ebuy, 2009).

2.3.2. Data Collection

This study used the indirect method of biomass assessment. This method consists of dendrometric measurements and conversion using allometric relationships. A systematic inventory of all *M. laurentii* plantations was conducted. All *M. laurentii* trees with a Dbh ≥10 cm were surveyed and measured. The wood density value of *M. laurentii* was obtained from the database of the “Centre de coopération Internationale en Recherche Agronomique pour le Développement” (CIRAD). Its average value is 0.8 classified as heavy wood.

2.3.3. Data processing

The data were entered into the Excelle spreadsheet and analyzed in the R software version 4.0.3 under its R studio interface. The comparison of the diametric structures was made thanks to the Chi-square test and the comparison of the biomass and carbon in the different plots was made possible by the Kruskal-Wallis test. The density in plantation was obtained by the number of individual trees inventoried and evaluated in hectare (N/ha) (Rondeux, 1999). The basal area expresses the cross-section of the trunk on the bark at 1.30 m from the ground and is expressed in m²/ha. It was calculated by the formula: $ST=\pi.(Dbh/2)^2$ (Rondeux. 1999); where ST is basal area and Dbh is diameter at breast height. Aboveground Biomass is the mass of dry woody plant material per unit area. The estimation of aboveground biomass (AGB) of all inventoried *M. laurentii* trees was done using the allometric equation recognized for dense rainforests from two inputs: diameter Dbh (cm) and wood density ρ. The mathematical relationship used is a regional Congo Basin forest model recommended by Fayolle et al., (2018).

$AGB = \exp\ [0.046+1.156\ \ln(\rho)\ +1.123\ *\ln\ (Dbh)+\ 0.436*(\ln(Dbh))^2-\ 0.045*\ (\ln(Dbh))^3\ ]$ (Fayolle *et al.*. 2018).

Where AGB is the aboveground biomass of a tree, ρ is the wood density of the species, and Dbh is the diameter at breast height. Forest carbon stock is calculated by multiplying the aboveground biomass dry matter by a conversion factor (CF) that is equal to 0.5 (Timothy & Brown. 2005).

3. Results

3.1 Diameter structure

The diametric structure grouped into diameter classes for the Layon, Blanc Etoc and Martineau method is shown in figure 02 below.

Figure 2 shows an "inverted J" diameter structure observed in the Blanc-étoc and Martineau technique. i.e. the number of individuals decreases with increasing diameter classes. However, the Layon technique shows a "sawtooth" or erratic distribution. The distribution of diameter classes is not similar in the 3 sites. The Chi-square test used to compare the three diameter structures shows a significant difference at the 0.01 threshold. $\chi2=52.47$; df=10; p-value=0.00009689***

3.2. Density

The relative density of individuals inventoried in the 3 planting methods under study is presented in Table 1 below.

Table 1. Density of individuals

	Area		
Methods	0.36 ha	0.25 ha	1 ha
Layon	-	-	170
Blanc etoc	106	-	294.4
Martineau	-	83	332

The highest density was recorded in the Martineau technique, on a plot of 50 m X 50 m with 83 plants, either 332 individuals per hectare, followed by Blanc etoc with 106 plants in a plot of 60 m X 60 m, either 294 individuals per hectare and in last position Layon with 170 plants per hectare.

3.3. Basal Area

The compiled basal area from the Layonnage, Martineau and Blanc etoc techniques is presented in Table 2 below.

Table 2 shows the highest total basal area for the Layon technique with 41.06 m²/ha followed by Martineau with 38.34 m²/ha and lastly Blanc Etoc with 36.58 m²/ha. However, the highest average basal area is observed in Martineau, then Blanc etoc and Layon. The Kruskal-Wallis test reveals a significant difference at the 0.01 threshold; F = 6.5; dl= 2 and p-value =0.001662 ***

3.4. Biomass and sequestered carbon

The amount of biomass and carbon sequestered in the Layon, Martineau and Blanc Etoc technique is presented in Table 3 below.

Table 3 shows that the highest amount of total biomass is 914.39 t/ha for the Layon method, followed by 767.67 t/ha for Martineau and lastly, Blanc étoc with 695.47 t/ha. The Kruskal-Wallis test used to compare the 3 methods reveals a significant difference at the 0.001 threshold; F=33.43; dl=2 and p-value =0.00000005486***.

The highest amount of carbon sequestered is 457.19 t/ha observed with the Layon method, followed by 383.8 t/ha for Martineau and 347.74 t/ha for Blanc étoc. Applying the Kruskal-Wallis test to compare the three methods, we find a significant difference at the 0.001 threshold; F = 44.808; dl = 2 and p-value = 0.0000000001862***.

3.5. Biomass and sequestered carbon by diameter class

The amount of biomass and sequestered carbon grouped by diameter class in the Layon, Martineau and Blanc Etoc technique are presented in Table 4.

Table 4 shows that the diameter class that is ≥ 110 cm produces more biomass and sequesters a lot of carbon in the Layon technique, followed by the one ranging from [70-80[cm. The other two techniques produce more biomass and sequester carbon in the [50-60[cm class. The [20-30[cm class produces less biomass in the layering method, however, the [80-90[,[90-100[,[100-110[classes are not represented in the Martineau method and the [90-100[,[100-110[, and ≥ 110 classes are not included in the Blanc étoc technique. The Qhi-squared test used to compare the three biomass distributions by diameter classes shows a significant difference at the 0.01 threshold; $\chi 2$=793.1; df=20, p-value=0.00009689***

4. Discussion

4.1. Diametric structure

The diametric structures of *M. laurentii* presented themselves differently according to the silvicultural techniques applied at the genesis of the plantation in 1940. The diametric structures of Blanc etoc and Martineau were in an "inverted J" pattern, i.e. the number of individuals decreases with increasing diameter classes. Similar observations were reported by Sabongo (2015) in *Gilbertiodendron dewevrei* monodominant forests, having diametric distributions typical of undisturbed tropical forests, with an exponential decay or inverted J structure. However, the Layon technique shows a "sawtooth" distribution, or erratic structure, reflecting a very irregular distribution in diameter classes (Sounon, 2007), i.e., the numbers of individuals decrease slowly and discontinuously with increasing diameter classes. This difference would be explained by the fact that the Layonnage plot was disturbed by anthropogenic activities, being located at the age of plantations and riparian habitats.

4.2. Density

The highest density was observed in Martineau's plot, with 332 individuals per hectare, followed by Blanc étoc with 294 individuals per hectare and in last place, Layon's plot with 170 individuals per hectare. Ebuy (2009) found a density of 300 individuals/ha in the *Drypetes likwa* species plantation, 308 individuals for the *Autranella congolensis* species; 361 individuals in the *Gilbertiodendron dewevrei* plantation at Yangambi. Our results found in the technique of Blanc etoc and Layonnage are slightly lower than those found by Ebuy (2009). This difference could be explained by the fact that the density of plantations depends on the species and the silvicultural techniques adopted.

4.3. Basal area

Layonnage technique contains a high basal area of 46.2831 m²/ha followed by Martineau with 44.7948 m²/ha and lastly, blanc étoc with 37.8924 m²/ha. Sabongo (2015) had found a slightly lower basal area than our results of 32.3m²/ha for *Gilbertiondendron dewevrei* individuals in Lenda Forest in Ituri. Sokpon et al. (2006) reported a range of basal areas from 7.6 to 36.4 m²/ha in a natural forest. Site conditions, tree species and age would better explain the observed variability in structural characteristics of *M. laurentii* plantations according to silvicultural techniques adopted and the values reported by the above authors. Furthermore, by statistically comparing the different silvicultural techniques, using the Kruskal-Wallis test, we find a significant difference at the threshold α=0.01; F= 6.62; dl = 2 and p-value = 0.001474 **. This shows that the Layonnage method is more suitable for silviculture of *M. laurentii*.

4.4. Biomass and sequestered carbon

The biomass produced and the amount of carbon sequestered in the three techniques under study (Layonnage, Blanc etoc and Martineau) are summarized as follows: 908.77 t/ha and 454.39 t/ha; 553.34 t/ha and 276.67t/ha; 605.05 t/ha and 302.53 t/ha respectively the biomass and carbon sequestered for the Layonnage, Blanc etoc and Martineau techniques. These results showed a statistically significant difference between the different planting techniques studied. This confirms our hypothesis that: silvicultural techniques have a significant impact on aboveground biomass production and carbon sequestration of *M. laurentii*. Shiekh et al., (2020) found a total biomass amount of 376.27 t/ha in the Northwestern Himalaya; Amir et al., (2018) reported a total biomass of up to 529.5 t/ha in Pakistan, Vaidya et al., (2017) reported a biomass of 456.61 t/ha in the subtropical forest of the Western Himalaya; Sharma et al. (2011) found a mean biomass value ranging from 169.2 to 633.8 t/ha in the temperate Garhwal Himalaya region of India; 20.08t/ha biomass obtained by Odiwe et al., (2012) in a 30-year-old *Tectonia grandis* plantation in Nigeria. Ebuy (2009) obtained 592.6 t/ha of biomass in a 60-year-old *Autranella congolensis* plantation in Yangambi, representing 296.3 t/ha of sequestered carbon; the 68-year-old plantation produced 487.1 tons of biomass, representing 243.55 tons of sequestered carbon; and the 70-year-old plantation produced 747.8 tons of biomass, representing 373.9 tons of sequestered carbon. The difference between our results and those reported by the above authors would be explained by the fact that biomass production and carbon sequestration vary according to tree size, species, age of the forest or plantation, site conditions, edaphic factors and rainfall regime (Banday et al., 2018).

Conclusion

In the present study, variability in biomass and carbon sequestration potential of *M. laurentii* depended not only on tree density and age, but also on the silvicultural method used. The layon technique was found to be more favorable for aboveground biomass production and carbon sequestration of *M. laurentii* in a 76-year-old plantation in Yangambi Biosphere Reserve, with 908.77 t/ha and 454.39 t/ha for aboveground biomass and sequestered carbon, respectively.

Table 2 . Basal area of the three planting methods studied

	ST (m²/ha) LA	ST (m²/ha) BE	ST (m²/ha) MA
Total	41.06	36.58	38.34
Mean	0.24	0.35	0.46
Standard deviation	0.26	0.34	0.80

Table 3 . Biomass and sequestered carbon

	AGB (t/ha) LA	C (t/ha) LA	AGB (t/ha) BE	C (t/ha) BE	AGB (t/ha) MA	C (t/ha) MA
Total	914.39	457.19	695.47	347.74	767.67	383.8
Mean	5.37	2.6	6.56	3.28	9.24	4.63
Standard deviation	6.75	3.37	7.81	3.9	20.88	10.43

Table 4. Biomass and sequestered carbon by diameter class

Diameter Classes (cm)	AGB(t/ha) LA	C(t/ha) LA	AGB(t/ha) BE	C(t/ha) BE	AGB(t/ha) MA	C(t/ha) MA
[10-20[	5.49	2.74	11.87	5.93	21.75	10.88
[20-30[	23.64	11.82	45.41	22.70	43.41	21.71
[30-40[	22.81	11.41	68.18	34.09	41.22	20.61
[40-50[	43.97	21.99	132.54	66.27	147.83	73.91
[50-60[	83.43	41.72	183.67	91.83	182.14	91.07
[60-70[	156.76	78.38	96.80	48.40	33.28	16.64
[70-80[	120.53	60.26	79.66	39.83	121.50	60.75
[80-90[	133.90	66.95	77.36	38.68	0.00	0.00
[90-100[	67.74	33.87	0.00	0.00	0.00	0.00
[100-110[	85.97	42.99	0.00	0.00	0.00	0.00
≥ 110	170.15	85.08	0.00	0.00	176.54	88.27
Total	914.39	457.20	695.48	347.74	767.67	383.84
Mean	83.13	41.56	63.23	31.61	69.79	34.89
standard deviation	56.53	28.26	59.90	29.95	72.49	36.24

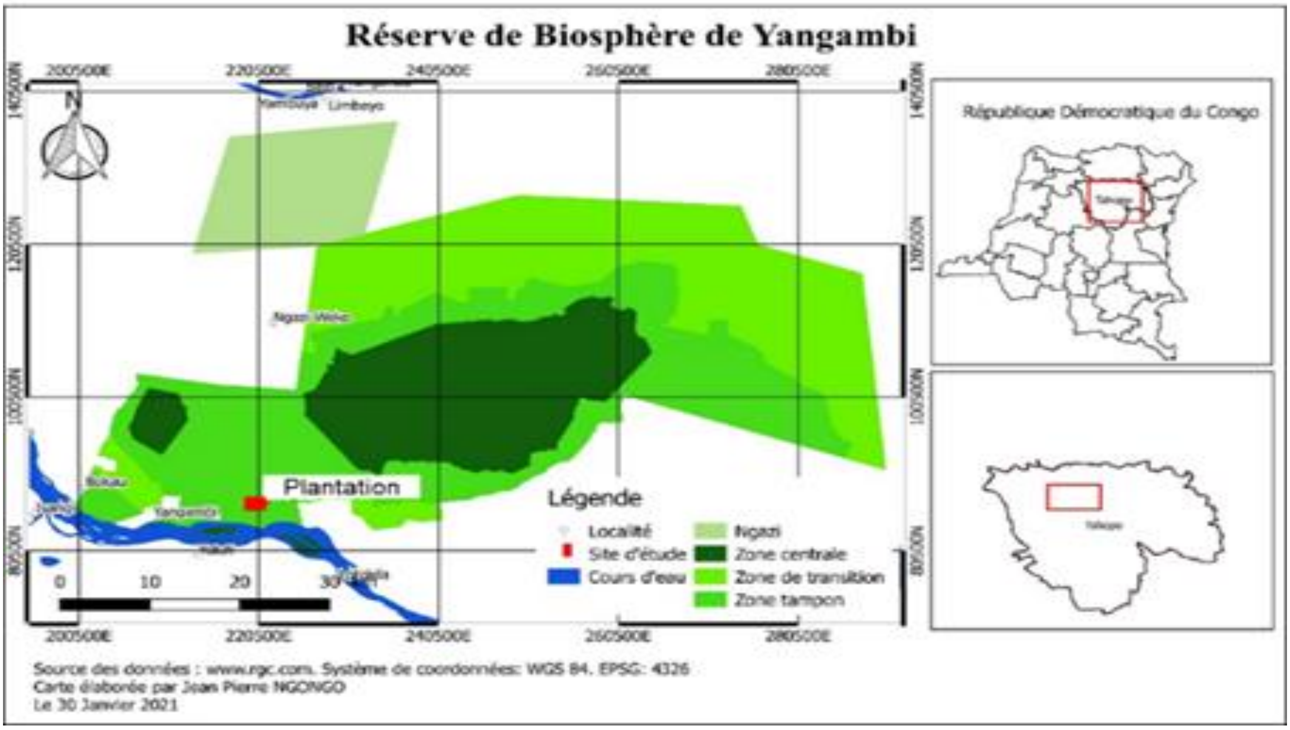

Figure 1. Study site location

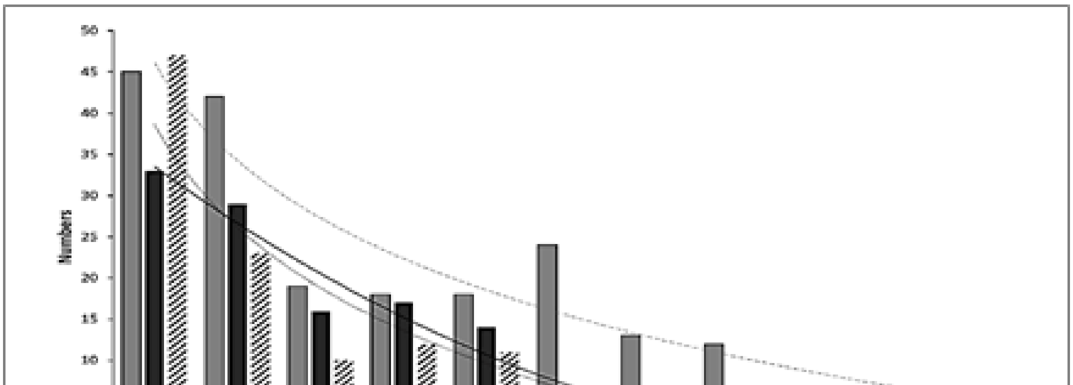

Figure 2. Diameter class of three plantations. Eff Layon: number of individuals in the layon plot. Eff Be: number of individuals in the blanc etoc plot. Eff MA: number of individuals in the martineau plot

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