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Silvicultural Methods Effects on the 82 Year Old Planted *Pericopsis elata (Fabaceae)* and *Entandrophragma cylindricum (Meliaceae)* Dendrometry in Yangambi Region, DR Congo

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Abstract: The effects of four silvicultural methods notably Layon, Blanc-Etoc (BE), Martineau and assisted natural regeneration (ANR) have been compared on the dendrometric traits of *Pericopsis elata Harms* and *Entandrophragma cylindricum Sprague* planted in 1938 in Yangambi for controlling anthropogenic activities (agricultural deforestation and forest degradation) threatening the species to extinction added to difficult natural regeneration. The sustainable pedo-silvicultural system will preserve Yangambi biosphere reserve. In case of variance analysis significance; the non-parametric test of Kruskal Wallis and the test of Tukey Honest Significant Differences were applied to separate the traits means. Results have revealed that the three plantation methods were significantly different from ANR. BE, Martineau and Layon have determined the Gaussian shape for *P. elata* diametric structures while Layon, Martineau and ANR presented the inversed J shape for *E. cylindricum*. BE method convenes for plantations of the two species whose trait values were higher than those of other methods. The difference was significant between the widest average breast height diameter (DBH) of 44.49±10.63cm with the total height mean of 24.46±4.45m for *P. elata* and DBH of 29.63±11.59cm with the total height mean of 22.04±5.80m for *E. cylindricum.* The differences were also identified respectively for the two species regarding the basal areas with 25.54±5.6 against 9.474±1.67 m^2/ha, the aboveground biomasses with 318.81±77.2 against 94.315±11.59t/ha and the loose volumes with 45069.49±12219.30 against 14 471.348±3 645.692m^3/ha. The Layon method did not have significant effect on the *E. cylindricum,* but has influenced the DBH, AGB and basal area of *P. elata*. The least productive method ANR has expressed a convenient natural regeneration inversed J shape for the two species, as related to Yangambi reserve preservation.

Keywords: Silvicultural Methods, Dendrometric Traits, *Pericopsis elata Harms*, *Entandrophragma cylindricum Sprague*, Tropical Humid Dense Forest, Yangambi Biosphere Reserve and DR Congo

1. Introduction

The importance of the ombrophilous evergreen dense forest of Yangambi is characterized by its role of shading between plants, microbial and animal species, photosynthesizing with vegetal carbonic respiration, purifying atmospheric air, structuring ligneous tissues and moderating climate warming willing to benefit carbon credit [1-3]. The forest serves through deeper tree roots recycling plant nutriments and controlling water and soil erosions [2, 4]. It furnishes financial income by selling forest ligneous products (wood) and non-ligneous foods (fruits, mushroom, caterpillars and snails), medicine (leaves and roots), and materials for clothing, handcrafts, housing, building and construction as well as arable soils [5-7].

The devastating shifting cultivation by slashing and burning in the Yangambi forest is associated with the atmospheric emission of gases and aerosols from biomass incinerations, forming acidic rains and wholes in ozone layers. The shifting is also combined with global warming and humidity decrease of denuded soils reducing evaporing surfaces and consequently proportional raining surfaces [5, 8]. This has caused latent hit flux of infrared rays from earth to the atmosphere in increasing temperature by 0.44°C in the Yangambi region [9, 10]. The devastating degradation of Yangambi reserve which sequestrates about 164 Mg C/ha aboveground carbon and 68 Mg C/ha underground carbon, would be thus negative to the environment by disturbing edaphic, hydrologic, human, plant and animal ecosystems in favoring climate heat [2, 5].

About 13% of the biosphere reserve has been devastated during political and economic crises running over the Democratic Republic of Congo (DRC) since 1980. In fact, about 97% of 85 000 inhabitants of the ecological region of Yangambi increasing at 2.9%/year live for burned shifting cultivation and consumable forest products. About 40% of inhabitants exploit timbers to build houses and construct canoes, others deforest for wood carbonization and crafts, clandestine small-scale diamond and gold mining [7, 11, 12, 13].

The context of the present study is laid on sustainable management of plantations of two indigenous species of the Yangambi humid tropical dense forest, *Pericopsis elata* and *Entandrophragma cylindricum*, to firstly control genetic extinction and secondly conserve durably the bio diversified reserve of the Yangambi region. The two species have the highest world economic trading for their best wood technologies appreciated in multiple industrial, art and craft uses. Studies on vegetal and edaphic behavior of the two forest species, in disappearance from West Africa onto Central Africa, in silviculture, forestation and reforestation fields, are justified for controlling the problematic of abuse over-exploitation and species erosions as to manage durably the natural ecosystem in African central depression region [1, 8, 14-16].

Genetic erosion is characterized by the weakly selective and intensive over-exploitation control, the non-respect of exploitation techniques and the lack of forest management plan as related to the multiplicity of usages and to the difficult natural regeneration when lacking light despite the important quantity of germinated seeds for *Pericopsis elata* [1, 14, 15]. On the other hand, for *E. cylindricum*, the natural regeneration is limited by the weakness of seed germination power, seed dispersion mediocrity and seed predation, slow growth speed, delayed maturity of seed producer trees, undefined fructification [15, 17, 18]. *E. cylindricum*is ranged as *vulnerable* in the red list of UICN [19], while *Pericopsis elata* is threatened of danger in the red list of IUCN and of extinction in the annexes II of the CITES [20].

In DR Congo, the annual productions from 2015-2016 of timbers of *Pericopsis elata* and *Entandrophragma cylindricum*in the Tshopo province were respectively about 46.80 m^3 and 1.461,37 m^3 for artisanal logging, 22.482,41 m^3 and 7.807,42 m^3 for industrial exploitation and 5.58 m^3 for semi-industrial exploitation of *P. elata* [21].

Thus, the sustainable natural management and plantation necessitate not only the availability of seeds and seedlings produced naturally from the forest or in nursing for good growing plantations of the two light demanding species [1, 14, 17, 22], but, also the integration of factors as soil physico-chemical proprieties, inter-annual variability of rainfalls, temperatures and relative air humidity; rentability and vegetal sociability [8, 23].

A sustainable management of the biodiversity is necessary to escape the vulnerability and extinction of the species. Recent studies have been being conducted on the ecology of *Pericopsis elata Harms* and *Entandrophragma cylindricum*in the experimental forest plantation applied to Layon, Blanc-Etoc, Martineau and assisted natural regeneration methods since 1938 in Yangambi [1, 2, 4, 17, 23, 24]. The present study compares the four silvicultural methods effects on dendro-pedological parameters of the two 82 year old species, which would determine a favorable sustainable system for both preserving species and protecting bio-diversified reserve of Yangambi [3, 14, 25, 26].

2. Methodology

2.1. Location of Study

The experimental site of forest plantations is situated in Yangambi (figure 1) in the central Africa depression of the DR Congo at 0°49'N, 24° 29'E limited between

0.7545157N-24.3944551E and 0.8553569N-24.5200252E and 470 meters of altitude mean on sandy clayey to clay sandy oxisoils of Yangambi (Y1) and Yakonde (Y2) soil series laid on the structural catena of Yangambi [14, 27, 28]. The biosphere floristic reserve of Yangambi covers 235000 hectares located in the ecological region of Yangambi which occupies about 444 000 hectares, dominated by the evergreen dense forests of *Gilbertiodendron dewevrei, Brachistegia laurentii, Pericopsis elata* and *Scorodophleus zenkeri* [1, 3, 6, 9].

The warm and humid climate of Yangambi is actually characterized by the bimodal monthly regime of rainfall peaked on April and October with the annual rainfall mean of 1822.19±214.8mm for 172.24±21.90 rainy days, 87.17±6.97% of relative air humidity, 1132.16±54.43 mm of potential evapotranspiration, 2020±98.17 hours of sunshine and 24.98±0.30°C of average temperature [9, 10, 13]. The change increase for average temperature to 0.44°C has been detected in 1986, relative air humidity in 1984, potential evapotranspiration in 1976 and sunshine in 2000. Despite the stationary yearly rainfalls, seasonal monthly rainfall disturbances have been observed since 2000 having defined increasing trends of rainfall in June, August, September and November characterizing thus the optimal period of active vegetation within the unique humid season of March to November. On the other hand, the dry season has been accentuated in December, then in January and February [9, 10, 13].

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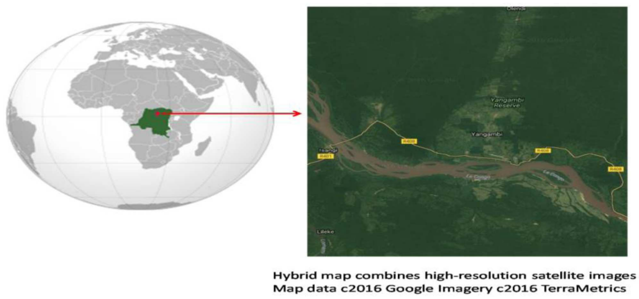

Figure 1. *Yangambi evergreen dense humid forest reserve crossed by the Congo river (to the right) located to the Northern DR Congo in red pointed on the world map (to the left) (Source: Google map, 2016).*

2.2. Studied Forest Species

Entandrophragma cylindricum and *Pericopsis elata* are the two studied species belonging to the botanical class of *Magnoliopsida* shown in table 1. They grow preferably in Guinéo-Congolaise region of African dense humid forests [3, 25, 26]. *E. cylindricum* settled from dense forests onto fallows is requireless, prefers versant and plateau soils with pH atypically high, dry well drained, with the rainfall ranged between 1200 and 2500mm and the average temperature from 15 to 32°C [17, 25]. Meanwhile, *Pericopsis elata* is nitrogen fixing legume, characteristic of fertile soils, atypically acid, clayey, with weak exchangeable aluminum content, rich in magnesium and available phosphorus. When naturally regenerated, it forms aggregates of high density [1, 3, 25].

Table 1. *Botany of Pericopsis elata and Entandrophragma cylindricum.*

Classification	***Entandrophragma cylindricum***	***Pericopsis elata***
Reign	Plantae	Plantae
Division	Magnoliophyta	Magnoliophyta
Class	Magnoliopsida	Magnoliopsida
Order	Sapindales	Fabales
Family	Meliaceae	Fabaceae
Genus	Entandrophragma	Pericopsis
Species	*E. cylindricum Sprague*	*P. elata Harms*
IUCN, Status of conservation	Threatened and vulnerable	Treatened and in danger

Source: Super kingdom Eukariota Plantae, 2018.

2.2.1. Entandrophragma Cylindricum Sprague (Sapelli)

The genus *Entandrogragma* is the richest of the *Meliaceae* family. It accounts for exclusively 12 African species. From taxonomic importance point of view, a multitude of genus is reattached with the high synonymy number of 36-44 based on economic interest [16]. *Entandrophragma* is the only genus having five species notably *E. Angolense* (white tiama), *E. congoense* (black tiama), *E. candollei* Harms (kosipo), *E. cylindricum (*Sprague) Sprague (sapelli) and *E. utile (Daweand Sprague) Sprague* (sipo) which are found and logged in the African evergreen and semi-deciduous dense humid forests, with very large distributions from Atlantic cost through the equator to the dorsal of Kivu in DRC. Its precious wood is exploited as woodwork of excellent technological quality available for diverse usages in industrial and artisanal logging [16, 17, 29].

Figure 2. *Entandrophragma cylindricum experimental plantations in Blanc-Etoc technique since 1938 in Yangambi, RDCongo. (Photo taken in 2015).*

*Sapelli*is is semi heliophilous, non-pioneer, anemochore, hermaphrodite and entomophilous. The species is abundant and more frequent in semi-deciduous than in evergreen forests. It is logged selectively for its red wood in the Congo basin [16, 17, 23]. It could measure meanly 6m height and 3m diameter [23]. It is disseminated in the DRC provinces of Tshopo, Equator and Bandundu [16, 21].

The species is used in the agro-forestry system, ornamental and shading trees. The species leaves host comestible caterpillar from butterfly *Imbrasia oyemensis*. The *Sapelli* wood density of 0.5 – 0.63 g/cm^3 allows multiple usages for woodwork, arts and crafts, canoe construction, fire wood and wood coal. The macerations of tree ectoderm are used against bronchitis, pulmonary affections, bowels flux, œdema and paludism [17, 23]

Figure 3. *Pericopsis elata experimental plantations in Blanc-Etoc technique since 1938 in Yangambi, RD Congo (Photo taken in 2018)*

2.2.2. Pericopsis Elata Harms Van Meerven (Afrormosia, Assamela)

Pericopsis elata Harms is of *Pericopsis* genus, *Sophoreae* tribe and the family of *Fabaceae* (table 1). It originates from the semi-deciduous tropical humid dense forest of central and occidental Africa, logging from Ivory Cost to DR Congo. In the DRC Tshopo province, the *Pericopsis elata* is met exclusively in the forests of Yangambi-Banalia-Kisangani triangle [1]. The species is gregarious, heliophilous, pioneer, anemochore with average pollens and seeds dispersion of more than 600 m. It could reach 130 cm diameter and 40-60 m height. The flower is bisexual principally allogam with a duplication of ploïdy (2n = 36 or 72) [17, 18, 22, 23].

Pericopsis tree color is golden-brown, with wood density mean of 0.57 – 0.71 g/cm^3, good dimensional stability and natural durability, heterogeneous, extremely hard and resistant against termites and other insects. It is used for internal and external woodworks [1, 17, 22].

2.2.3. Experimental Layout

The forestry research department of Yangambi INERA had in 1936-1946, split lands on Lusambila plateau located between rivers Lusambila and Isalowe, and planted 23 indigenous forest species for the forest management experimentation [14]. Before planting trees, soil was covered with an old secondary forest where trees reached 35 m height and 3 m circumference [14].

From table 2, the present study concerns *Pericopsis elata Harms* with the method of Layon on 100m X 100m plots 3A and 3C with 20mX4m distanced plants, the method of Blanc-Etoc on 60m X 60m plots 5A and 7C with 2mX3m distanced plants and the method of Martineau on 50m X 50m plots 9A and 3E with 2mX2m distanced plants. For the method of assisted natural regeneration (ANR), observations were made in the managed blocks on two plots of 100 m X 100m.

Based on plant density, the 82 year old plantation recorded the mortality of 78.4-91.34% for B. E, 88.50-97.92% for Martineau and 23.2-61.6% for Layon methods.

From table 3, the same dimension spaces and plant density used for *Pericopsis elata* were applied to *Entandrophragma cylindricum.* The 82 year old plantation has registered the mortality of 82-89.34% for BE, 63.52-96.67% for Martineau and 64% for Layon methods.

Table 2. *Plantation of Pericopsiselata Harms (Afrormosia) settled in 1938 in Yangambi, DRC.*

Plantation techniques	Plot identity	Ha	Planting dates	Planting space	N initial	Nactuel	Initial Density (plants/ha)	Actual Density (Plants/ha)	Mortality (%)
Blanc-étoc	5 A	0.36	29 oct. 1938	2 X 3 m	600	52	1666	51	91.34
Blanc- étoc	7 B	0.36	2 april 1942	6 X 2 m	300	68	833	54	78.4
Blanc- étoc	7 C	0.36	31march1942	6 X 2 m	300	48	833	37	84
Total						168			
Martineau	9 AB	0.25	10 nov. 1939	2 X 2 m	625	13	2500	52	97.92
Martineau	9 B CD)	0.25	5 august 1938	2 X 4 m	312.5	36	1250	144	88.50
Total						49			
Layon	3A	1.0	28 sept 1940	20 X 4m	125	96	125	173	23.2
Layon	3B	1.0	28 sept 1940	20 X 4m	125	48	125	216	61.6
Total						144			
Assisted Nat. Regeneration		1.0	1940		1.2	31		6.2	

From table 3, based on *Entandrophragmacylindricum* plant density, the 82 year old plantation has registered the mortality of 82-89.34% for BE, 63.52-96.67% for Martineau and 64% for Layon methods.

Table 3. *Plantation of Entandrophragma cylindricum Sprague (Sapelli) settled in 1938 in Yangambi, DRC.*

Plantation techniques	Plot Identity	Ha	Planting dates	Planting spaces	Initial N	Actual N	Initial Density (plants/ha)	Actual Density (Plants/ha)	Mortality (%)
Blanc- étoc	2A	0,36	2 april 1942	2 X 6 m	300	32	833,3	88,8	89,34
Blanc- étoc	4D	0,36	31march1942	2 X 6 m	300	54	833,3	122,2	82
Total						86			
Martineau	2AB	0,25	10 nov. 1939	2 X 2 m	625	27	2500	108	96,67
Martineau	2AC	0,25	5august 1938	2 X 4 m	312,5	114	1250	456	63,52
Total						141			
Layon	2CD	1,0	28 Sept 1940	20 X 4m	125	44	125	44	64,8
Layon	3AD	1,0	28 Sept 1940	20 X 4m	125	45	125	45	64
Total						89			
Assisted. Natural Regeneration		1.0	1940	-	-	28	-	-	-

2.2.4. Dendrometric Structure

Dendrometric observations made on the two species in plantation have regarded the principal traits such as diameter, height, basal area, aboveground biomass, loose volume and trunk slenderness.

The diameter at breast height (DBH, cm) is obtained in measuring the circumference at the tree breast height of 1,30m from soil with metric ruler, and multiplied by pi (π).

The merchantable height (m), the total height (m) and the crown radius (m) were measured with Bitterlich relascope.

The diametric structure has considered the classes of DBH constant of 10 cm. Tree population structures and regeneration level were represented by the dispersion curve of trees number per diameter classes.

The density of a tree population was measured by the number of trees per hectare by taking in account for its total basal area per hectare.

The basal Area (ba)- {$\Pi/4. (DBH)^2=C^2/4\pi$ (m^2/ha)}, is the surface of ligneous mater occupied by the tree breast height [1, 23].

The slenderness coefficient = H/D or Π x H/C (D = Diameter at 1.30 m from soil (H=total height and C=circumference or D=diameter are expressed in meter). The tree slenderness determines the tree stability facing chablis vulnerability or wind damages. A stable tree population has the slenderness coefficient inferior to 60-80, the unstable trees from 80-100, the very unstable trees superior to 100, and the trees growing in seclusion has the slender less than 45 [30].

The aboveground biomass (AGB) is estimated by the height-diameter regression following the model adapted to Yangambi forest based on Akaike Information Criterion (AIC) and Residual Standard Error (RSE) [1, 2, 32, 33].

The Loose volume (Lv, m^3/ha)=$\frac{SCxHh}{3}$, where:-Sc=Surface of tree crown (m^2/ha) =πr^2, -Hh= crown height, -π=3,14. Thus, the tree crown diameter (DC=2r with r = crown radius) is straightly related to the tree growth area. The crown radius was measured in eight magnetic directions oriented from the tree: S, NE, E, SW, SE, W, NW et N [27, 30].

2.2.5. Statistical Analyses

The statistical layout of ANOVA has considered four treatments which are the silvicultural methods notably Layon, Blanc-Etoc, Martineau and assisted natural regeneration and two objects, *Pericopsis elata Harms* and *Entandrophragma cylindricum Sprague*. Variance analyses, correlation and regression of Spearman were used for the significance of forest species dendrometric traits as compared to the different silvicultural methods. The non-parametric test of Kruskal Wallis, the test of Tukey HSD (Honest Significant Differences) and the test of Chi-carré (χ^2) were applied to separate the means of traits such DBH, basal surface, AGB, loose volume and slenderness. The logiciels R 3.4, SPSS 14.0, Statistics 10.0 and Excel served for statistical analyses and graphs [1, 2, 4].

3. Results

3.1. Comparisons of Dendrometric Traits

The analysis of variance presented in table 4 shows the differences between the four silvicultural methods related to each dendrometric parameter of *Pericopsis elata*. The difference has been very highly significant (p-value=0.00137) for basal areas, highly significant (p-value = 0.0023) for aboveground biomasses and significant (p-value<0.05) for DBH, slenderness and loose volumes. The dendrometric parameters have shown significant homogeneity (p< 0.0091-0.048) without normality of residuals as facing silvicultural methods.

Table 4. *Analysis of variance, normality of residuals and homogeneity of variances for dendrometric parameters of Pericopsis elata on silvicultural methods in plantation settled in 1938 in Yangambi, DRC.*

Dendrometric traits of P. elata	ANOVA			Normality of residuals		Homogeneity of Variances	
	df	F- values	P-values	Shapiro-Wilk (W)	P-values	Breusch-Pagan (BP)	P-Values
DBH	3	4.28	0.01206*				
Basal area	3	14.41	0.00137***	0.9205	0,2903	9,017	0,0291*
Trunk Slenderness	3	8.28	0.0099*				
Crown surface	3	6.369	0.0163*	0.9834	0,9938	11,366	0,0099**
Loose Volume	3	6.14	0.018*	0.9787	0,9777	11,547	0,0091**
Aboveground Biomass	3	12.17	0.0023**	0.9159	0,254	7,8803	0,048*

Légende: ***: Very highly significant at.001 probability level; **: highly significant at.01 probability level; *: Significant at.05 probability level

For *Entandrophragma cylindricum* presented on table 5, differences have been significant (p<0.05) between the four silivicultural methods as regarding dendrometric parameters and did not express the homogeneity of variances nor the residual normality (p > 0.2).

Table 5. *Analyses of variance, normality of residuals and homogeneity of variances for dendrometric parameters of Entandrophragma cylindricum planted in 1938 in Yangambi.*

Dendrometric traits of Entandrophragma cylindricum	ANOVA			Normality of residuals		Homogeneity of Variances	
	df	F-values	P-values	Shapiro-Wilk (W)	P-values	Breusch-Pagan (BP)	P-Values
DBH	3	4.55	0,0427*				
Basal area	3	5,424	0,0304*	0,93104	0,4215	4,2228	0,2384
Slenderness	3	4.97	0.0486*				

Dendrometric traits of Entandrophragma cylindricum	ANOVA			Normality of residuals		Homogeneity of Variances	
	df	F-values	P-values	Shapiro-Wilk (W)	P-values	Breusch-Pagan (BP)	P-Values
Crown Surface	3	7,389	0,0142*	0,9759	0,9394	8,9062	0,0305*
Loose Volume	3	4,35	0,0499*	0,89975	0,1835	2,4617	0,4823
Aboveground Biomass	3	4,76	0,041*	0,9519	0,6683	4,4412	0,217

Légende: *: significant at.05 probability level.

3.1.1. Diametric Structure

Pericopsis elata

The DBH means of *P. elata* in plantations presented in table 6 have not shown a significant difference between BE method with DBH=44.49±10.63cm and the total height mean of 24.46±4.45m, Layon method with DBH=40.84±17.30 cm and the total height mean of 23.76±6.55m and Martineau method with DHP=39.61±14.65 cm and the total height mean of 25.06±5.66m. But the DBH mean for ANR has been significantly (p-value < 0.05) the widest with D=58.58±38.45 cm and the total height mean of 36.35±12.58 m. The *Pericopsis elata* has reached the highest diameter of 94cm particularly with the method of Layon.

The tree slenderness coefficients in different methods have been inferior to 80 characterizing tree stability thus the resistance against chablis. For *Pericopsis elata*, BE and Layon slendernesses have been goodly the lowest with 54.98 and 58.20, while Martineau and ANR reached 62.0.

Table 6. *Means values of DBH, Height and slenderness for Pericopsis elata and Entandrophragma cylindricum on four silvicultural methods settled in 1938 in Yangambi, DRC.*

Dendrometric parameters	Silvicultural methods	*Pericopsis elata*	*Entandrophragma cylindricum*
1 DBH (cm)		45.878±25.244	33.790±23.405
	ANR	58.579±32.447b	72.69±61.27a
	BE	44.485±10.628 a	29.63±11.59b
	Layon	40.840±17.295 a	23.97±12.78b
	Martineau	39.607±14.850 a	13.86±7.58bc
2. Total height (m)		27.406±7.310	21.47±8.330
	ANR	36.352±12.583 a	32.37±±14.88a
	BE	24.459±4.446 b	22.04±5.80ab
	Layon	23.756±6.552 b	18.69±6.21b
	Martineau	25.059±5.660 b	12.77±5.45bc
3. Slenderness coefficient		59.619	72,255
	ANR	62.056a	44.532c
	BE	54.983b	74.380b
	Layon	58.169ab	77.973ab
	Martineau	63.269a	92.136a

Legend: ANR: assisted natural regeneration, BE: Blanc-Etoc; numbers followed by the same letter a, b and c are not statistically different at 0.5 probability level

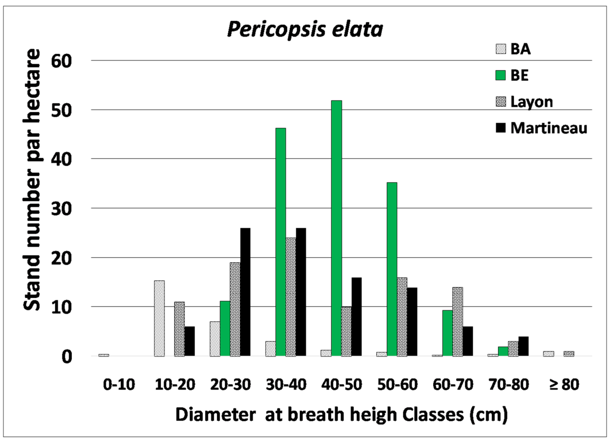

Figure 4. *Individuals distribution of 82 year old Pericopsis elata per diameter class under four silvicultural techniques in Yangambi, DR Congo.*

The diameter class distribution of *P. elata* for the four silvicultural methods is presented in the figure 4.

With BE method, *Pericopsis elata* has been identified with 20 to 70 cm DBH Gaussian shape. The highest density of 52 individuals/ha was observed in the class of 40-50 cm, followed by 47 individuals/ha in the class of 30-40 cm, 36 individuals/ha in the class of 50-60 cm, 9 individuals/ha in the class of 60-70 cm and 2 individuals/ha for the class of 70-80 cm.

The Kurtosis shape has characterized the diametric dispersion of *P. elata* in the methods of Layon and Martineau. The Martineau method has covered the diametric dispersion of 10-80 cm with the highest density of 26 individuals/ha in the DBH classes of 20-30 cm and 30-40 cm. whereas the method of Layon covered in the same classes 19 and 23 individuals/ha respectively. Then, 15 for Layon and 10 individuals/ha for Martineau were found in the class of 60-70 cm.

For the ANR method (assisted natural regeneration), the diametric structure has ranged from >1 to more than 80 cm, with the highest density of 16 individuals/ha in the class of 10-20 cm decreasing asymptotically (decreasing exponential curve) in form of inversed J characteristic of a managed natural forest contrarily to other three plantation methods characteristic of missed regeneration proved also by the missing of 0-10 cm DBH class.

Entandrophragma cylindricum

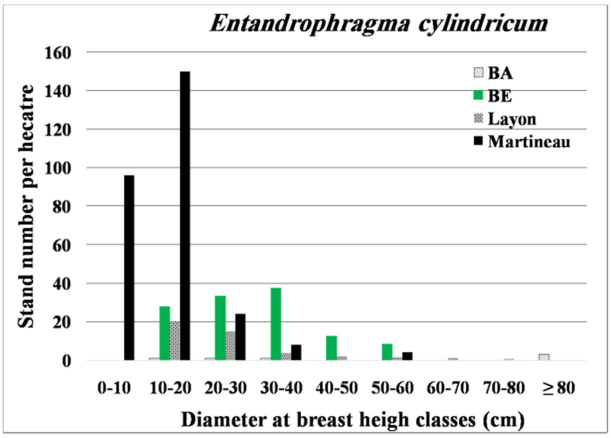

Figure 5. *Individuals distribution of Entandrophragma cylindricum per DBH class under four silvicultural techniques.*

The DBH means of *E. cylindricum* presented in table 6 have shown significant differences (p-value<0.05) between methods. The widest diameter mean has been identified for ANR method with 72.69±61.27cm and the total height mean of 32.37±14.88m, significantly different from BE method with 29.63±11.59cm and the total height mean of 22.04±5.80m, Layon method with 23.97±12.78cm and the total height mean of 18.69±6.21m and Martineau method with 13.86±7.58cm and the total height mean of 12.77±5.45m. The lowest *Entandrophragma cylindricum* slenderness was registered for ANR method with 44.53 and the highest one was reached by Martineau with 92.14. BE and Layon methods have no significant slenderness difference respectively with 74.38 and 77.97.

The weakly densities distribution at lower DBH for *Entandrophragma cylindricum* under the four forest management methods is presented in figure 5.

The highest individual density was for Martineau method at 10-20 cm DBH class with 148 individuals/ha, followed by 93 individuals/ha at 0-10 cm DBH class. Then the lower density of 22 individuals/ha was observed in the 20-30 cm class. The characterized Kurtosis shape would indicate the very slow growth in plantation. For the Blanc-Etoc method, the feeble Gaussian shape has indicated the feeble density at the diameter classes of 0-10, 10-20, 20-30, 30-40 and 40-50 cm respectively with 27, 36, 39, 5 and 8 individuals/ha. The method of Layon has presented the 10-20 and 20-30 cm DBH classes, respectively with 20 and 17 individuals/ha in inversed J shape, while are they planted individuals. For ANR, only 2 individuals/ha have been registered in the class of >80 cm DHP, indicating the very hard regeneration of the *E. cylindricum*.

3.1.2. Basal Areas

The basal area means of *P. elata* and *E. cylindricum* registered from the four silvicultural methods are presented in figure 6.

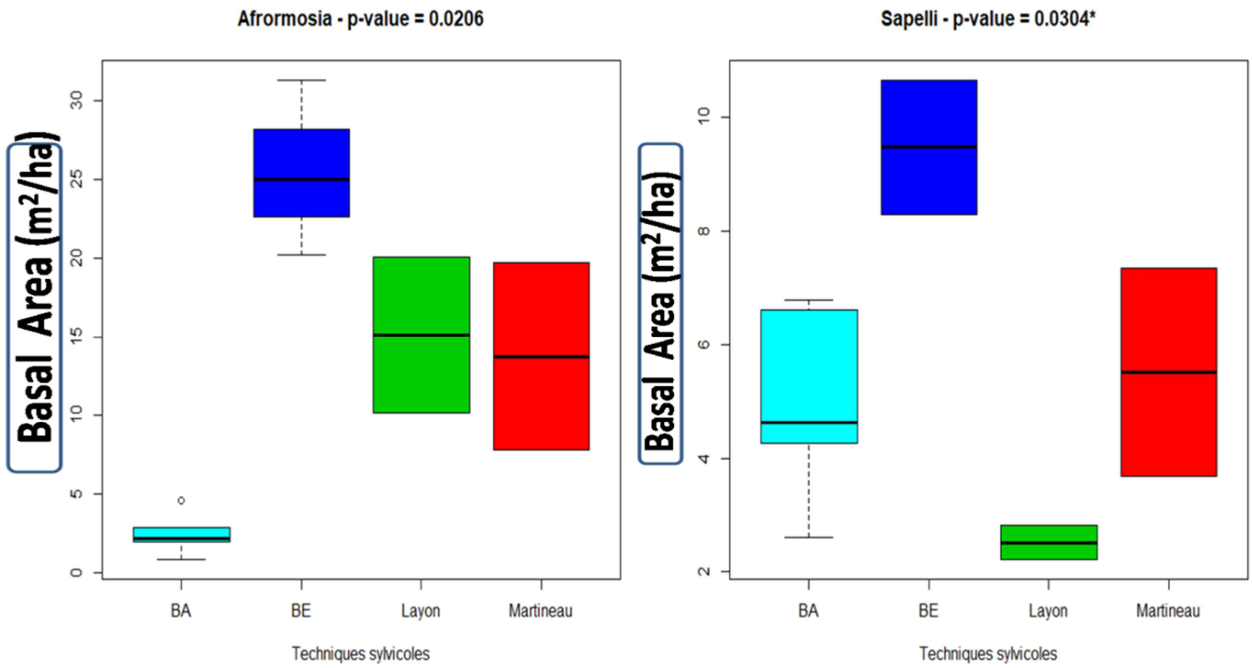

Figure 6. *Basal area dispersion values for Pericopsis elata and Entandrophragma cylindricum between the plots of ANR method (assisted natural regeneration). BE (Blanc-Etoc), Layon and Martineau. The box represents the interval in which are regrouped 50% of basal area and the thick bar in the box indicates the average basal area. the lower bar indicates the minimum basal area and the upper bar the maximum basal area.*

Pericopsiselata

The basal area mean values for *Pericopsis elata* presented in figure 6, have shown the significant difference at p-value = 0.02066 between the four silvicultural techniques. The multiple comparison Tukey test (annexed table 7) has determined the highly significant difference (p adj = 0.0008747) of BE basal area with 25 m^2/ha from ANR basal area with 2.55 m^2/ha; and the significant difference (p adj = 0.0578367) between Layon basal area with 15.2 m^2/ha and that of ANR. Layon and Martineau were not significantly different.

Entandrophragmacylindricum

From figure 6, the comparison of basal area values for Sapelli (*Entrandrophragma cylindricum*) between the four silvicultural techniques has been significant at p-value = 0.0304. The multiple comparison Tukey test (annexed table 8) has determined significant difference (p<0.1; p adj = 0.07064) between BE basal area with 10.657 m^2/ha and ANR basal area with 6.779 m^2/ha and highly significant difference (P<0.05 p adj = 0.02257) between BE and Layon with 2.807 m^2/ha.

3.1.3. Aboveground Biomasses

The figure 7 shows the aboveground biomasses (AGB) of *P. elata*and *E. cylindricum* from the four silvicultural methods in Yangambi.

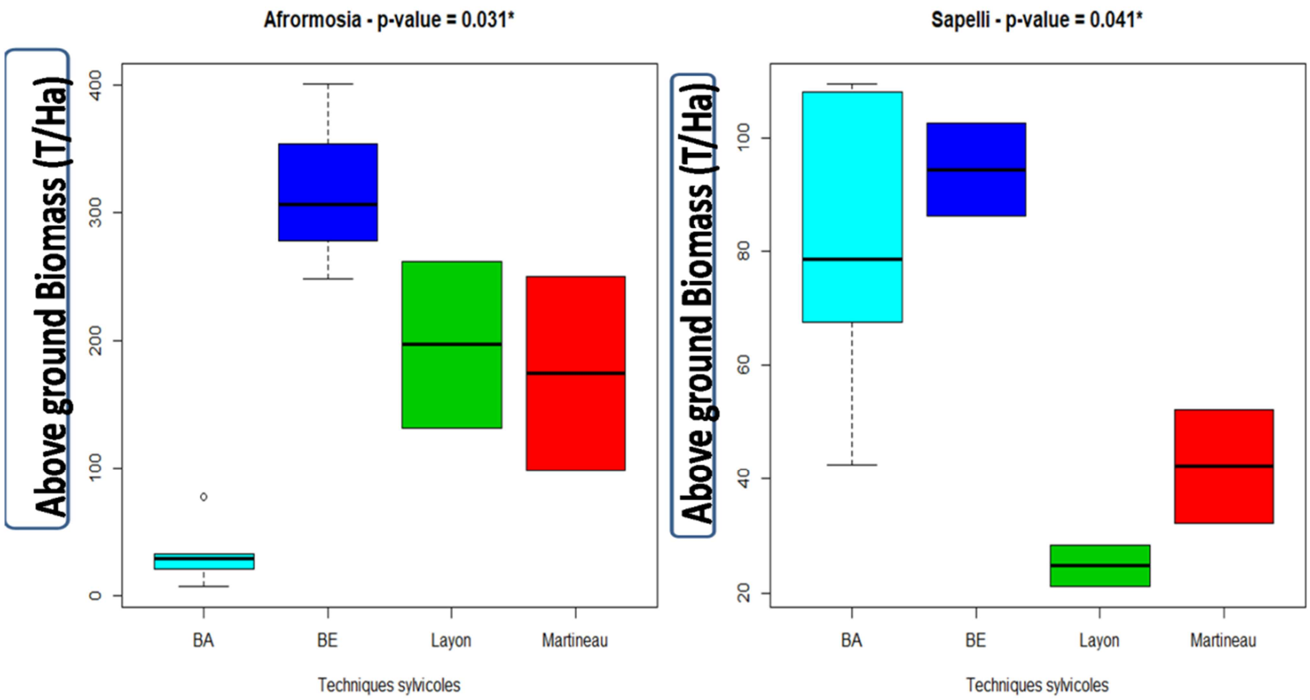

Figure 7. *Aboveground biomasses dispersion for Pericopsis elata (to the left) and Entandrophragma cylindricum (to the right) between the plots of ANR (assisted natural regeneration). BE (Blanc-Etoc), Layon and Martineau methods. The box represents the interval in which are regrouped 50% of aboveground biomasses and the thick bar within the box indicates the average aboveground biomasses. the lower bar indicates the minimum aboveground biomass and the upper bar the maximum aboveground biomass.*

Pericopsis elata

From figure 7, the AGB mean values between the silvicultural techniques applied to Pericopsis elata *have presented significant difference (p-value = 0.031). The multiple comparison Tukey test (annexed table 7) has shown that only the BE AGB with 320 t/ha has been highly superior (p adj = 0.0015) to ANR AGB with 37 t/ha. The three planting methods were not significantly different.*

Entandrophragma cylindricum

In figure 7, the AGB means for Sapelli *Entrandrophragma cylindricum* have shown significant difference (p< 0.05; p-value = 0.041) between the four silvicultural techniques. The multiple comparison Tukey test (annexed table 8) presents significant (p<0.1) superiority of BE AGB with 94.310±11.57 and ANR AGB with 81.16±28.34 on Layon AGB with 24.75±5.15 t/ha.

3.1.4. Loose Volume

In figure 8, the loose volume values of four silvicultural methods have been differently significant at p-value = 0.04319 for Afromosia and p-value= 0.0499 for Sapelli.

Pericopsis elata

In figure 8, the loose volume means for *Pericopsis elata* showing significant differences between the four silvicultural; in annexed table 7 the multiple comparison test has retained only BE method with the loose volume of 41000 m^3/ha as being significantly (p adj = 0.0234019) superior to that of

ANR method with 465 m^3/ha. The loose volumes have been statistically similar between BE, Layon and Martineau respectively with 41300, 37300 and 41292 m^3/ha.

Entandrophragma cylindricum

In figure 8, the loose volume means for *Entandrophragma cylindricum* showing significant differences between the four silvicultural techniques; the multiple comparison has determined Layon and Martineau loose volumes as being significantly (p< 0.1) inferior to that of BE respectively with 4795.99±2450.63 and 4912.50±1874.98 to 14 471.348±3645.69 m^3/ha.

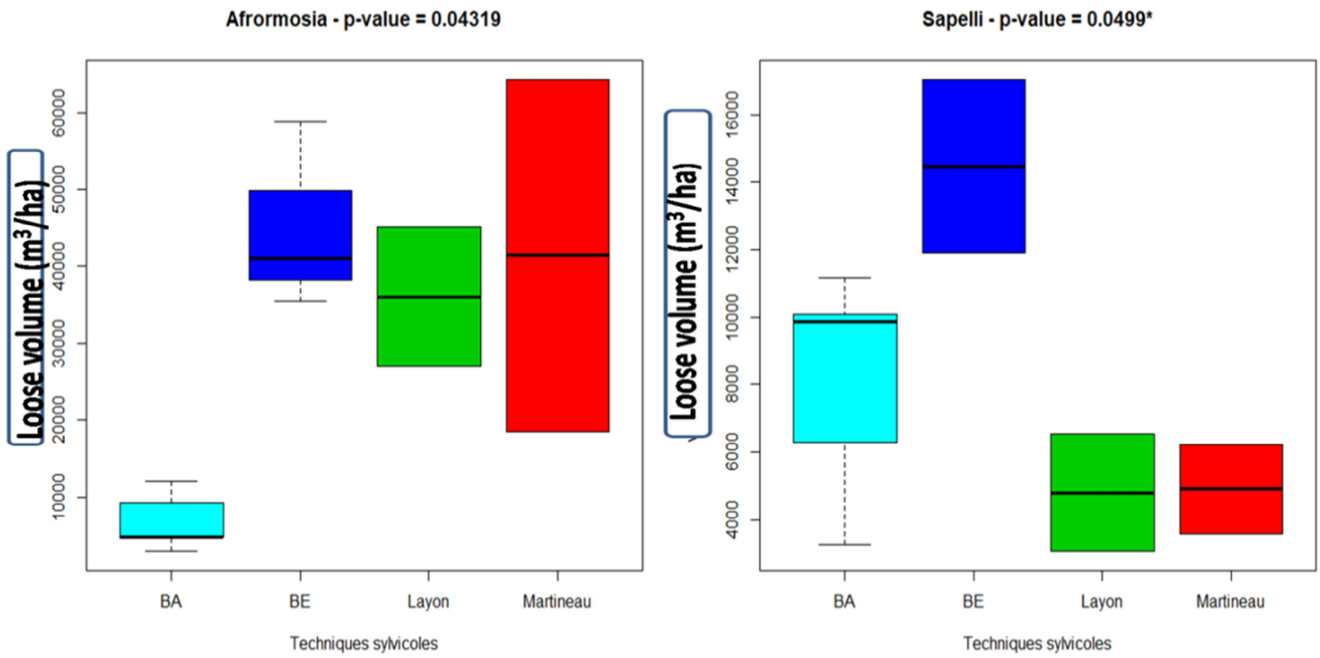

Figure 8. *Loose volume values dispersion for Pericopsis elata (afromosia) and Entandrophragma cylindricum (Sapelli) between plots of ANR (assisted natural regeneration). BE (Blanc-Etoc), Layon and Martineau methods. The box represents the interval in which are regrouped 50% of loose volumes and the thick bar within the box indicates the loose volume means. the lower bar indicates the minimum loose volume and the upper bar the maximum loose volume.*

3.2. Comparison of the Two Forest Species

3.2.1. Diameter Structures

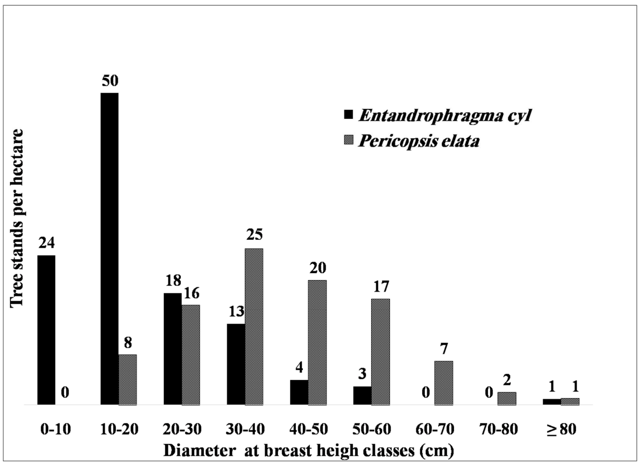

Figure 9. *Comparison between 82 year old P. elata and E. cylindricum concerning DBH classes under four silvicultural techniques taken together in Yangambi, DR Congo.*

In figure 9, the two species have presented significant (p-value <0.05) two different shapes of the DBH class dispersion. The total individuals density means for *E. cylindricum* taking together all the methods, have presented the inversed J shape found decreasingly in the classes of 10-20 cm with 50 individuals/ha, 0-10 cm with 24 individuals/ha, 20-30 cm with 18 individuals/ha and 30-40 cm with 13 individuals/ha. The individuals' concentration in the 0-20cm DBH range shows the mediocre diametric growth of the species. For the *P. elata,* the highest population density for all methods taken together is situated in the median of the Gaussian form with the 30-40 cm class accounting for 25 individuals/ha. The following classes are 40-50cm with 20 individuals/ha, 50-60 cm with 17 individuals/ha, 20-30 cm with 16 individuals/ha and 60-70 cm with 7 individuals/ha.

3.2.2. Basal Area, Aboveground Biomass and Loose Volume

In figure 10, the dendrometric trait total averages on the management methods taken together for *Pericopsis elata* have been significantly (P≤0.1) 4 times higher than those of *Entandrophragma cylindricum* concerning the loose volume 32314.530±17452.59 against 8077.835±4533.927 m^3/ha (p-value= 0.06507). *P. elata* was not significantly different from *E. cylindricum* concerning respectively the aboveground biomass with 180.7±117.05 against 60.608±32.57 t/ha de (p-value=0.1301); and the basal area with 14.205±9.45 against 5.619±2.88 m^2/ha (p-value=0.1661).

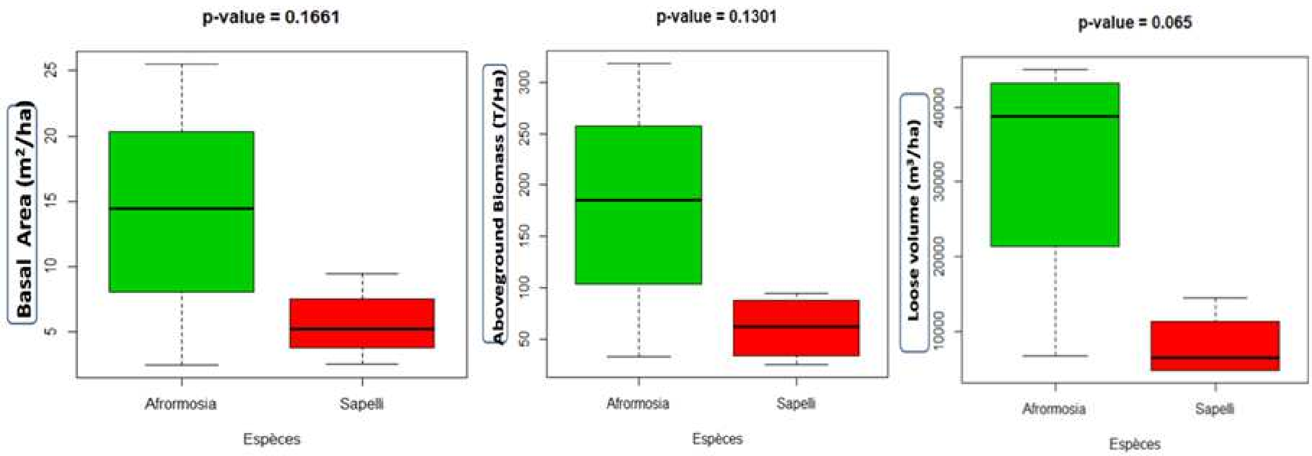

Figure 10. *Comparison between 82 year old P. elata and E. cylindricum concerning basal area (left), abovegroud biomass (middle) and loose volume (right) for the silvicultural methods settled in 1938 in Yangambi, DRC.*

4. Discussion

4.1. Diameter Structure

Both *Pericopsis elata (*heliophilous) and *Entandrophragma cylindricum* (semi-heliophilous preferring shading at lower age), require large canopy openings of about 10 000 m^2 for light for their sustainable natural regeneration and development [1, 14, 15]. Therefore, exposed to solar light, the two different species have been differently favorable mostly to Blanc-Etoc method concerning the studied parameters.

For *P. Elata* with BE method, about 65% representing the highest density of 52 individuals/ha in 40-50cm class, 36 in 50-60cm class, 9 in 60-70cm class and 2 individuals/ha in 70-80cm class, could be gradually logged. The exploitation would be completed with 35% ten-range of individuals/ha found in the classes of 50-60cm and 60-70cm for Layon and Martineau methods. However, *E. cylindricum* has accounted for less than 20% of individuals per method for logging.

At natural state, the forest legislation has fixed the exploitation diameter of the two species to 80cm [16] to manage sustainably the forest. For the present *P. elata* ANR case, only the class of diameter≥80cm with the weak density of 2 stands/ha was found to be logged over the total of 6.2 stands/ha. These stands could be the seed tree producers dated before management in 1940, comparatively to the results obtained from plantations having reached the diameter means of 40-70cm with about 50 individuals. Boyemba [1] has found that in the same forest managed in 1950, 1.2 stands/ha have produced in 2009 6.2 stands ≥ 10 cm DBH/ha and 0.06-5.2 stands<10cm DBH/ha.

Despite the same age of plantation and climatic conditions, although the methods of BE, Layon and Martineau express statistically similar *P. elata* global diameter means, respectively with 44.49, 40.84 and 39.61 cm; the DBH classes express different annual diameter growth rate (related to height or trunk slenderness) for a given silvicultural technique. The difference is pointed out because of the botanical nature of each of the two species, different tree diameters (or basal areas) based on different methods for the same species, border effect, light deficit for Martineau, lack of appropriated clearing following the management methods, mortality, vegetal sociability, natural regeneration rate, density and volume of planted stems, pedo-hydrological and eco-topographical variables, exploited and non-exploited forest zones and plantations [1, 17, 23, 27, 28, 31, 32].

The diametric Gaussian shape with high median classes population density observed on *Pericopsis elata* would be characteristic of good plantation because the plantations installed in the same year 1938 growing at different growth speeds for the BE, Layon and Martineau have yielded large diameters (because of light presence despite weak density (because of mortality). The inversed J shape (or L) of the *E. cylindricum* is characteristic of bad growth in plantation with high densities and small diameter because of the lightlessness in Martineau. Beside the generalized mortality on the two species in plantation, although *E. cylindricum* would be favorable to the ANR (assisted natural regeneration) method, the feeble density of the species in ANR would come from such seed germination strength weakness and their predation as well as undefined period of fructification [17, 23].

In fact, the *P. elata* basal area has been significantly superior to that of *E. cylindricum* for the same causes as cited for DBH notably lightlessness, feeble diameter and mortality. The *P. elata* basal area has been influenced by the BE with 25.54m^2/ha, the Layon with 15.11m^2/ha and the Martineau with 13.73m^2/ha because of their higher density and diameter in the median class of 30-70cm. Whereas, the second species basal area was weakly influenced by BE 9.474m^2/ha, Martineau 5.514m^2/ha and ANR 4.976m^2/ha because of the feeble diameter and high density in the class 1-20cm. The less influential methods for *E. elata* and *E. cylindricum* basal areas have been respectively ANR with 2.444m^2/ha and Layon 2.514m^2/ha. In ANR, the stands in the forest are aggregated, while in plantations the stands are range-planted. The basal area means of 14-19.3 m^2/ha observed in plantations in South Cameroun are not far from values found in BE and Layon for the two species in Yangambi.

For the two species, the BE method has been influent on DBH, AGB, basal area and loose volume with respectively the coefficients of correlation (r) of 0.8823; 0.8406; 0.7728 and 0.7221 for the *P. elata*; and 0.8177; 0.8008; 07133 and 0.7322 for the *E. cylindricum*.

4.2. Aboveground Biomass and Loose Volume

The values of «biomass Plus» would be defined as the sum of AGB and loose volume (crown volume) values which will express more about aboveground biomass for a tree [30, 32]. Thus, the biomass-plus values of the two species for the BE method have been higher favored by the opened solar light on the canopies. In contrast, the weaker values were observed in dominated stratum as ANR for *Pericopsis* and Layon and Martineau for *E. cylindricum* are concerned. With Martineau method, the *Pericopsis* in dominated status has also yielded a high loose volume while being the less diametric. The loose volume would be integrated to the AGB for carbon stock estimation. The aboveground biomass for *E. cylindricum* has produced the corresponding carbon stocks of 44.327±5.448 t/ha with BE method and 38.145±13.319 t/ha for ANR significantly superior to Martineau method with 19.841±6.635t/ha and Layon method with 11.632±2.418t/ha. Meanwhile the *P. elata* has respectively produced the carbon stocks of 149.839±36.29t/ha significantly different from 92.397±43.396t/ha and 81.908±50.394t/ha and then from 15.642±12.523t/ha.

5. Conclusion

Silvicultural techniques (Blanc-Etoc, Layon, Martineau and assisted natural regeneration) effects on dendrometric traits of two indigenous forest species, *P. elata (Fabaceae)* and *E. cylindricum (Meliaceae)* planted in 1938, of valuable international economic trading have been studied to determine a sustainable pedo-silvicultural system in preserving Yangambi biosphere reserve. The DBH, basal area, AGB and loose volume mean values of *P. elata* have been superior to those of *E. cylindricum* without being significantly different at the.05 Probability level. Martineau and Layon were not significantly different on all the parameter means of *P. elata* and they have shown weak values for *E. cylindricum*. The Blanc-Etoc (BE) method convenes for plantations. It has produced dendrometric results significantly higher as compared to other methods.

On the other hand, the assisted natural regeneration (ANR) has yielded the feeblest values for the *P elata,* but it has been favorable to AGB and loose volume of the *E. cylindricum.* The Layon method did not have significant effect on the *E. cylindricum,* but has influenced the DBH, AGB and basal area of *P. elata*.

The edaphic knowledge related to tree ecology will elucidate more about the differences between the two species regarding the four silvicultural methods.

Appendix

Table 7. *Multiple comparison Tukey test on four silvicultural techniques applied to Pericopsis elata planted in 1938 in Yangambi, DR Congo.*

Silvicultural techniques	DBH	Basal area	Crown Surface	Loose Volume	Slenderness coefficient	Above ground Biomass
BE-ANR	0.0116*	0,000875***	0,0145**	0,0234**	0.0264*	0,0015**
Layon-ANR	0.0094*	0,0578*	0,2097	0,1339	0.1854	0,07*
Martineau-ANR	0.0099*	0,0930*	0,1099*	0,0705*	0.1566	0,124
Layon-BE	0.0788	0,1676	0,594	0,8923	0.2226	0,253
Martineau-BE	0.1654	0,1092*	0,8254	0,9911	0.0183*	0,1541
Martineau-Layon	0.3485	0,9916	0,9781	0,9797	0.4751	0,985

Table 8. *Multiple comparison Tukey test on four silvicultural techniques applied to Entandrophragma cylindricum planted in 1938 in Yangambi, DR Congo.*

Silvicultural techniques	DBH	Basal area	Trunk slenderness	Crown Surface	Loose Volume	Aboveground Biomass
BE-ANR	0.0055**	0,07064*	0.0374*	0,0144**	0,15108	0,895
Layon-ANR	0.0048**	0,40572	0.0426*	0,9981	0,59262	0,076*
Martineau-ANR	0.00022***	0,9208	0.0033**	0,1099*	0,0705*	0,124*
Layon-BE	0.0776	0,02257**	0.2162	0,02878**	0,06177*	0,067*
Martineau-BE	0.0443*	0,2015	0.0449*	0,3144	0,064895*	0,185
Martineau-Layon	0.0397*	0,3908	0.04793*	0,3239	0,999979	0,864

References

[1] Boyemba F., 2011. Écologie de *Pericopsis elata* (Harms) Van Meeuwen (Fabaceae), arbre de forêt tropicale africaine à répartition agrégée. PhD thesis: Université Libre de Bruxelles (Belgique).181 p.

[2] Kearsley E., 2015. Carbon storage and functional diversity of tropical rainforest in the Congo basin. PhD thesis in applied biological sciences. Ghent University, Belgium. 183 p.

[3] Louis J., 1947. Contribution à l'étude des forêts équatoriales congolaises. C. R. Semaine Agricole de Yangambi 1947. Publ. INEAC.

[4] Bauters M., 2018. Biogéochemical cycles in contrasting tropical forests of the Congo Basin. PhD thesis, faculty of Bioscience Engineering. Ghent University, Belgium. 155p.

[5] GIEC (groupe intergouvernemental pour l'évolution du climat), 2018. Le cycle de l'eau modifié par le réchauffement climatique. Jonathan Sare. Futura modifié le 11/09/2018.

[6] Marien J. N. and Gourlet-Fleury S., 2014. Les plantations forestières en Afrique centrale: des sylvicultures nouvelles pour répondre aux nouveaux besoins des sociétés. *In:* De Wasseige C., Flynn J., Louppe D., HiolHiol F., Mayaux Ph. (éds). Les forêts du bassin du Congo-ꜫtat des forêts 2013. Neufchâteau, Belgique. Weyrich. 197-212. http://www.observatoire-comifac.net/docs/edf2013/FR/EDF 2013_FR_chap8.pdf

[7] Projet FORETS (formation. recherche et environnement en province de Tshopo). 2017. Valeur économique totale du paysage de Yangambi. Fiche N° 19/24

[8] Likoko Bambele Alexandre, Murefu Kashuva, Likoko Abaya Georges et Posho Ndola Boniface, 2018. Effets des biomasses de légumineuses ligneuses sur la croissance et le rendement du maïs en couloir sur un ferralsol de Yangambi, RD Congo. Journal of Applied Biosciences. Vol. 131, pp 13382-13391.

[9] Likoko Alexandre B, Sylvain Alongo L, Michel Lokonda O, Faustin Boyemba B., Ferdinand Kombele B., 2020. Recent Climate Trend of Yangambi Region, DR Congo. Ad. Oceanogr & Marine Biol. 2 (1): 2020. AOMB. MS. ID. 000530. DOI: 10.33552/AOMB.2020.02.000530.

[10] Likoko B. A., Likoko A. G., Likoko A. B., Likoko K. J., Alongo L. S., *et al*. (2019a). Agricultural Monthly Rainfall Trends Disturbances in Yangambi Region. DR Congo. J Aqua Sci Oceanography 1: 105

[11] INERA (Institut National pour l'Etude et la Recherche Agronomiques), 2001. Rapport annuel INERA Yangambi 2001, Pp 33-35

[12] INERA (Institut National pour l'Etude et la Recherche Agronomiques), 2018. Rapport annuel INERA Yangambi 2018, Pp 45-58

[13] Likoko B. A., Mbifo N., Besango L., Totiwe T., Badjoko D. H., *et al*. (2019b) Climate Change for Yangambi Forest Region. DR Congo. J Aqua Sci Oceanography 1: 203.

[14] Donis C., 1956. La forêt dense congolaise et l'état actuel de sa sylviculture. *Bull. Agric. Congo Belg*. 47 (2), 261-289.

[15] Doucet J.-L., Dainou K., Ligot G., Ouédraogo D. Y., Bourland N., Ward S. E. et al., 2016. Enrichment of Central African logged forests with high-value tree species: testing a new approach to regenerating degraded forests. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manage*. 12 (1-2). 83-95.

[16] Kasongo, Yakusu E., Monthe F. S., Bourland N., Hardy O. J., Louppe D., Bola Mbele Lokanda F., *et al.,* 2018. Le genre *Entandrophragma,* (Meliaceae): taxonomie et écologie d'arbres africains d'intérêt économique (synthèse bibliographique). Biotechnologie, *Agronomie, Société et Environnement. 22 (2).* https://popups.uliege.be:443/1780-4507/index.php?id=16353.

[17] Kasongo Yakusu E., Louppe D., Monthe F. S., Hardy O. J., Mbele Lokanda F. B., Hubau W., Van Den Bulcke J., Van Acker J., Beeckman H., Bourland N.,2019. Enjeux et amélioration de la gestion des espèces du genre *Entandrophragma,* arbres africains devenus vulnérables. Bois et Forêts des Tropiques, 339: 75-94. Doi: https://doi.org/10.19182/bft2019.339.a31717

[18] Monthe F. K., Hardy O. J., Doucet J.-L., Loo J., Duminil J., 2017a. Extensive seed and pollen dispersal and assortative mating in the rain forest tree *Entandrophragma cylindricum* (Meliaceae) inferred from indirect and direct analyses. Molecular Ecology, 26: 5279-5291. https://doi.org/10.1111/mec.14241

[19] IUCN 2019. The IUCN Red List of Threatened Species, Version 2019-2. http://www.iucnredlist.org. Downloaded on 18 July 2019.

[20] CITES (Convention pour le commerce international des espèces de faune et flore sauvages menacées d'extinction), 1983. Texte de convention. Version amendée à Gaborone. https://cites.org/fra/disc/text.php (consulté le 31/03/2020).

[21] Omekaya S. B. L. and Kabeya S. JP., 2017. Gestion des ressources naturelles en Province Orientale démembrée. Etat de lieux. Défis et perspectives.

[22] Bourland N., Kouadio Y. L., Fétéké F., Lejeune P. and Doucet J. L., 2012. «Ecology and management of *Pericopsiselata* (Harms) Meeuwen (Fabaceae) populations: a review». Biotechnol. Agron. Soc. Environ., volume 16 (2012) numéro 4: 486-498 http://popups.ulg.ac.be/Base/document.php?id=9176

[23] Fétéké F., Fayolle A., Daïnou K., Bourland N., Dié A., Lejeune P., *et al.*, 2016. Variations saisonnières de la croissance diamétrique et des phénologies foliaire et reproductive de trois espèces ligneuses commerciales d'Afrique centrale. Bois et Forêts des Tropiques. 330: 3-21. https://doi.org/10.19182/bft2016.330.a31315

[24] Assumani. A. D., 2009. Bilan dendrométrique de plantations expérimentales de *Pericopsiselata (Harms) Van Meeuwen* et *Millettia de Wild*, installées à Yangambi (RD Congo) entre 1938 et 1942, P 160.

[25] Louis J., 1943. Contribution à l'étude du genre *Afrormosia* au Congo Belge. Bull. Jard. Bot. de l'État à Bruxelles. 17(1), 109-116.

[26] Louis J. and Fouarge J., 1943. *Essences forestières et bois du Congo*. Coll. in-4°. fasc. 2. Bruxelles: INEAC.

[27] Alongo S., Visser M., Kombele F., Colinet C., Bogaert J., 2013. Propriétés et diagnostic de l'état agropédologique du sol de la série Yakonde après fragmentation de la forêt à Yangambi, R D Congo. Annales des instituts supérieurs d'études agronomiques, 2013, 5(1), pp36-51. <hal-00875748>.

[28] Monthe F. K., Hardy O. J., Doucet J.-L., Loo J., Duminil J., 2017a. Extensive seed and pollen dispersal and assortative mating in the rain forest tree *Entandrophragma cylindricum* (Meliaceae) inferred from indirect and direct analyses. Molecular Ecology, 26: 5279-5291. https://doi.org/10.1111/mec.14241

[29] White F., 1986. *La végétation de l'Afrique*. Mémoire accompagnant la carte de végétation de l'Afrique. Paris: Orstom et Unesco.

[30] Kaźmierczak Katarzyna, Wojciech Borzyszkowski, Robert Korzeniewicz, 2015. Slenderness of 35-year-old pines from a dominant stand as an indicator of a stand Stability. POZNAŃSKIE TOWARZYSTWO PRZYJACIسŁ NAUK, Forestry letters For. Lett. No 108: 32-35, 2015.

[31] Ndamiyehe Ncutirakiza J.-B., Lejeune P., Gourlet-Fleury S., Fayolle A., Ndjele Mianda-Bungi L., Ligot G., 2020. Quantifier les dimensions des houppiers à l'aide d'images aériennes à haute résolution pour estimer l'accroissement diamétrique des arbres dans les forêts d'Afrique centrale. Bois et Forêts des Tropiques, 343: 67-81. Doi: https://doi.org/10.19182/bft2020.343.a31848

[32] Loubota Panzou, G. J., 2020. Biomasse et stocks de carbone en Afrique centrale: importance de l'allométrie des arbres. Bois et Forêts des Tropiques, 343: 85-86 Doi:https://doi.org/10.19182/bft2020.343.a31853

[33] Litemandia N. Y. et Alongo L. S., 2018. Validité des équations allométriques pantropicales pour l'estimation du stock de carbone dans les forêts denses humides du bassin du Congo. *Afrique* SCIENCE *14(3) (2018) 85-95* 85. ISSN 1813-548 X. http://www.afriquescience.net