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 9.47±1.67 m²/ha, the aboveground biomasses with 318.81±77.2 against 94.31±11.59t/ha and the loose volumes with 45069.49±12219.30 against 14 471.348±3 645.692m³/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 evaporation 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 m³ and 1.461.37 m³ for artisanal logging, 22,482,41 m³ and 7,807,42 m³ for industrial exploitation and 5.58 m³ 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* 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
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±214.8 mm 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 stationarity of 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].

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 [1, 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].

*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   | Threatened and in danger     |

Source: Super kingdom Eukariota Plantae, 2018.
2.2.1. Entandrophragma Cylindricum Sprague (Sapelli)

The genus *Entandrophragma* 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 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].

2.2.2. Pericopsis Elata Harms Van Meerven (Afromosia, 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,
amenochore 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 ploidy (2n = 36 or 72) [17, 18, 22, 23].

Pericopsis tree color is golden-brown, with wood density mean of 0.57 – 0.71 g/cm³, 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].

| Plantation techniques | Plot identity | Ha | Planting dates | Planting spaces | 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 | 31 march 1942 | 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 aug. 1938   | 2 X 4 m        | 312.5     | 36      | 1250                        | 144                         | 88.50         |
| Total                 |              |      |                |                 | 49        |         |                             |                             |               |
| Layon                 | 3 A          | 1.0  | 28 sept 1940  | 20 X 4 m       | 125       | 96      | 125                         | 173                         | 23.2          |
| Layon                 | 3 B          | 1.0  | 28 sept 1940  | 20 X 4 m       | 125       | 48      | 125                         | 216                         | 61.6          |
| Total                 |              |      |                |                 | 144       |         |                             |                             |               |
| Assisted Nat. Regen.  |              |      |                |                 | 1.0       | 28      |                             |                             | 6.2           |

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.

| Plantation techniques | Plot identity | Ha | Planting dates | Planting spaces | Initial N | Actual N | Initial Density (plants/ha) | Actual Density (Plants/ha) | Mortality (%) |
|-----------------------|--------------|----|----------------|-----------------|-----------|---------|-----------------------------|-----------------------------|---------------|
| Blanc-étoc            | 4D           | 0.36 | 2 april 1942  | 2 X 6 m        | 300       | 32      | 833                         | 88.8                        | 89.34         |
| Blanc-étoc            | 2A           | 0.25 | 10 nov. 1939  | 2 X 6 m        | 300       | 54      | 833                         | 122.2                       | 82            |
| Total                 |              |      |                |                 | 86        |         |                             |                             |               |
| Martineau             | 2AB          | 0.25 | 5 aug. 1938   | 2 X 2 m        | 625       | 27      | 2500                        | 108                         | 96.67         |
| Martineau             | 2AC          | 0.25 | 5 aug. 1938   | 2 X 4 m        | 312.5     | 114     | 1250                        | 456                         | 63.52         |
| Total                 |              |      |                |                 | 141       |         |                             |                             |               |
| Layon                 | 3CD          | 1.0  | 28 Sept 1940  | 20 X 4 m       | 125       | 44      | 125                         | 44                          | 64.8          |
| Layon                 | 3AD          | 1.0  | 28 Sept 1940  | 20 X 4 m       | 125       | 45      | 125                         | 45                          | 64            |
| Total                 |              |      |                |                 | 89        |         |                             |                             |               |
| Assisted Nat. Regen.  |              |      |                |                 | 1.0       | 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.

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.

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) - 𝜋/4 (DBH)^2 = C^2/4𝜋 (m^2/ha), is the surface of ligneous mater occupied by the tree breast height [1, 23].

The slenderness coefficient = H/D or 𝜋 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 tree slenderness determines the tree stability facing chablis vulnerability or wind damages. A stable tree population has 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) = 3/4𝜋Hh, where: -Sc=Surface of tree crown (m²/ha) = 𝜋 r², -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].

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.

### 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 (χ²) 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. Differences have been significant (p-value<0.05) between the four silvicultural methods as regarding dendrometric parameters and did not express the homogeneity of variances nor the residual normality (p > 0.2).

### 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*                | 0.9205           | 0.2930           | 9.017             | 0.0291*  |
| Basal area                      | 3     | 14.41                  | 0.00137***              | 0.9938           | 0.0091**         | 11,366            | 0.0091**  |
| Trunk Slenderness               | 3     | 8.28                   | 0.0099*                 | 0.9977           | 0.0091**         | 11,547            | 0.0091**  |
| Crown surface                   | 3     | 6.369                  | 0.0163*                 | 0.9159           | 0.0480*          | 7,8803            | 0.0480*   |
| Loose Volume                    | 3     | 6.14                   | 0.018*                  | 0.9787           | 0.0480*          | 7,8803            | 0.0480*   |
| Aboveground Biomass             | 3     | 12.17                  | 0.0023**                | 0.0480*          | 7,8803            | 0.0480*          |

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 silvicultural 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*                 | 0.93104          | 0.4215           | 4,2228            | 0.2384   |
| Basal area                                        | 3     | 5,424                  | 0.0304*                 | 0.93104          | 0.4215           | 4,2228            | 0.2384   |
| Slenderness                                       | 3     | 4.97                   | 0.0486*                 | 0.93104          | 0.4215           | 4,2228            | 0.2384   |
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Dendrometric traits of Entandrophragma cylindricum

| ANOVA                      | Normality of residuals | Homogeneity of Variances |
|---------------------------|------------------------|--------------------------|
| Df | F-values | P-values | Shapiro-Wilk (W) | P-values | Breuach-Pagan (BP) | P-Values |
| Crown Surface             | 3 | 7,389 | 0,0142* | 0,9759 | 8,9062 | 0,0305* |
| Loose Volume              | 3 | 4,35  | 0,0499* | 0,8975  | 0,1835 | 2,4617  |
| Aboveground Biomass       | 3 | 4,76  | 0,041*  | 0,9519  | 0,6683 | 4,4412  |

Légende: *: significant at 0.05 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)             | ANR                   | 45.878±25.244   | 33.790±23.405              |
|                         | BE                    | 58.579±32.447   | 72.69±61.27a               |
|                         | Layon                 | 44.485±10.628   | 29.63±11.59b               |
|                         | Martineau             | 40.840±17.295   | 23.97±12.78b               |
| 2. Total height (m)     | ANR                   | 27.406±7.310    | 21.47±8.330                |
|                         | BE                    | 36.352±12.583   | 32.37±14.88a               |
|                         | Layon                 | 24.459±4.446    | 22.04±5.80ab               |
|                         | Martineau             | 25.059±5.660    | 18.69±6.21b                |
| 3. Slenderness coefficient | ANR                  | 59.619          | 62.056a                    |
|                         | BE                    | 63.269          | 54.983                     |
|                         | Layon                 | 62.056          | 58.169ab                   |
|                         | Martineau             | 69.619          | 75.929ab                   |

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.

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±61.27 cm and the total height mean of 32.37±14.88 m, significantly different from BE method with 29.63±11.59 cm and the total height mean of 22.04±5.80 m, Layon method with 23.97±12.78 cm and the total height mean of 18.69±6.21 m and Martineau method with 13.86±7.58 cm and the total height mean of 12.77±5.45 m. 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.
Pericopsis elata

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 m²/ha from ANR basal area with 2.55 m²/ha; and the significant difference (p adj = 0.0578367) between Layon basal area with 15.2 m²/ha and that of ANR. Layon and Martineau were not significantly different.

Entandrophragma cylindricum

From figure 6, the comparison of basal area values for *Entandrophragma 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 m²/ha and ANR basal area with 6.779 m²/ha and highly significant difference (P<0.05 p adj = 0.02257) between BE and Layon with 2.807 m²/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-Etoe), 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.](image)

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 *Entandrophragma cylindricum* have shown significant difference (p< 0.1; 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 m³/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 14471.348±3645.69 m$^3$/ha.

3.2. Comparison of the Two Forest Species

3.2.1. Diameter Structures

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 Entandrophragma 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).
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 m² 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 25.54m²/ha, the Layon with 15.11m²/ha and the Martineau with 13.73m²/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 9.474m²/ha, Martineau 5.514m²/ha and ANR 4.976m²/ha because of the
feebler diameter and high density in the class 1-20 cm. The less influential methods for *E. elata* and *E. cylindricum* basal areas have been respectively ANR with 2.444 m²/ha and Layon 2.514 m²/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 m²/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 influential 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; 0.7133 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) which will express more about aboveground biomass for a tree [30, 32]. Thus, the biomass plus of the two species for the BE method have been higher favored by the opened solar light 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±6.635 t/ha and Layon method with 11.632±2.418 t/ha. Meanwhile the *P. elata* has respectively produced the carbon stocks of 149.839±36.29 t/ha significantly different from 92.397±43.396 t/ha and 81.908±50.394 t/ha and then from 15.642±12.523 t/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 0.05 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

| 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   |

| 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           | 0.0002*** | 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   |
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