e-ISSN:2320-0189
p-ISSN:2347-2308

Research & Reviews: Journal of Botanical Sciences

# Dendrometric and Structural Characterization of Moringa Oleifera Agroecosystems in Central Africa: A Case Study from Cameroon

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## Review Article

Received date: 02/09/2021
Accepted date: 30/10/2021
Published date: 06/11/2021

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**Keywords:** Agroecosystems, Dendrometry, Far North, Cameroon, *Moringa oleifera*, Structure

**ABSTRACT**

The main objective of this study is to analyze the dendrometric and structural parameters of *Moringa oleifera* populations in the agroecosystems of the Far North Cameroon. The method quadrat 25 m × 25 m was undertaken to evaluate dendrometric parameters using the average diameter, average height and radius of the average crown. The population structure of *M. oleifera* is determined by density, basal area and rate of aerial cover. A total of 288 plots have been installed. The data collection was carried out in an area of 1 ha per plot. The parameters calculated in three subdivisions (Diamaré, Mayo-Danay and Mayo-Tsanaga) showed that the average diameter varies from5.63 ± 2.74 to 17.7 ± 7.43 cm; the average height of 3.37 ± 0,80 to 6.21 ± 1.75 m; an average crown of 1,50 ± 0,75 à 3,16 ± 1,23 m.With an average density between707 ± 16.64 and 1457 ± 45.41 stems/ha; an average basal area between 1.70 ± 0.02 and 10.86 ± 0.009 m²/ha and an aerial cover between 13.48 et 54.93%. The population distribution showed a predominance of individuals with a diameters of between 5 and 10 cm with a height of between 2 and 6 m and a crown radius of less than 2m reflecting a young population. The result show a significant correlation between diameter, height, and crown (p= 0,0001) in the three subdivisions. This study can be used as part of the sustainable management of this species in Cameroon.

## INTRODUCTION

The ligneous plants in natural ecosystems are subject to disturbance linked to human action combined with climatic factors with threaten their survival [1]. This leads to overexploitation of multipropose trees and potential socio-economic, placing the populations of these species in a regressive dynamic characterized by scarcity or absence of young individuals [2]. Among these important agroforestry resources available in Cameroon is *Moringa oleifera*.

*Moringa oleifera* is a species native to India, which is among the plant varieties found in the ecosystem sahelian region of the Far North Cameroon [3]. It passed in a decade the status of marginal plant, even unknown, to that of the new food and economic resource [4]. It is a multifunctional species with the economic, socio-cultural, medicinal, commercial and agroforestry has been widely documented in the Far-North Cameroon [5,3, 6-9]. Its exceptional nutritional properties make a *M. oleifera* leaves food interesting for the fight against malnutrition in the region [10]. The species in this region is used as part of reforestation projects such as « Green Sahel » by NGOs such as ABIOGeT and Codas Caritas for its adapatation to arid conditions and thus its heat resistance [11]. *M. oleifera* is cultivated intensively as agroforestry species in association with vegetables, tubers and cereals [6], with a view to diversify the revenue from the sale of their output in order to also resolve the security problems social [12]. His agroecological capacity also protects the soil against wind and water erosion [12].

However, despite its widely recognized socio-economic potential in the Far North Cameroon, basic scientific information on the structure and population status of this species in agicultural system are still limited. This hampers indeed developing strategies for conservation and sustainable use [13]. Better management of resources would require the restoration of degraded ecosystems [14]. This construction must be based on knowledge of the current state of these resources [15]. Thus knowledge of the population status of *M. oleifera* in agroecosystems Far Norh Cameroon would guide the actions of reforestation and enrichment in this species. This study's main objective is to analyze the demographic structure and dendrometric population parameters of *M.*

*oleifera* in agroecosystems Far North Cameroon to diagnose the state of place in this species and provide necessary information to the sustainable management of this highly prized natural resource in this region.

# MATERIALS AND METHODS

### Study site description

The study was conducted in the region of the region of the Far North Cameroon, precisely in the three subdivisions (Diamaré, Mayo-Danay and Mayo-Tsanaga) (**Figure 1**). This region is between 10° and 13° North latitude and 12° and 15° East longitude [16]. The average annual temperature is 28°C and rainfall varies from 400 to 1000 mm [17]. The climate is tropical Sudano-Sahelian [18]. Woody and herbaceous vegetation has Sudanian savannah, dry savannahs and steppes [19]. Hydrography consists of periodically flooded rivers [20]. Soils in the Far North region are vertisol, hardy, sandy, rocky and muddy [21]. The local population engages in several subsistence activities (agriculture, livestock, and exploitation of forest resources, trade and handicrafts) [22].

### Data Collection

### Choice of study sites and experimental design

The observation unit are plantations dominated by *M. oleifera*. The age of the plantations and the density in number of stems per hectare are also reasons for choosing Diamaré, Mayo-Danay and Mayo-Tsanaga subdivisions to make comparative analyzes dendrometric parameters and structural and establish correlations between these dendrometric parameters. Three types of Moringaplantations were selected according to the age groups based on observations made by farmers to examine its dynamics (0-5 years; 6-10 years and over 10 years).

The experimental device is a split plot on two factors;the main treatments are study subdivisions (Diamaré, Mayo-Danay and Mayo-Tsanaga) and secondary treatments are the three types of Moringa plantations selected according to the age groups (0-5 years; 6-10 years and over 10 years) chosen in each subdivisions. Quadrats of 25 m × 25 m are repetitions.

### Sampling methods

The quadrat method was used to assess structure in Moringa plantations. Sampling was carried out in the 25 m × 25 m (625 m$^2$) plots using the method developed by Hall and Swaine [23]. This method has been successfully used by several authors [24-31]. A total of 288 plots have been installed.

The sampling bands were established using compass, decameter, GPS and twine. At the ends of each strip, the stakes were marked at an equidistant 5 m from the base. At each distance of 5 m, M. oleifera were systematically counted and measured. The circumferences were measured at 30 cm above the ground due to its branches below 30 cm from the ground. Thus each branched branch is considered an individual. In addition to measured circumference other dendrometric parameters were measured in the field namely the total height and the two perpendicular diameters of the crown. The total heights and the average diameters of the crown were measured using a graduated pole and made.

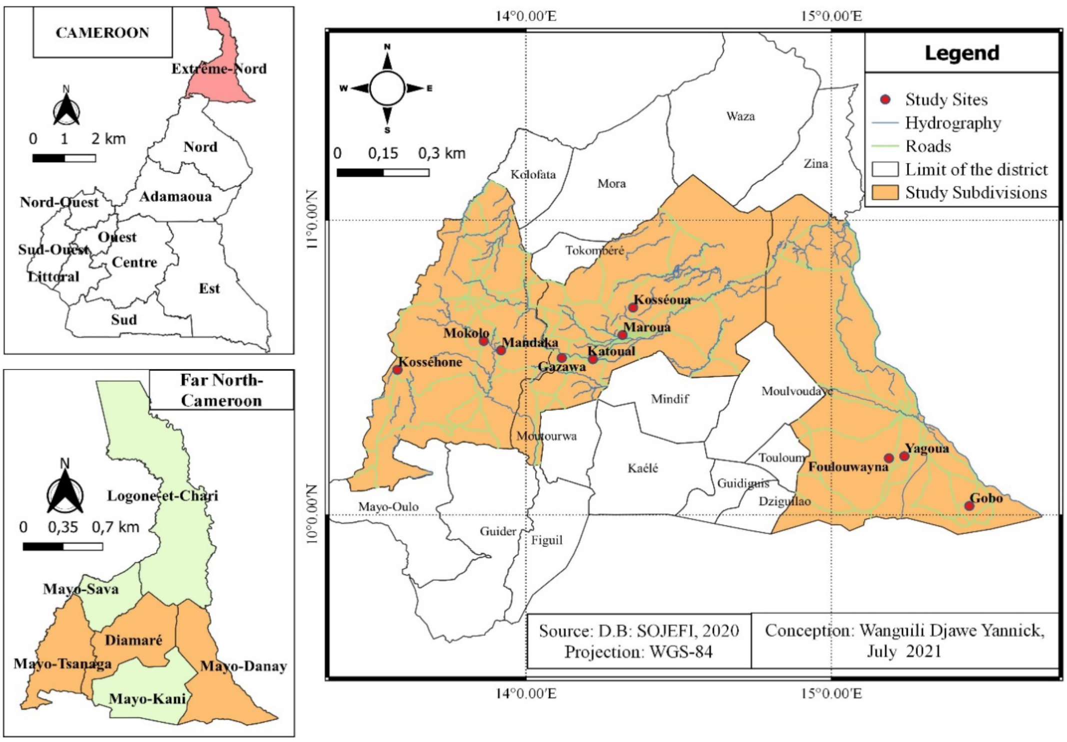



**Figure 1**: Location of the Study Site.

The circumference values were then converted to diameter (DBH) according to the formula:$C = \pi D$, with C = circumference, D = diameter, and $\pi = 3.14$ and the average crown = (d1+d2) /2 with d1 and d2 respectively the average of the East/West and North/ Southdiameters.

**Dendrometricand structural characterization**

The collected dendrometric and structural data were used to evaluate the following paramaters:

- the average diameter(Dbm), the average height (Hm) and the average crown (Hpm)were calculated [32]. $Dbm = \sum di/n$ ; $Hm = \sum Hi/n$ ; $Hpm = \sum Hpi/n$.

Di= diameter of treei (cm) ; Hi : height of treei (m) ; Hpi : crown of treei (m) ; n : the total number of trees.

- The population density estimated in number of individuals per hectare [33];

- The Basal Area [33]: $BA = \frac{\pi}{4}\sum_{i=1}^{n} d_i^2 = \frac{1}{4\pi}\sum_{i=1}^{n} C_i^2$

Avec BA: Basal Area ($m^2$/ha), d: diameter (cm), C : circumference (m).

The crown diameter (Hpm) was used to calculate the total crown area (Sc) from the following formula [34]: $Sc\ (m^2/ha) = \sum_{i=1}^{n} Hpm^2/4$

La Sc is used to calculate the aerial cover from crowns [34].

The aerial cover (R) expressed as a percentage per hectare is calculated by:

R (%)= ((TotaleSc × 10.000) / (numberof quadrat × 625)) ×100.

Distribution by diameter classes was adopted in order to assess the dynamics and evolutionary trends of these stands [35]. It was distributed in the form of histograms constructed from the observed densities of amplitude diameter classes equal to 5 cm and arranged as follows : Class 1 or class of juvenile individuals = <5 cm ; Class 2 : 5-<10 cm ; Class 3 : 10-<15 cm ; Class 4 : 15-<20 cm ; Class 5 : 20-<25 cm ; Class 6 : 25-30 cm ; Class 7 : 30-35 cm ; Class 8 : 40-45 cm.

The height and crown structures are generally histograms constructed from the observed densities of height and crown classes with an amplitude of 2 m the amplitude [36] and arranged as follows :0–2 m ; >2–4 m ; >4–6 m ; >6–8 m, >8-10 m.

For to establishing a correlation, the correlation test and simple linear regression allowed us to assess the effect of the increase between height, crown and diameter of M. oleiferapopulations in agro-ecosystems.

**Data Analysis**

The data collected in the field were treated in the excel spreadsheet to look for different dendrometric parameters and structural study (density, average diameter, average height, average crown, basal area, aerial cover, distribution). Xlstat (2020) 5.0 software was used for the analysis of variances. Turkey's multiple comparison tests was used to compare the means of each parameter at the 5% significance threshold. It also made it possible to do the correlation test and the linear regression between the established dendrometric parameters.

# RESULTS

**Dendrometric characterizations of M. oleifera populations**

In the three subdivisions, the diamater, the height, the crown average of *M. oleifera* varysignificantly according to age and subdivisions in the agroecosystems (Table1). These dendrometric values are high in Mayo-Tsanaga subdivisions (average diameter: 12.22 ± 4.61 cm; average height: 5.30 ± 1.28 m; average crown :2.98 ± 1.06 m) and the lowest values were observed in the Diamaré subdivision(average diameter : 8.19 ± 4.63 cm ; average height: 4.45 ± 1.29 m; average crown :2.07 ± 1.08 m) (**Table 1**).

**Ecological structure of M. oleifera population**

**Table 2** shows that the density. The basal area and the aerial cover rate vary significantly according to age and subdivisions in the agroecosystems. The table also show that the total density is maximum in Diamaré subdivision(3245 ± 96.35 stems/3ha) and minimum in Mayo-Tsanaga subdivision(2933 ± 80.31 stems/3ha). Basal aera and aerial cover are maximum in Mayo-Tsanaga subdivisions (BA: 19.95±0.069 $m^2$/3ha; R(%): 38.48%)and minimum in Diamaré subdivision(BA: 10.60 ± 0.25 $m^2$/3ha; R(%): 21.78%) (**Table 2**).

**Distribution M. oleifera populationsaccording to the subdivisions**

**Diametric distribution of M. oleiferapopulations**

The **Figure 2** shows a positive asymmetric distribution (right) with predominance of individuals with diameters between 5-10 cm in all three subdivisions investigated. The maximum number of individuals is concentrated in this diameter class with a percentage of 40.86%, 46.68% and 39% respectively in Diamaré, Mayo-Danay and Mayo-Tsanaga subdivisions. Moreover the general distribution of stands of different ages studied fits the model type exponential decreasing and individuals to large diameter (> 25 cm) are rare as in all subdivisions.

e-ISSN:2320-0189
p-ISSN:2347-2308

**Table 1.** Comparative studies of the dendrometric parameters of M. oleifera according to the subdivisions and by sites.

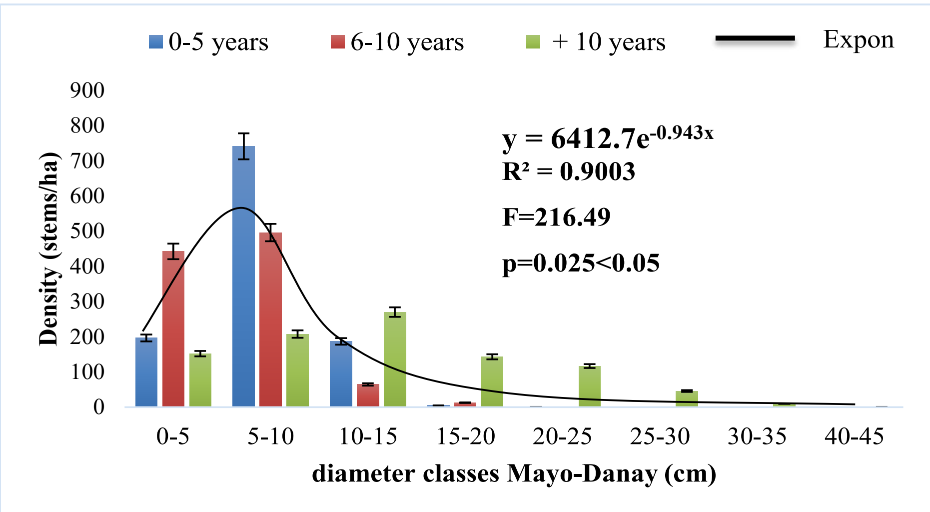
| Subdivisions | Sites (Ages) | Dbm (cm) | Hm (m) | Hpm (m) |
|---|---|---|---|---|
| Diamaré | 0-5years | 5.63±2.74a | 3.75±1.006a | 1.50±0.75a |
| | 6-10years | 9.19±5.25b | 4.72±1.41b | 2.26±1.18b |
| | +10years | 9.76±5.90c | 4.88±1.46c | 2.46±1.31c |
| | **Total** | **8.19±4.63 ;** p=0.0001<0.005 | **4.45±1.29** p=0.0001<0.005 | **2.07±1.08** p=0.0001<0.005 |
| Mayo-Danay | 0-5years | 7.43±2.17b | 3.50±0.83b | 1.75±0.48b |
| | 6-10years | 5.90±2.10a | 3.37±0.80a | 1.73±0.68a |
| | +10years | 12.95±5.77c | 5.43±1.28c | 3.16±1.23c |
| | **Total** | **8.76±3.34** p=0.0001<0.005 | **4.1±0.97** p=0.0001<0.005 | **2.21±0.79** p=0.0001<0.005 |
| Mayo-Tsanaga | 0-5years | 6 ±1.93a | 3.85±0.95a | 1.58±0.60a |
| | 6-10years | 12.97±4.48b | 5.86±1.15b | 3.32±1.11b |
| | +10years | 17.7±7.43c | 6.21±1.75c | 4.06±1.47c |
| | **Total** | **12.22±4.61** p=0.0001<0.005 | **5.30±1.28** p=0.0001<0.005 | **2.98±1.06** p=0.0001<0.005 |

*For each column, the average values assigned the same letter are not significantly different at the 5% level (Turkey test). Dbm : Average basal diameter (cm) ; Hm : Average height (m) ; Hpm : Average crown (m).

**Table 2.** Comparative studies of the density, basal areaand cover aerial of *M. Oleifera* according to the subdivisions and by sites.

| Subdivisions | Sites (Ages) | Density (stems/ha) | BA ($m^2$/ha) | R (%) |
|---|---|---|---|---|
| Diamaré | 0-5years | 1457±45.41a | 2.24±0.02c | 16.16c |
| | 6-10years | 1081±34.30b | 4.75±0.179a | 27.61a |
| | +10years | 707±16.64b | 3.61±0.06b | 21.58b |
| | **Total** | **3245±96.35** p=0.005 | **10.60±0.25** p=0.0001 | **21.78** p=0.0001 |
| Mayo-Danay | 0-5years | 1131±21.45a | 2.77±0.03b | 14.43a |
| | 6-10years | 1017±24.52b | 1.70±0.02c | 15.26b |
| | +10years | 947±17.86c | 8.03±0.09a | 45.17c |
| | **Total** | **3095±63.83** p=0.019 | **12.5±0.14** p=0.0001 | **24.95** p=0.0001 |
| Mayo-Tsanaga | 0-5years | 1206±38.27a | 1.88±0.01c | 13.48a |
| | 6-10years | 976±22.99b | 7.21±0.05b | 47.05b |
| | +10years | 751±19.05c | 10.86±0.009a | 54.93c |
| | **Total** | **2933±80.31** p=0.0001 | **19.95±0.069** p=0.0001 | **38.48** p=0.0001 |

*For each column, the average values assigned the same letter are not significantly different at the 5% level (Turkey test). BA : Basal aera ($m^2$/ha) ; R : cover aerial (%).



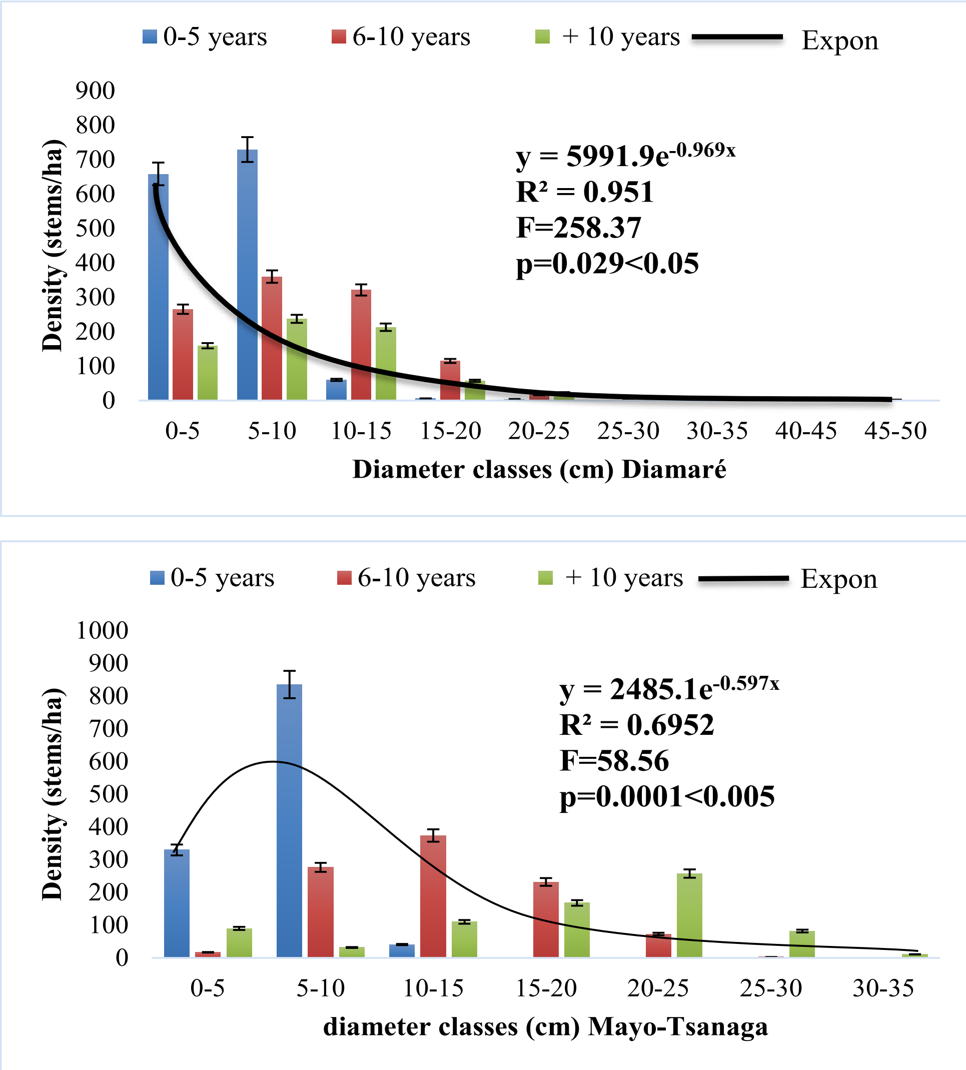



**Figure 2**: Diametric distribution of *M. oleifera* individuals in the different agroecosystems by subdivisions studied: A: Diamaré; B: Mayo-Danay; C: Mayo-Tsanaga.

**Height distribution of M. oleiferapopulations**

The **Figure 3** shows that individuals with a height between 2-4 m are the most dominant in Diamaré and Mayo-Danay subdivisions with a respective maximum representation of 41.69% and 48.69% of the total population. On the other hand, individuals with a height between 4-6 m are the most dominant in Mayo-Tsanaga with a maximum representation of 37.47% of the total population. Individuals belonging to the height class between 2-4 m in Diamaré and Mayo-Danay subdivision and between 4-6 m are dominant in young stands less than 5 years, followed by stands of 6-10 years and stands over 10 years old. The distribution of population of different ages in all subdivisions presents a shape of a « bell » adjusting to the polynomial type model where the individuals belonging to the class of height less than 2m and that of upper class of height between 6-10 m are poorly represented in all stands.

**Crown distribution of M. oleiferapopulations**

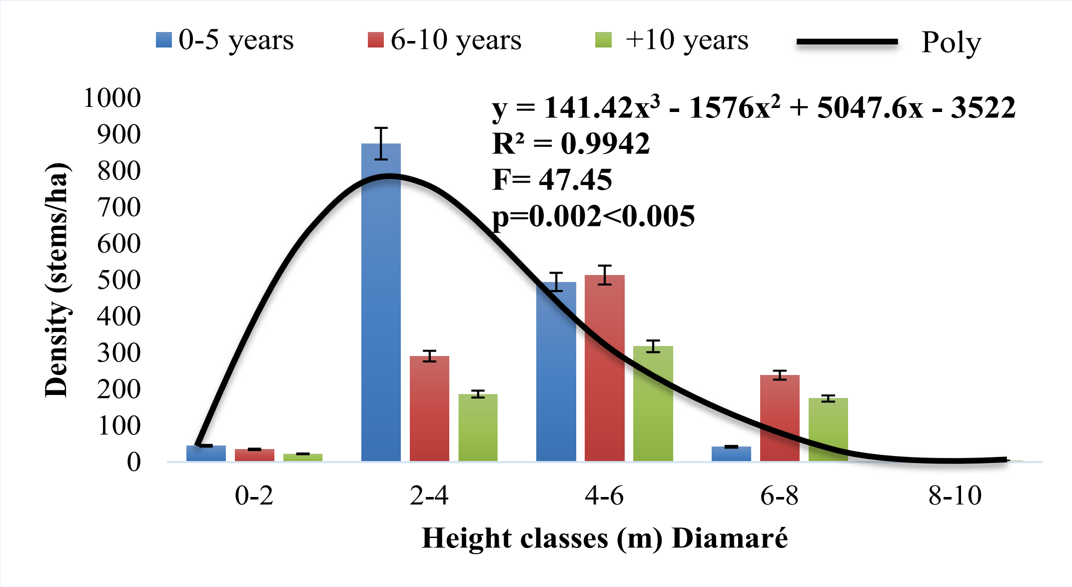
The **Figure 4** shows that individuals with a crown lower than 2 m are the most dominant in all the three subdivisions studied. The maximum number of individuals is concentrated in this crown class with the percentage of 59.87%, 54.70% and 39.78% respectively in Diamaré. Mayo-Danay and Mayo-Tsanaga subdivisions. Class are dominant in young stands less than 5 years old, followed by stands 6-10 years old and stands over 10 years old in all three subdivisions. In addition, the overall distribution has an inverted « L » or « J » shape and fits the decreasing polynomial type model where individuals over 6m are rare in all subdivisions studied.

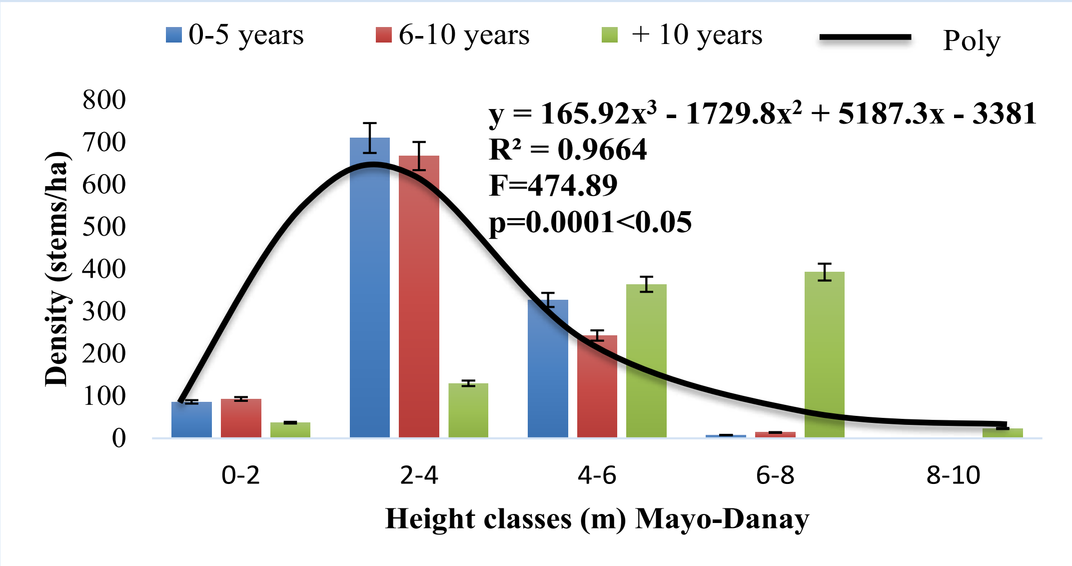
**Correlation between Dendrometric parameter**

**Height/Diametercorrelation**

More height increases, more the diameter increases, so there is a very good correlation between the height and diameter with a pearson correlation coeffecicients ($R^2$) which is 80.30% in Diamaré (Figure 5A), 74.20% in Mayo-Danay (Figure 5B) and 73.30% in Mayo-Tsanaga (Figure 5C). Linear regression equations obtained in this **Figure 5** was calculated from the height and diameter

e-ISSN:2320-0189
p-ISSN:2347-2308



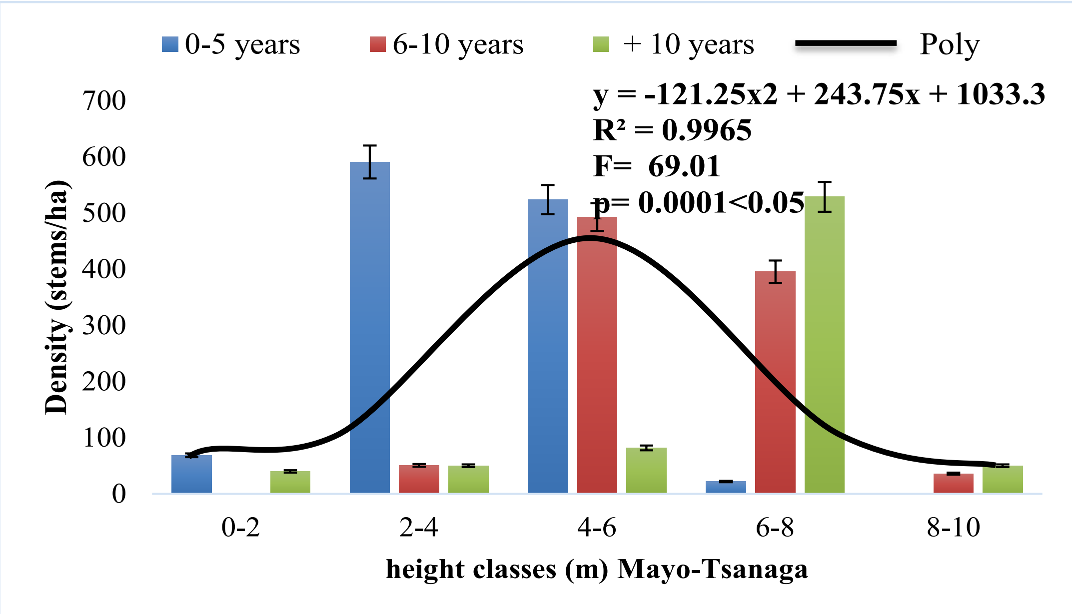




**Figure 3**: Distribution of *M. oleifera* individuals by height class in the different agroecosystems by subdivisions studied: A: Diamaré; B: Mayo-Danay; C: Mayo-Tsanaga.

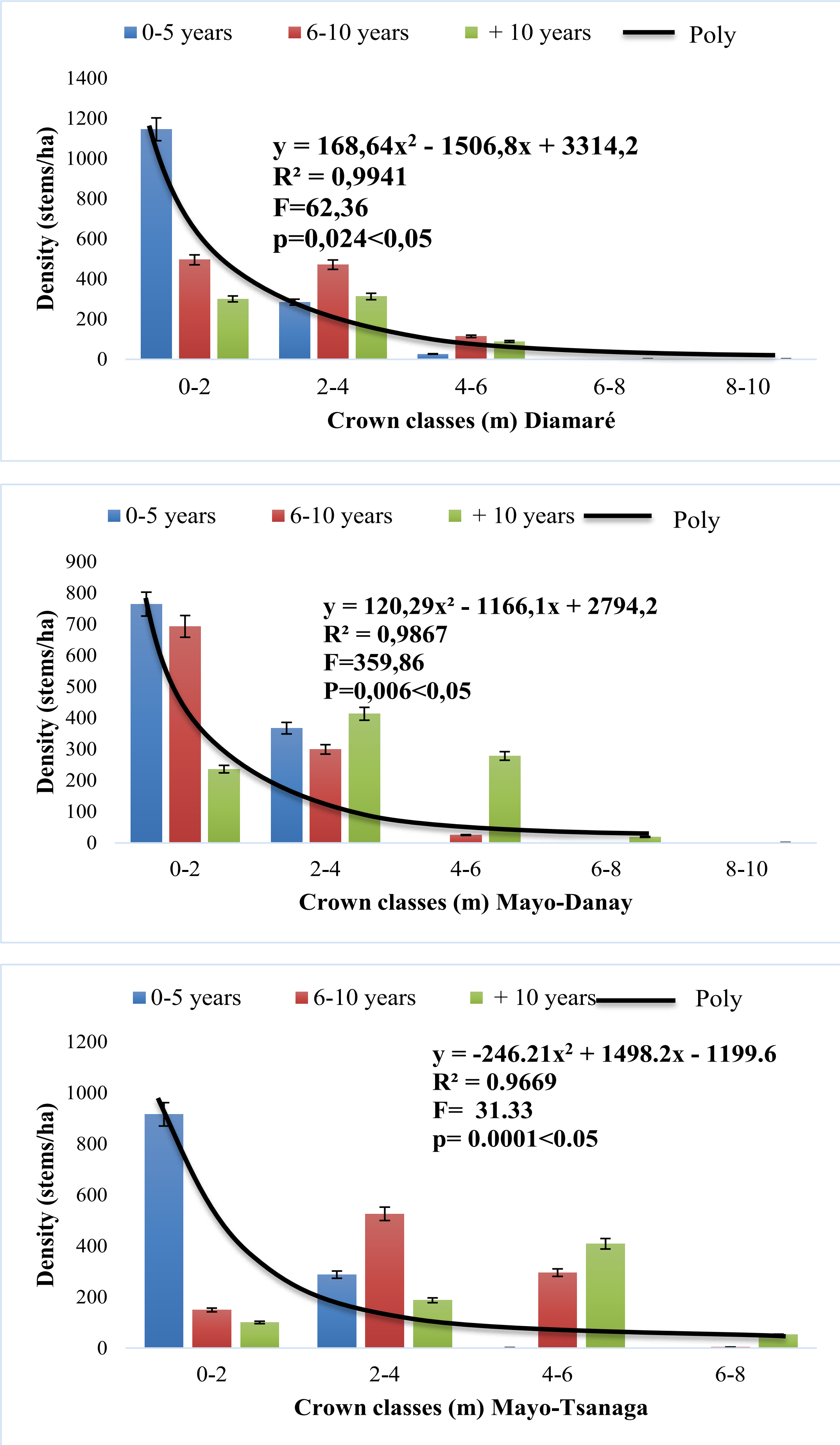



**Figure 4**: Distribution of *M. oleifera* individuals by crown class in the different agroecosystems by subdivisions studied: A: Diamaré; B: Mayo-Danay; C: Mayo-Tsanaga.

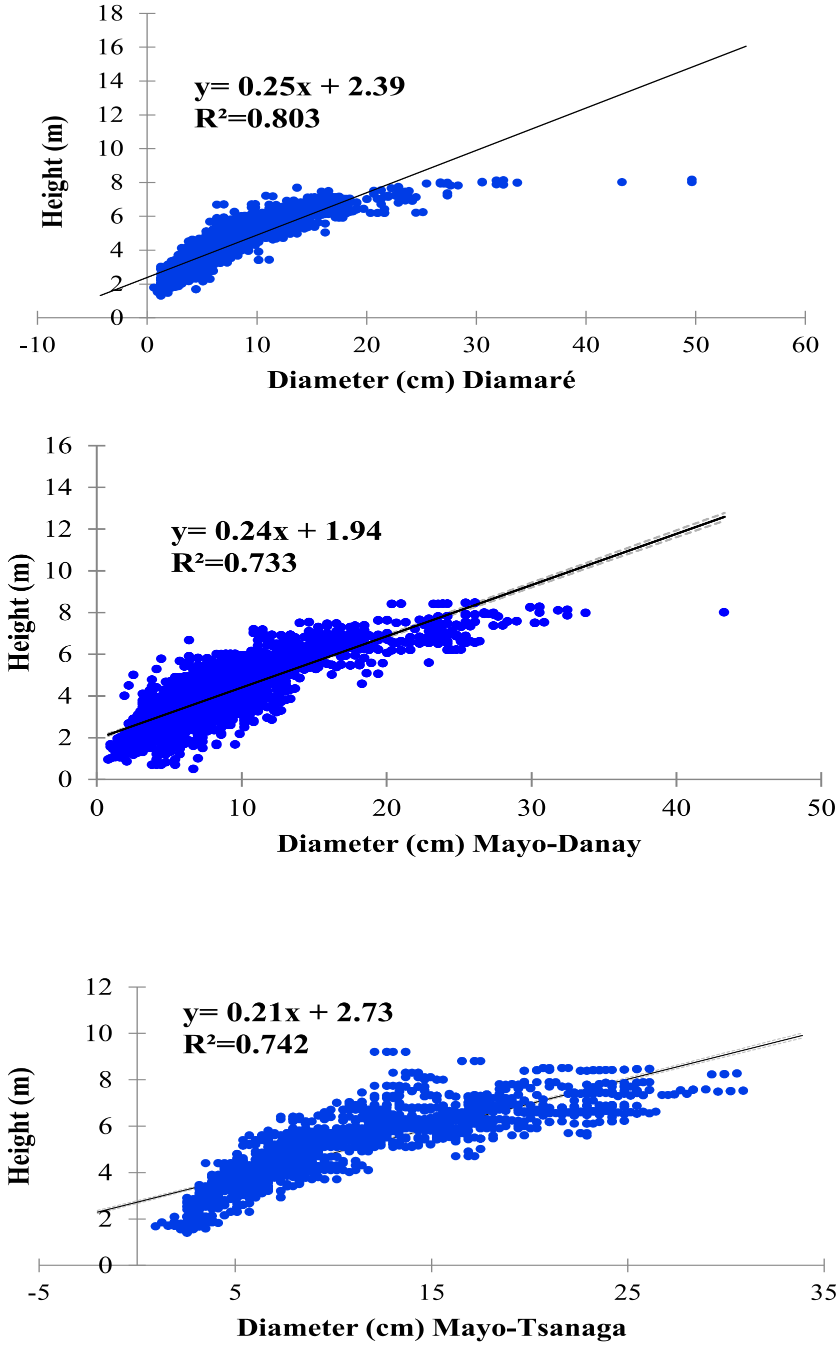



**Figure 5**: Regression curves showing the relationship and the evolution of height growth as an a function of the diameter of *M. oleifera* in agroecosystems as a function of the subdivisions.(A : Diamaré ; B : Mayo-Danay ; C : Mayo-Tsanaga).

and show that there is a significant correlation between these twodendrometric parameters in the Diamaré (F=132.20 and p=0.0001<0.05), Mayo-Danay (F=146.10 and p=0.0001<0.05) and Mayo-Tsanaga (F=84.18 et p=0.0001<0.05).

**Crown/Diametercorrelation**

The allometric relationship between the total crown and the diameter of *M. oleifera* individuals is shown that in **Figure 6** (A ; B ; C). Galton simple regression model expressing the crown and the total diameter is highly significant at the 5% for both Diamaré (F = 168.37 ; P < 0.0001< 0.05), Mayo-Danay (F = 146.10 ; P < 0.0001< 0.05) and Mayo-Tsanaga (F = 206.51 ; P < 0.0001< 0.05). Over the crown is increasing the diameter increases. So there is very good correlation between height and diameter. We deduce that 83.9%; 82.5% and 87.6% of the pearson correlation variation crown *M. oleiferais* explained by the variation in diameter respectively for Diamaré. Mayo-Danay and Mayo-Tsanaga.

**Crown/Height corrélation**

The **Figure 7** show that the simple regression model of Galton expressing the total height and the crown is highly significant at the 5% level both for Diamaré (F = 114.11; P < 0.0001< 0.05),for Mayo-Danay (F = 91.92; P < 0.0001< 0.05) and Mayo-Tsanaga (F = 118.79; P < 0.0001< 0.05). We deduce that 77.9%; 79.3% and 75.8% of the variation in the crown of *M. oleiferais* explained by the variation in height respectiveley forDiamaré, Mayo-Danay and Mayo-Tsanaga.

e-ISSN:2320-0189
p-ISSN:2347-2308

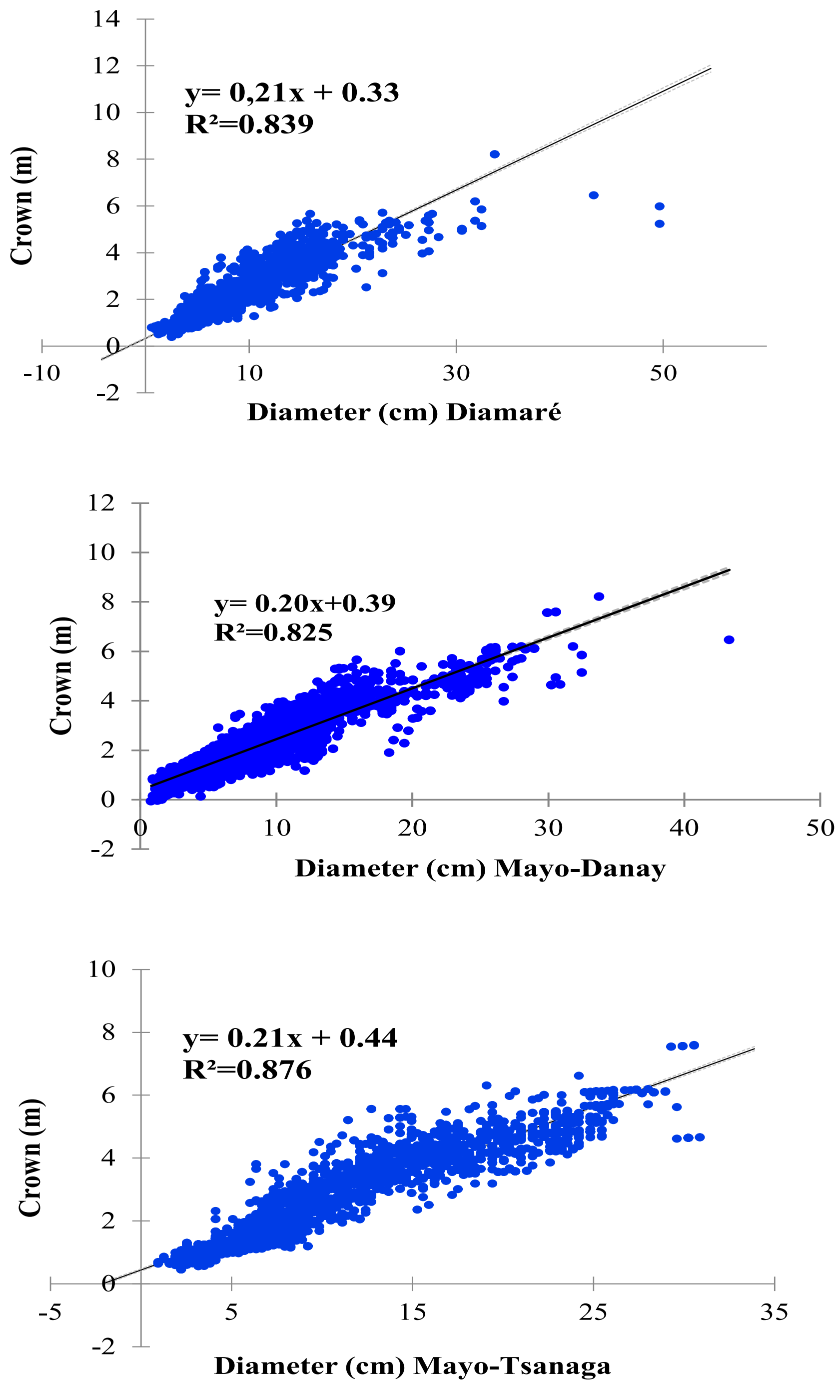
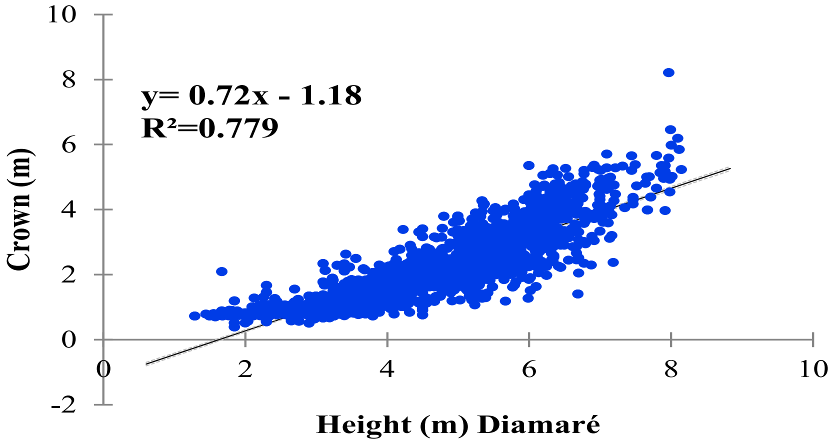



**Figure 6**: Regression curves showing the relationship and the evolution of crown growth as an a function of the diameter of *M. oleifera* in agroecosystems as a function of the subdivisions. (A : Diamaré ; B : Mayo-Danay ; C : Mayo-Tsanaga).



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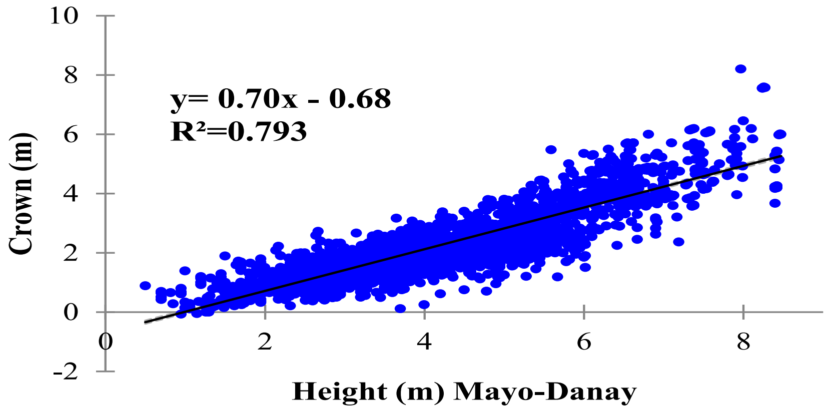


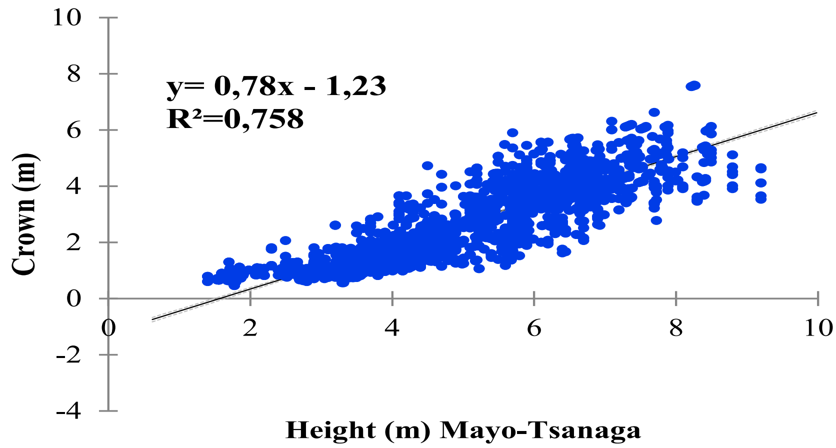


**Figure 7**: Regression curves showing the relationship and the evolution of crown growth as an a function of the height of *M. oleifera* in agroecosystems as a function of the subdivisions. (A : Diamaré ; B : Mayo-Danay ; C : Mayo-Tsanaga).

## DISCUSSION

### Dendrometric Characterizations M. Oleifera Populations

Analysis of population dendrometric parameters of *M. oleiferain* agroecosystems in the Far North Cameroon show that the average diamater. Average height and average crown increases significantly with age in the three subdivisions studied. These three high dendrometric parameters in Mayo-Tsanaga can be explained by the predominance of old trees and the low values observed in Diamaré reflect the predominance of young trees. This observation was noticed on the populations of Pterocarpus erinaceus in Ivory Coast [36]. This difference in value at the level of subdivisions is explained by ecological variabilities namely, the type of soil, the climate and the selective differences in agroforestry production techniques of the plant by farmers guided by commercial opportunities. The *M. oleifera* overall average diameter ranges from5.63 ± 2.74 cm to 17.7 ± 7.43 cm; an average height of between 3.50 ± 0.83 m to 6.21 ± 1.75 m for an average crown of between 1.50 ± 0.75 m to 4.06 ± 1.47 m. The values of the average diameters obtained were close to the values in Chad Burkina Faso and Far North Cameroon [37-40]. The values of the average height are close to those of authors in Chad [41]. Far North Cameroon and Burkina Faso, The values of the average crown are close to the work of authors on the stands of Jartropha curcas in Burkina Faso [38-40].

### Ecologicalstructure of M. oleifera population

The high total density observed in Diamaré (3245 ± 96.35 stems/3ha) and low in Mayo-Tsanaga subdivision(2933 ± 80.31 stems/3ha) could be explained by the fact that farmers do not respect the same system distance between two shafts. The overall density varying between751 ± 19.05 stems/ha and 1457 ± 45.41 stems/ha is close to the works of authors in North Cameroon [42]; but higher than those authors found in the same study area [40-43].

The high basal area observed in the Mayo-Tsanaga subdivision (19.95 ± 0.069 $m^2$/3ha) would reflect the existence of large diameter trees in the plantations while the lowest value observed in the Diamaré subdivision (10.60 ± 0.06 $m^2$/3ha) would translate the existence of trees of small diameters in the fields due to elimination of old trees by the farmers of this subdivision. The basal area varying between1.70 ± 0.02 $m^2$/ha and 10.86 ± 0.009 $m^2$/ha are low compared to the values found in North Cameroun [42], in the same area [43] andin main Benin [32] due to the fact that their studied carried out on trees. This is not the case in our study which is a shrub.

The value of aerial cover on average is all less than 50% in the three subdivisions.reflecting the practice of pruning and coppicing this shrub in the plantations. This anthropogenic pressure is due to the collection of *M. oleifera* leaves by farmers for consumption or marketing combined with the installation of crops. It is more pronounced in the Diamaré subdivision (21.78%) these percentage values are high compared to the work carried out in Niger [44,45].

**Distribution of M. oleifera population in agroecosystems**

The diametric structure of *M. oleifera* population in the different agroecosystems showed a positive asymmetric distribution (right) with dominance of young individuals of small diameter between 5-10 cm. This can be explained by the fact that those responsible for the plantations tend to rejuvenate the species. The fact that the numbers of the diameter class between 5-10 cm are greater than those of the regeneration of the diameter class 0-5 cm probably indicates a recent disturbance which may be of anthropogenic or climatic origin. This may thus be linked to the selective elimination or death of young plants of less vigorous *M. oleifera* by farmers in the plantations. In addition the general distribution of M.oleifera population according to the studied subdivision adjusts to the model of eponential type has been observed in Cameroon [46]. Large diameter individuals (> 25 cm) are rare as in all subdivisions reflects the systematic felling of old plants by peasants [6].

The height structure of the *M. oleifera* population in the three subdivisions presented showed a bell-Shaped distribution dominated by intermediate class individuals (2-4 m in Diamaré and Mayo-Danay subdivisions and 4-6 m in the Mayo-Tsanaga subdivision) indicating a disturbed settlement. This reflects the fact that individuals of large size in shrubs (>6 m) and the small size in *M. oleifera* are subjected to enormous pressure from excessive cutting to harvest the leaves for food or marketting. « Bell » shape has been found by several authors in Benin, Senegal and in Chad [15,47,48].

In addition, the overall distribution of the species crown has an inverted «L» or «J» shape with a predomiance of individuals having a crown of less than 2 m. This could be justified by the fact that it was observed in the field the presence of numerous traces of pruning cut on individuals of large diameters.regularly pruned on the one hand for the harvest of leaves and on the other and in view. The establishment of vegetablecrops. This would strongly influence the radius of the crown. These results were observed on Balanites aegyptiaca stands [2].

**Correlation between dendrometric parameter**

These linear regression analyzes show a close association between the three dendrometric parameters, namely the diameter, the height and the crown of the shrub in the three subdivisions. However, the height and radius of the crown do not follow the same variations as the diameter and the connection is subject to many factors, more particularly stationary and sylvicultural. This is beacause the height and crown do not grow indefinitely with the diameter. The height growth and the radius of the crown of the shrub stabilizes around 8 m, while the diameter may continue to increase. This means that we are dealing with a shrub species rarely reaching 7 m. These results are close to the correlations observed by several authors [49-51].

## CONCLUSION

The present study made it possible to compare the dendrometric and structural parameters of the *M. oleifera* population in agroseco systems of the Far North Cameroon. The results showed that the average diameter, average height, average crown, density, basal area and aerial cover varied by subdivision and by age. This variation observed between the stands is due to the different pedoclimatic conditions namely the nature of soil, topography and climate but also to anthropization (pruning, topping, felling of trees). In agroecosystems, the distribution of the population shows a predominance of individuals of small diameters with a height of between 2-6 m for a crown radius of less than 2 m, reflecting good conservation of this species with high multiple use by farmers in plantations. Protection for the species, it seems important to promote the implementation of inexpensive assisted regeneration techniques in degraded areas and to control anthropogenic pressures that will threaten the survival of the species.

## ACKNOWLEDGEMENTS

The authors thank all the agricultural producers who agreed to participate in this study.

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