

Fine Roots Dynamics in Two Forest Strata of a Semi-Deciduous Forest in Northern Republic of Congo

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Abstract

The belowground biomass is represented by coarse and fine roots. Concentrated in the superficial horizons of the soil, the fine roots play a crucial role in the functioning of a forest ecosystem. However, studies on their dynamics in natural forests are almost non-existent in the Republic of Congo. Here, we estimated the biomass, production, turnover and fine root lifespan of two forest strata of a semi-deciduous forest: the *Gilbertiodendron dewevrei* (De Wild.) J. Léonard forest (GF) and the mixed forest (MF) of land. The in-growth cores method was used to estimate the biomass, production, turnover and lifespan of fine roots. The results of this study revealed that the biomass, production and fine root turnover of the two forest strata studied significantly decreased with increasing soil depth, with an increase in lifespan. The annual fine root biomass of GF ($2284.50 \pm 37.62 \text{ g}\cdot\text{m}^{-2}$ and $1034.61 \pm 14.52 \text{ g}\cdot\text{m}^{-2}$) was slightly lower than that of MF ($2430.07 \pm 40.68 \text{ g}\cdot\text{m}^{-2}$ and $1043.10 \pm 11.75 \text{ g}\cdot\text{m}^{-2}$) in the 0-15 cm and 15-30 cm horizons, respectively. The annual production of fine roots from these latter horizons was respectively $1300.19 \pm 32.17 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ and $539.18 \pm 11.55 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in GF and $1362.24 \pm 39.59 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ and $492.95 \pm 14.38 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in the MF. Root turnover was higher in the GF ($1.68 \pm 0.05 \text{ yr}^{-1}$ and $1.35 \pm 0.03 \text{ yr}^{-1}$) than in the MF ($1.57 \pm 0.05 \text{ yr}^{-1}$ and $1.13 \pm 0.02 \text{ yr}^{-1}$). The lifespan of fine roots increased with the depth of the soil. The difference in fine root dynamics observed between the forest strata studied was influenced by the Evenness index and the above-ground biomass.

Keywords

Republic of Congo, Forest Strata, Biomass, Fine Root Production, Turnover

1. Introduction

Each forest ecosystem has five carbon pools: above-ground and below-ground biomass, coarse woody debris, litter and soil. However, the estimates of biomass, and therefore carbon, carried out in recent years have focused more on above-ground biomass (Baishya et al., 2009; Alves et al., 2010; Makana et al., 2011; Lewis et al., 2013; Slik et al., 2013; Duchesne et al., 2016). Although some studies have taken into account two to three carbon pools (Tang et al., 2012; Ekoungoulou et al., 2015; Doetterl et al., 2015; Bocko et al., 2017), those which concern the whole are almost non-existent and we will only mention the work of Ngo et al. (2013). As mentioned by Suarez et al. (2019), the tropical zone requires a lot of study of the variation of biomass, and therefore of carbon.

Belowground biomass is represented by coarse (diameter > 2 mm) and fine (diameter \leq 2 mm) (Brechet, 2009; Yunusa et al., 2012; Wang et al., 2018). Concentrated in the superficial horizons (0 - 30 cm) of the soil (Christina et al., 2011; Defrenet, 2012; Zhiyanski, 2014; Cardinael et al 2015; Du et al., 2019) the fine roots play a crucial role in the functioning of a forest ecosystem. They are involved in the absorption of mineral elements and water (Tobner et al., 2013; Meng et al., 2018), in the accumulation of organic matter in the soil (Luizao et al., 1992) and in the flow of mineral elements (Liu et al., 2018; Du et al., 2019). Their net primary production which oscillates between 21% and 67% (Pausch & Kuzyakov, 2018) and their turnover play a key function in the regulation of the carbon flux of forest ecosystems (Peng et al., 2017). Despite their revealed importance in the functioning of the forest ecosystem, the dynamics of fine roots and their influence on the carbon cycle of belowground biomass are little studied (Persch et al., 2015).

In the Republic of Congo, studies on the functioning of forest ecosystems have more concerned the litter pool. The thickness of the litter layer, the production, the rate of decomposition and the fallout of the litter on the ground (Schwartz, 1993; Loumeto, 2002; Bernhard-Reversat & Loumeto, 2002) have helped to understand the functioning of certain forest ecosystems in the south of the country. At present, only three studies have focused on the below-ground biomass pool through the study of fine roots in Eucalyptus plantations in the south of the country (Laclau, 2001; Thongo-M'bou, 2008) and in forest types of the Teke Plateau (Ifo et al., 2015). No specific study has been conducted in the northern forest of the Republic of Congo.

In this study, we evaluated the fine roots dynamics in two forest strata (*Gilbertiodendron dewevrei* (De Wild.) J. Léonard forest and mixed forest of land) of low and medium altitude semi-deciduous forest of Likouala department in northern Republic of Congo. The assessment of this dynamic focused on the estimation of biomass, production, turnover and the lifespan of fine roots.

2. Materials and Methods.

2.1. Study Area

This study was conducted in the north of the Republic of Congo in the Loun-

doungou—Toukoulaka forest management unit (**Figure 1**). Located in Dongou district of Likouala department, the average annual temperature and rainfall were 25°C and 1600 mm respectively (ANAC, 2018). The soils were relatively rich on a substrate of quartzite (Freycon, 2014) and ferralitic types. The semi-deciduous forest that characterised the study area presented two main forest types: mixed forests of dry land and mono-dominant forests of *Gilbertiodendron dewevrei* (Gillet, 2006). The relief was practically flat, with an altitude varying between 350 and 400 meters.

2.2. Study Device

The study device of the present study consisted of three (03) non-adjoining hectares, each spaced 20 m apart, subdivided into twenty-five (25) plots of 400 m². Five (05) fine root collection points were selected for five (05) plots of each study plot. That is a total of seventy-five (75) points for the fifteen (15) sample plots (**Figure 2**). The five (5) collection points selected for each plot were disposed as follows:

- Four (4) collection points located every one meter from the ends of the plot along the diagonals;

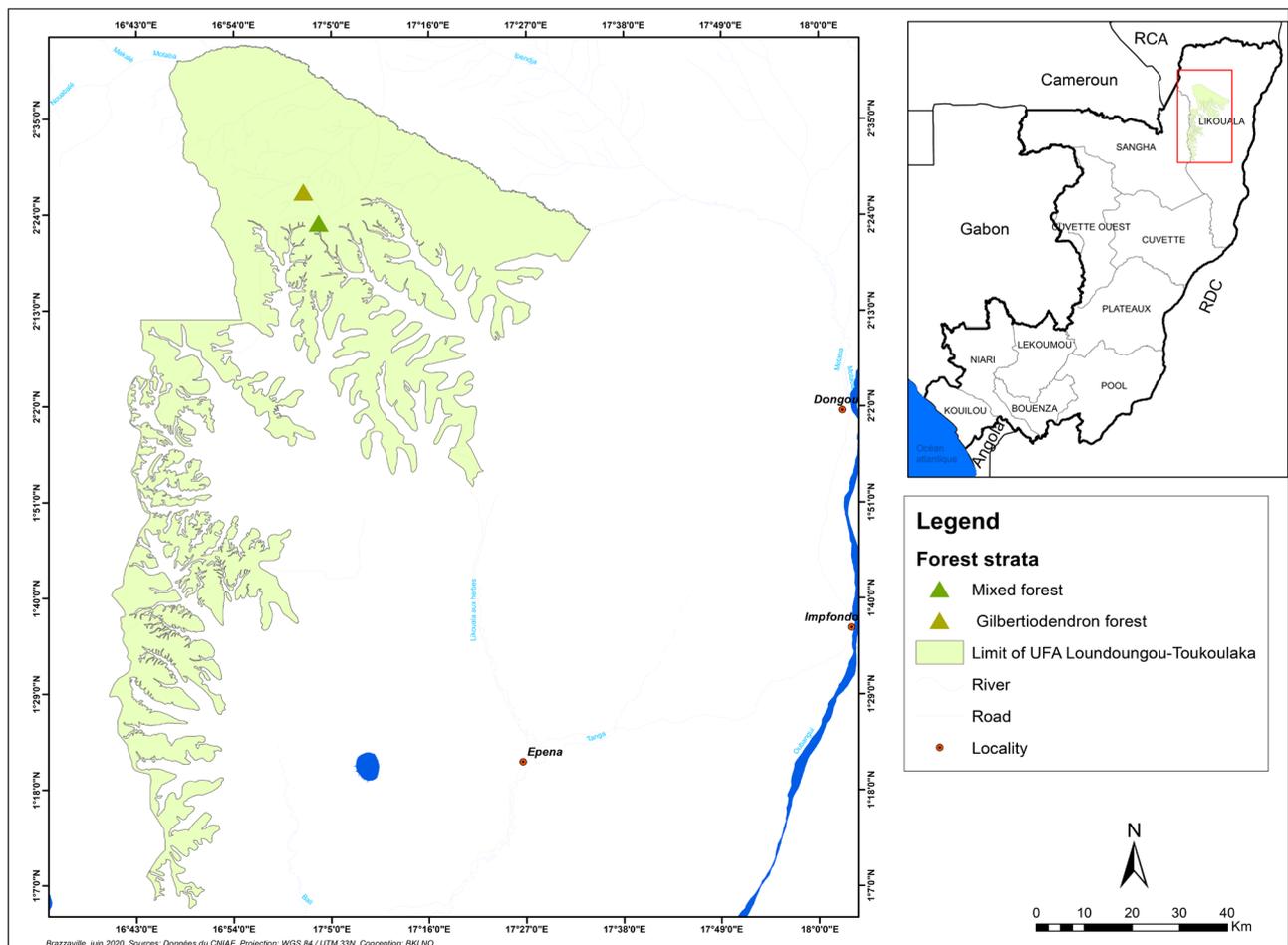


Figure 1. Location of study area.

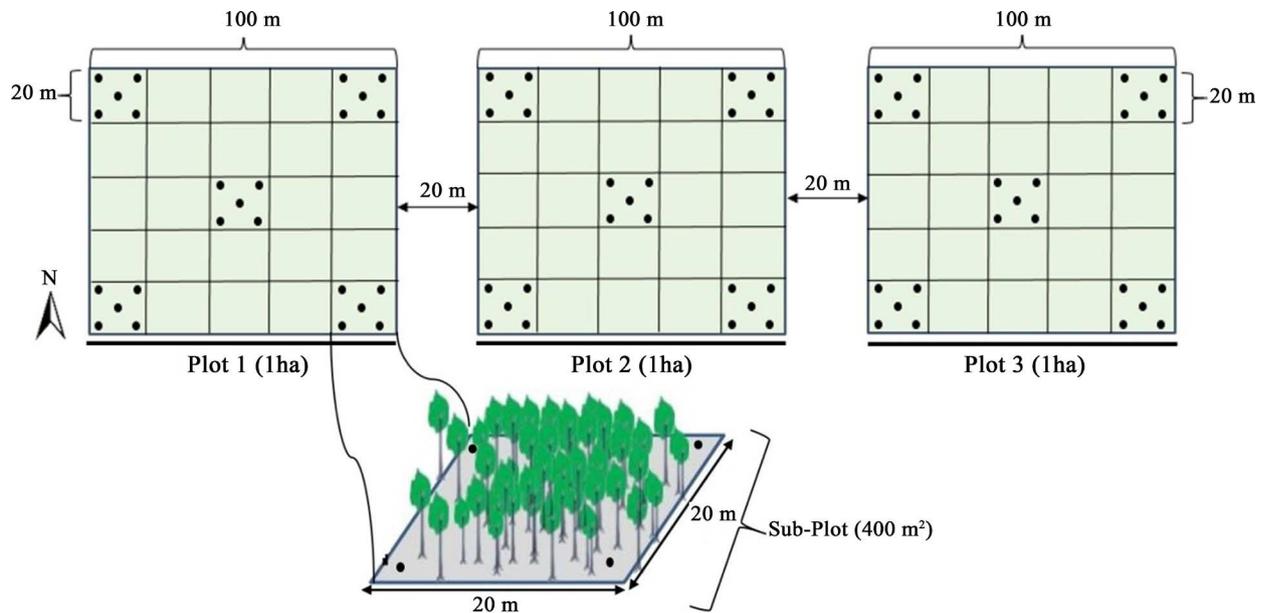


Figure 2. Study device of these the two forest strata.

Table 1. Floristic and structural characteristics of the two forest strata studied.

Strata	Plots	AGB (t·ha ⁻¹)	BA (m ² ·ha ⁻¹)	Stem·ha ⁻¹	<i>H'</i>	<i>H</i> _{max}	Evenness
GF	Plot 1	393.19	25.05	349.00	0.73	1.53	0.47
	Plot 2	503.81	28.92	293.00	1.01	1.59	0.63
	Plot 3	531.26	29.84	289.00	0.96	1.64	0.59
	Mean	476.09 ± 42.19	27.94 ± 1.45	310.33 ± 19.37	0.90 ± 0.09	1.59 ± 0.03	0.56 ± 0.05
MF	Plot 1	345.94	27.21	530.00	1.76	2.00	0.88
	Plot 2	344.05	25.51	379.00	1.67	2.00	0.84
	Plot 3	457.78	30.70	395.00	1.77	1.92	0.92
	Mean	382.59 ± 37.60	27.81 ± 1.53	434.67 ± 47.89	1.74 ± 0.03	1.97 ± 0.03	0.88 ± 0.02

AGB: Aboveground biomass; *H'*: Shannon Index; *H*_{max}: Maximum diversity; GF: *Gilbertiodendron dewevrei* forest strata; MF: Mixed forest strata; Evenness: regularity index; BA: Basal area.

- One (1) collection point located in the center of the fine root collection plot.
This study device was placed in two forest strata 7.3 km apart: the mixed forest, characterized by a complex structure, great plant diversity and the single-dominant forest of *Gilbertiodendron dewevrei* (Gillet, 2006). The floristic and structural characteristics of these two forest strata were presented in **Table 1**.

2.3. Fine Roots Biomass

A harvest of fine roots was carried out in November 2016, February 2017, August 2017 and in February 2018, using a root auger (8 cm in diameter) in two forest strata: the *Gilbertiodendron dewevrei* forest and the mixed forest of land. Only the depth of 30 cm from the ground was used for this study (Brassard et al.,

2013; Liu et al., 2018; Du et al., 2019). In each forest strata, a total of 150 soil samples at a rate of 75 samples per horizon (0 - 15 cm and 15 - 30 cm) were taken on each occasion. Visual inspection helped to distinguish fine living roots from fine dead roots (Vogt & Person, 1991; Liu et al., 2018):

- Fine living root: clear color, firm, intact and resilient;
- Fine dead root: brown or black color, tender and non-resilient.

Each fine living root and having a diameter less than or equal to 2 mm (measurement carried out using a caliper) was put in a plastic bag, then brought to the laboratory to be dried at a temperature of 70°C and weighed until a constant dry mass is obtained (Liu et al., 2018; Du et al., 2019). The biomass of fine roots was estimated from the formula presented by Ifo et al. (2015):

$$B_{fr} \left(g \cdot m^{-2} \right) = \frac{\text{Fine root dry mass (g)}}{\text{Size of area (m}^2\text{)}} \quad (1)$$

where, B_{fr} is the biomass of fine roots expressed in $g \cdot m^{-2}$.

2.4. Fine Roots Production

The ingrowth cores method was used to estimate the production of fine roots of the two forest strata studied (Vogt et al., 1998; Thongo-M'bou et al., 2008; Brechet, 2009; Ifo et al., 2015). The recolonisation cores were taken three months (February 2017 at time t_1), nine months (August 2017 at time t_2) and fifteen months (February 2018 at time t_3) after the harvest used to estimate the initial fine roots biomass (November 2016 at time t_0). The fine roots were treated in situ and in the laboratory exactly as described in the section on estimating the biomass of fine roots. Root production was considered to be the difference in biomass obtained between the third and ninth month, all divided by the elapsed period (Hendricks et al., 2006; Thongo-M'bou et al., 2008; Brechet, 2009).

2.5. Fine Roots Turnover and Lifespan

The turnover of fine roots was obtained by making the ratio of their production to the initial biomass (Burke & Raynal, 1994; Brechet, 2009).

$$T_{fr} = \frac{\text{Fine root production}}{\text{Initial Biomass}} \quad (2)$$

where, T_{fr} is the turnover of fine roots

The lifespan of fine roots (L_{fr}) was deduced from the inverse of root turnover, then expressed in years (Thongo-M'bou et al., 2008).

$$L_{fr} = \frac{1}{\text{Fine roots Turnover}} \quad (3)$$

2.6. Data Analysis

The biomass of fine roots was calculated for each core and an average value of the seventy-five core samples taken at each horizon (0 - 15 cm and 15 - 30 cm) was obtained after each sample in the two strata studied. The annual fine root

biomass for each horizon was obtained after summing the three average biomass values found in the period February 2017 to February 2018. Each average biomass value was accompanied by a standard error. The means of biomass, production, turnover and lifespan of the fine roots of the two forest strata were compared by using a one-way analysis of variance (ANOVA) and Tukey's Honestly Significant Difference test.

3. Results

3.1. Fine Root Biomass

The initial fine root biomass of the studied horizons was significantly ($p < 0.05$) different between the *Gilbertiodendron dewevreii* forest (GF) strata and the mixed forest (MF) strata (Figure 3). The initial fine root biomass averages were $784.95 \pm 17.09 \text{ g}\cdot\text{m}^{-2}$ and $865.71 \pm 15.45 \text{ g}\cdot\text{m}^{-2}$ in the 0 - 15 cm horizon; then $393.79 \pm 3.68 \text{ g}\cdot\text{m}^{-2}$ and $431.16 \pm 6.26 \text{ g}\cdot\text{m}^{-2}$ in the 15 - 30 cm horizon (respectively, for the GF strata and the MF strata).

The amounts of total annual biomass (0 - 30 cm) of fine roots were not significantly ($p\text{-value} > 0.05$) different between the two forest strata studied (Figure 4(a)). However, highly significant differences ($p\text{-value} < 0.001$) were observed between the biomass of the 0 - 15 cm horizon and that of the 15 - 30 cm horizon in each of the forest strata studied (Figure 4(b)). The amount of the

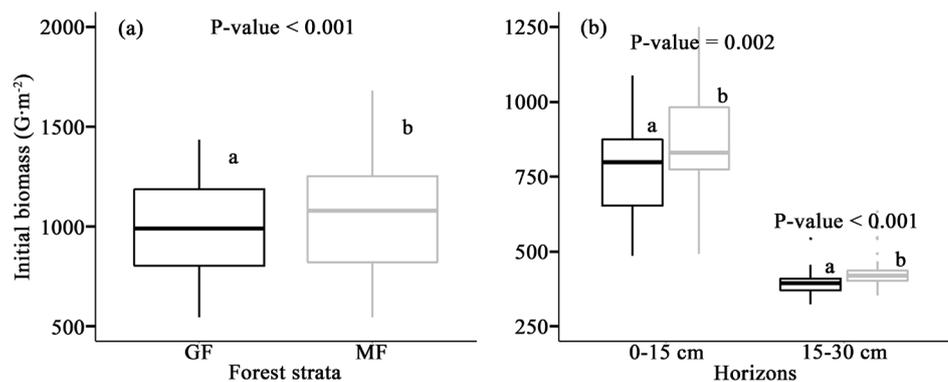


Figure 3. Variation of initial fine root biomass by strata and horizons.

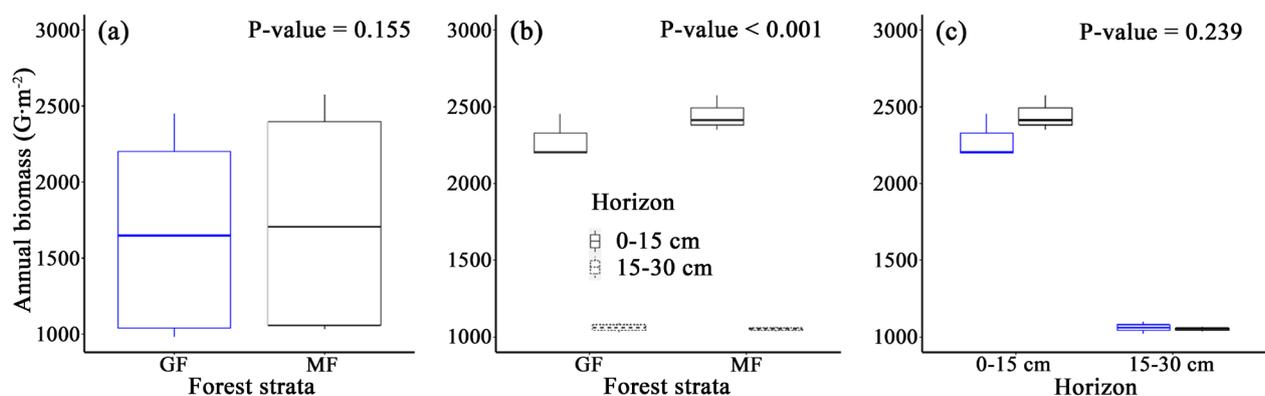


Figure 4. Variation of annual fine root biomass by strata and horizons.

annual biomass was $2284.50 \pm 37.62 \text{ g}\cdot\text{m}^{-2}$ and $1034.61 \pm 14.52 \text{ g}\cdot\text{m}^{-2}$ respectively in the 0 - 15 cm and 15 - 30 cm horizons in the GF strata; then $2430.07 \pm 40.68 \text{ g}\cdot\text{m}^{-2}$ and $1043.10 \pm 11.75 \text{ g}\cdot\text{m}^{-2}$ respectively in the 0 - 15 cm and 15 - 30 cm horizons in the MF strata. Although the biomass amounts for the 0 - 15 cm and 15 - 30 cm horizons are slightly higher in the mixed forest strata, the variance analysis did not reveal significant differences between the two forest strata (Figure 4(c)).

3.2. Fine Roots Production

The annual average production of fine roots from the 0 - 15 cm horizon was $1300.19 \pm 32.17 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in the *Gilbertiodendron dewevreii* forest (GF) strata and $1362.24 \pm 39.59 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in the mixed forest (MF) strata. In the 15 - 30 cm horizon, it was $539.18 \pm 11.55 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in the GF strata and $492.95 \pm 14.38 \text{ g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in the MF strata. The annual average production of fine roots of the considered integral profile (0 - 30 cm) did not show any significant difference ($p > 0.05$) between the two forest strata studied (Figure 5(a)). However, a significant difference was observed between the annual production of fine roots of the two forest strata in the horizon 15 - 30 cm on the other hand (Figure 5(b)).

3.3. Turnover and the Lifespan of Fine Roots

The mean turnover of fine roots obtained in the *Gilbertiodendron dewevrei* forest (GF) strata was higher than that of the mixed forest (MF) strata (Table 2). The turnover of fine roots decreased with soil depth in the two forest strata studied (Table 2).

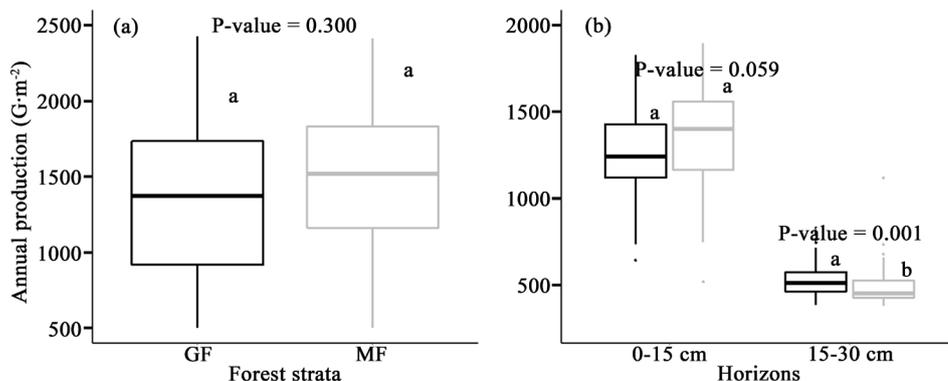


Figure 5. Variations in the production of fine roots between strata and in the two horizons.

Table 2. Average value of fine root turnover for the horizons studied (0 - 15 cm, 15 - 30 cm and 0 - 30 cm) in the two forest strata.

Forest strata	Turnover (yr ⁻¹)			Lifespan (yr ⁻¹)	
	0 - 15 cm	15 - 30 cm	0 - 30 cm	0 - 15 cm	15 - 30 cm
GF	1.68 ± 0.05	1.35 ± 0.03	0.78 ± 0.02	0.64 ± 0.02	0.76 ± 0.01
MF	1.57 ± 0.05	1.13 ± 0.02	0.71 ± 0.02	0.42 ± 0.25	0.93 ± 0.03

The average lifespan of fine roots increased with soil depth in the two forest types studied (**Table 2**). It was higher in the 0 - 15 horizon in the GF. However, the MF showed a higher average lifespan in the 15 - 30 cm horizon (**Table 2**).

4. Discussion

4.1. Fine Root Biomass

The results of the present study revealed that the annual total biomass of fine roots of the superficial horizon (0 - 15 cm) represented more than 68% of the biomass of the soil profile studied (0 - 30 cm) and was 2.21 and 2.33 times greater than that of the 15 - 30 cm horizon in *Gilbertiodendron dewevrei* forest (GF) strata and mixed forest (MF) strata, respectively. This decrease in fine root biomass with increasing soil depth has been observed by many authors in other tropical forest ecosystems (Valverde-Barrantes et al., 2007; Brechet, 2009; Leao et al.; 2014; Ifo et al., 2015; Du et al., 2019). And it could be related to the difference in water and nutrient contents in different soil layers (Hansson et al., 2013; Wang et al., 2016; Shu et al., 2018).

Although the comparison of annual fine root biomass averages showed no significant difference between the two forest strata studied, that of the MF was greater. This finding was highlighted by Yunusa et al. (2012) and Ma and Chen (2016). It should be noted that the amount of fine root biomass obtained in the GF (3319.11 g·m⁻²) and in MF (3473.17 g·m⁻²) in the horizon 0 - 30 cm were close to that found by Brechet (2009) in the same horizon of a humid tropical forest (2925 ± 800 g·m⁻²) in French Guyana. They also fell within the range of values found by Luizao et al. (1992) in the first 20 cm of the soil of a tropical forest (3500 to 5300 g·m⁻²) in Brazil. However, they were more than three times greater than that found by Ifo et al. (2015) in the 0 - 40 cm horizon in the gallery forest of the Teke Plateau (940 g·m⁻²) of the Republic of Congo and more than twice that found by Yunusa et al. (2012) in a multi-species forest (1230 g·m⁻²) in Australia. Several factors can justify this spatial variability in fine root biomass observed between the data of this study and those of the above authors. The influence of forest structure (Ifo et al., 2015), floristic composition (Ma & Chen, 2016) and above-ground biomass of the ecosystem (Liu et al., 2018) on the amount of the biomass of fine roots in the tropics has been highlighted.

4.2. Fine Root Production

Decreasing with the depth of the soil, the average annual production of fine roots of the two forest strata studied were in the range of the values found in the tropics by Priess et al. (1999) in the western Amazon (990 - 2090 g·m⁻²·yr⁻¹) and Roderstein et al. (2005) in southern Ecuador (510 - 2080 g·m⁻²·yr⁻¹). In addition, they were slightly higher than that found by Brechet (2009) in Paracou in French Guyana (605 ± 278 g·m⁻²·yr⁻¹), Ifo et al. (2015) in a gallery forest (460 g·m⁻²·yr⁻¹) in the Republic of Congo and by Silver et al. (2005) in a tropical forest (229 ± 35 g·m⁻²·yr⁻¹) in Brazil. This variability in the production of fine roots could be ex-

plained by the evenness index (Brassard et al., 2013), the forest structure (Ifo et al., 2015), the above-ground biomass (Liu et al., 2018), the sampling period and the calculation method (Katayama et al., 2019). For example, the basal area and the above-ground biomass averages of the two forest strata studied (Table 1) were much higher than that obtained by Ifo et al. (2015) in a gallery forest of the Teke Plateau in the Republic of Congo.

4.3. Turnover and Lifespan

The values of the average turnover of the fine roots of the two forest strata studied decreased with the depth of the soil. This observation was also made by Liu et al. (2018) in three forest types in the eastern subalpine region of the Qinghai-Tibetan Plateau in China and by Cordeiro et al. (2020) in a central Amazon rainforest. However, Ifo et al. (2015) observed an increase in the turnover of fine roots with soil depth in a gallery forest of the Teke Plateau of the Republic of Congo. This finding noted the need to conduct studies of the dynamics of fine roots in the different forest types of the Congo Basin forests, to improve knowledge of their functioning.

Although the analysis of variance could not reveal a significant difference between the means of turnover in the 0 - 30 cm horizon of the two forest strata studied, that of the GF (0.78 ± 0.02) was slightly higher than that of the MF (0.71 ± 0.02). This result showed that the turnover of fine roots decreases with the increase in the evenness index and the floristic richness of a forest ecosystem. This observation was supported by some results obtained in some monospecific forests such as *Eucalyptus* and *Terminalia superba* plantations (Schroth & Zech, 1995; Jourdan et al., 2008; Thongo-M'bou et al., 2008; Assefa et al., 2017) and multispecies forests (Silver et al., 2005; Brechet, 2009; Ifo et al., 2015; Assefa et al., 2017). But it was contradictory to the observation made by Liu et al. (2018) when comparing the turnover of fine roots from two mixed forests with a *Picea asperata* forest. As for the lifespan of the fine roots of the two forest strata studied, it increased with increasing soil depth. This observation was simply a reflection of the turnover rate of fine roots, which was high in the superficial horizon (0 - 15 cm). Thus, revealing a difference in the functioning of the two forest strata in the superficial soil horizons.

5. Conclusion

The present study revealed that the biomass, production and fine root turnover of the two forest strata studied decreased with increasing soil depth. The density of stems per hectare and the evenness index explained the high averages of biomass and the production of fine roots observed in the mixed forest strata compared to those of the *Gilbertiodendron dewevrei* forest strata. It was shown in this study that the turnover of fine roots tended to decrease with the increase in the evenness index and the floristic richness of a forest ecosystem. In short, knowledge on the functioning of the forest strata of a semi-deciduous forest of

low and medium altitude was made available through a study of the dynamics of fine roots.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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