Spatio-Temporal Variations of the Accumulated Litter on the Ground in the Loundoungou-Toukoulaka Forest Management Unit of Congo

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Abstract: ***The functioning of tropical rainforests in the Congo Basin is still poorly understood, although their role in climate regulation has been reported for several years. The litter compartment, because of its important role in the transfer of nutrients and organic matter between the vegetation and the soil, contributes to the balance of these forest ecosystems and to the translation of the functioning of these ecosystems. However, there is little information on the forests of Northern Congo. This work focuses on the litter accumulated on the ground in order to contribute to the improvement of the knowledge of the functioning of the forests of North-Congo in general and those of the Loundoungou-Toukoulaka Forest Management Unit (FMU) in particular. Two forest types were chosen: a monodominant Gilbertiodendron dewevrei forest (GF) and a mixed forest (MF). The experimental set-up consisted of three square plots of one hectare each, subdivided into 25 plots of which 5 were selected for sampling. The method used was quarterly sampling of litter from 50 cm x 50 cm areas. The results obtained showed more litter accumulation in the G. dewevrei forest than in the mixed forest, varying respectively from 36.96 t/ha/yr to 25.12 t/ha/yr. These amounts are higher in the wet season than in the dry season for all litter components. However, there was no seasonal variation in woody organs. A weak correlation was observed between rainfall and the different litter components, except for GF reproductive organs.***

Keywords: Ground litter, variations, rainfall, north Congo forest

1.Introduction

The tropical rainforests of the Congo Basin have a surface area of 205 million hectares [1], the largest tropical forest in the world after the Amazon Basin forest. Their functioning is still poorly understood, although their role in climate regulation has been reported for several years [2]. While they are important reservoirs of biodiversity [3], [4] and are spread over six countries including the Congo with a forest area of 23.517.000 hectares or 69% of the national territory [5]. In this country, the forest areas are subdivided into 17 Forest Management Unit (FMU), including Loundoungou-Toukoulaka located in the north of the Republic of Congo and managed by the company CIB-OLAM. This FMU has a management and exploitation plan that should be accompanied by research studies on the functioning of these forests [6].

Several studies have shown the importance of the litter compartment in the functioning of forest ecosystems [6], [7], [8]. Indeed, litter contributes to the maintenance of the balance of forests [9]. Through its decomposition, it allows us to understand the cycle of mineral elements [10] between different reservoirs. The decomposition of litter in situ plays a crucial role in tropical forest ecosystems where their vegetation depends on the recycling of nutrients contained in plant detritus [11] because the soils are poor in mineral elements [12]. The biogenic elements that litter releases are necessary for the regeneration of vegetation [13]: 70-90% of the necessary nutrients are provided each year for plant growth [14]. The litter accumulated on the ground, as the litterfall and the decomposition, undergoes the action of the climatic factors (Precipitation) and, varies with the type of formation [15]. Moreover, Devineau [16] underlines that the distribution of this litter evolves with the seasons.

All these functions justify the interest that many researchers have in studying litter. In southern Congo, litter accumulated on the ground has already been the subject of numerous studies [6], [17], [18], [19]. But in northern Congo, apart from the experiments conducted by Walker et al. [20], the bibliography remains limited. In addition, the Loundoungou-Toukoulaka FMU has benefited from research studies in the framework of the Dynaf for and PREREDD+ projects. However, neither of these two projects have included a study on litter.

In the perspective of a better mastery of the functioning of the forests of northern Congo in general and those of the FMU in particular, it would therefore be essential to know ecological tools, notably the functioning of the forest, in order to compensate for this lack of important data in the accompaniment of forestry missions with a view to the management of these forests. This is the objective of this work through the study of the storage of litter on the ground in two types of forests and the monthly variations of this litter in relation to climatic parameters (rainfall).

2.Materials and Methods

2.1 Study area

This study took place from March 2017 to December 2018, in the north of the Republic of Congo in the Loundoungou-Toukoulaka forest management unit (Fig.1), located in

Dongou in the Likouala department. The topography was a relatively homogeneous plateau with an altitude ranging from 350 to 400 meters [21]. The soils were of the ferralitic type, sandy-clayey brown-red in color, very acidic and highly desaturated [22]. The climate was equatorial with an average annual rainfall of 1669 mm at the Impfondo meteorological station (located 90 km from the FMU) and an average annual temperature of 25.8°C (Fig.2). Of the four (04) major vegetation types characterizing the FMU [23], two were selected for this study: the *Gilbertiodendron dewevrei* Monodominant Forest (GF) and the Mixed Forest (MF). The two forests are approximately 13km apart and have a basal area of 28.60 (±1.85) and 27.04 (±0.69) for the FG and FM respectively.

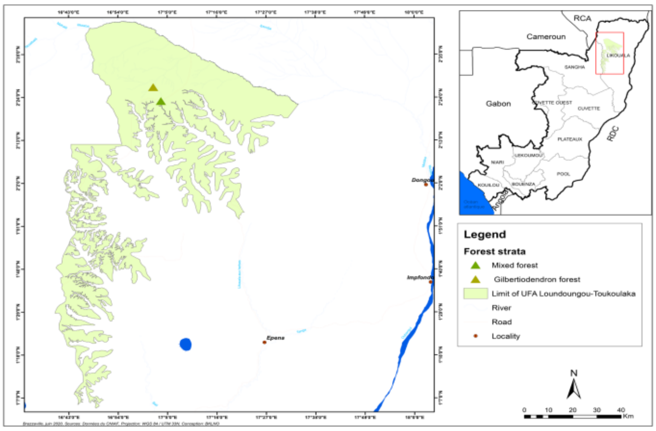

Figure1: location of study area [24]

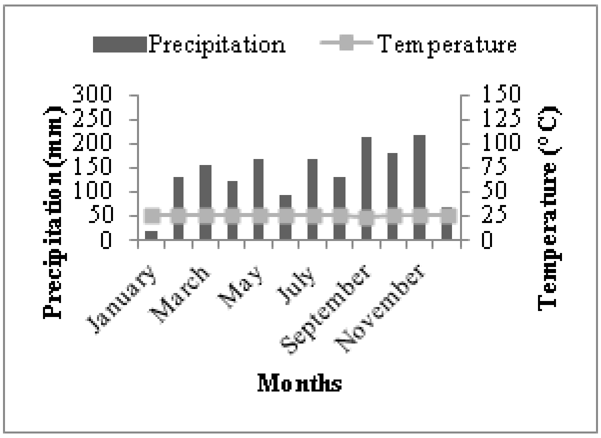

Figure 2: Impfondo umbrothermal diagram period 2014-2018 (data collected from the National Civil Aviation Agency in 2019)

2.2 Sampling device

An identical set-up in both forests was installed. The design consisted of a transect 340 m long and 100 m wide, covering an area of 34, 000 m². The transect was subdivided into three plots of one hectare each, which were separated by a 20 m buffer zone. Within these plots, 25 subplots of 20 m x 20 m were delineated. Five were selected for collection of accumulated litter on the ground (Fig.3).

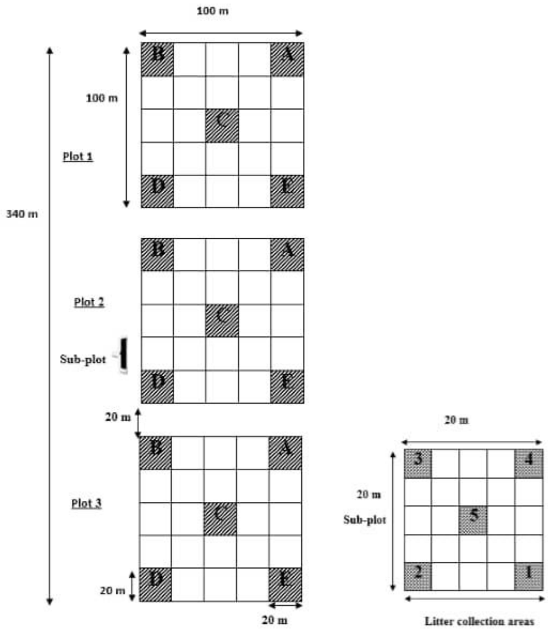

Figure 3: Study device

2.3 Collection of litter

The amount of litter accumulated on the ground was determined by taking quarterly samples of all plant debris accumulated on the ground from five (05) 50 cm x 50 cm areas in each plot, one sample from each sub-plot. In the laboratory, these plants were separated manually and then using a sieve. These are:

- Recognizable plants: leaves, woody organs (bark, branches and twigs), reproductive organs (flowers, fruits and seeds) [6], [16];
- Unrecognizable plants of different sizes: debris ≥ 4mm, 2-4 mm and 0.5-2mm [6], [25].

All components obtained after sorting were oven-dried at 70°C until a constant weight was obtained.

2.4 Data analysis

The data obtained were entered using EXCEL 2013 software. The interpretation of the results obtained was carried out using statistical tests and analysis of variance at the 5% significance level, with the R software version 4.1.1. The comparisons of the means for the different variables studied were obtained by a two-way ANOVA and by the Welch's t. The Welch's t was used to test whether the means of the litter amounts of the different forests were significantly different. These ANOVA were conducted to test the effect of forest type, time period and their interaction for each litter component. Spearman's test was also conducted to test the correlation between precipitation and accumulated litter on soil. Precipitation data were pooled quarterly.

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3.Results

3.1 Amount of litter

Total amounts of litter on the ground in the GF were higher than in the MF (Table 1; t = 5.21; P < 0.0001). In general, the amounts of debris were significantly higher than those of recognizable organs in both forests (Table 1).

When considering recognizable organs, they were higher in the GF than in the MF (Table 1; t = 3.19, P < 0.005). The amounts of leaves and reproductive organs on the ground were significantly higher in the GF than in the MF (t = 10.17, P < 0.0001 and t = 4.50, P < 0.0001; respectively). But they were not significantly different for woody organs (t = 0.15, P = 0.884). The proportions of woody organs were higher than other organs, 15.39% to 15.04% of the total weight, in GF and MF, respectively. They were followed by leaves (9.04% for GF and 4.11% for MF). The percentages of reproductive organs were lowest of all components studied, 4.42% and 1.03% in GF and MF respectively.

With respect to debris, it was also higher in the GF than in the MF (Table 1; t = 4.52, P < 0.0001). Debris ≥ 4 mm was the most represented. They were significantly higher in the GF than in the MF (t = 5.42, P < 0.0001). Debris 2-4 mm was also higher in the GF than in the MF (t = 2.37, p-value = 0.022). In contrast, debris 0.5-2mm was similar between the two forests (t = 0.87, P = 0.389).

Table 1: Average annual amount (t/ha) of litter accumulated on the ground in the two forests

Components	GF	MF
Leaves	3.34 ± 0.75	1.52 ± 0.62
Woody organs	5.69 ± 3.96	5.56 ± 2.65
Reproductive organs	1.64 ± 1.42	0.38 ± 0.57
Sub-total	**10.67 ± 4.53**	**7.46 ± 3.09**
Debris ≥ 4mm	17.78 ± 5.70	10.88 ± 3.94
Debris 2-4mm	6.09 ± 2.46	4.87 ± 1.36
Debris 0, 5-2mm	2.42 ± 1.47	1.91 ± 2.78
Sub-total debris	**26.29 ± 8.60**	**17.66 ± 5.84**
Total	**36.96 ± 10.23**	**25.12 ± 6.95**

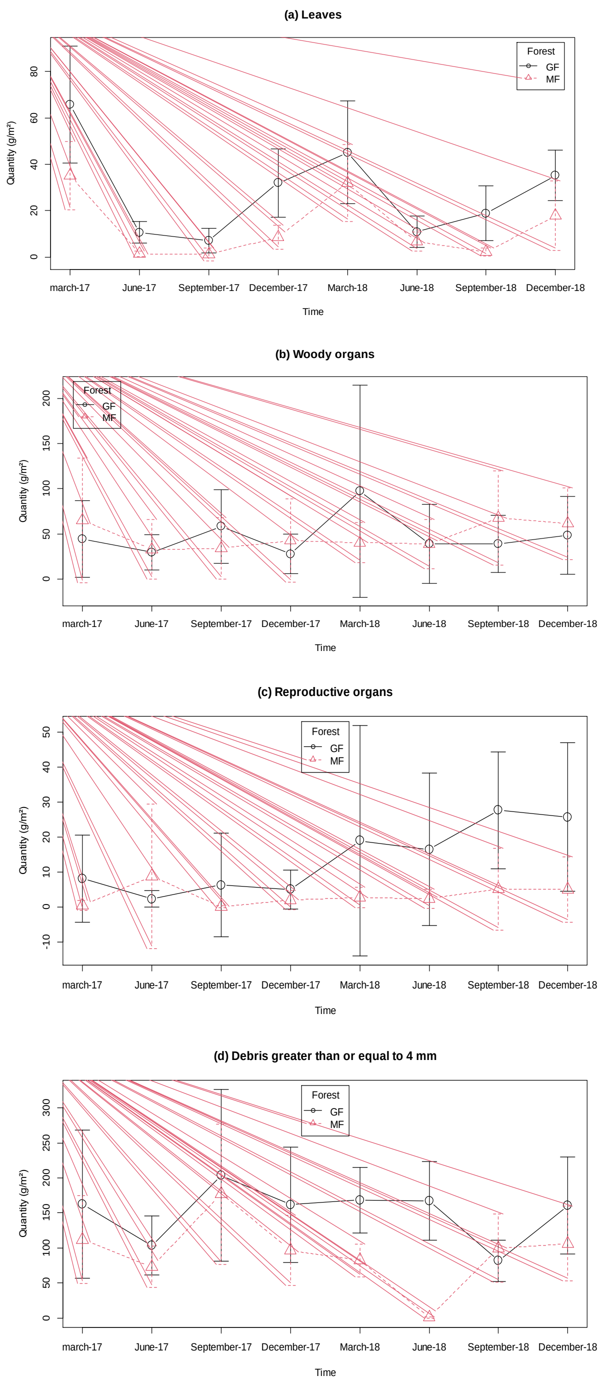
3.2 Temporal variations of litter

The analysis of rainfall data over the study period (Fig.2), revealed the existence in this area of a bimodal rainfall regime with two peaks of rainfall, in May and November. The observation showed a clear decrease in rainfall from December to January and a slight dip in rainfall in June.

The amounts of litter accumulated on the ground showed the seasonal variation in leaves of and reproductive organs (Table 2). The seasonal pattern was more pronounced for leaves than for reproductive organs. Peak leaf litter production was synchronous in both forests (Fig.4 (a)). Maximum amounts of leaf litter on the ground were observed in March in 2017 and 2018 in both forests. Low leaf litter amounts were observed in June and September in both years. Reproductive organs (Fig.4 (c)) also had high amounts of litter in March in 2017, September in 2018, with low amounts in June (2017 and 2018) on the ground in the GF. In the MF, reproductive organs showed almost no variation; a peak was observed in June of 2017. In contrast, for woody organs, there was no significant difference in the seasonal evolution of ground litter in the two forests (Table 2, Fig.4 (b)).

Debris ≥ 4 mm and that between 4-2 mm showed almost the same pattern in both forests, with maximums in September and minimums in June in 2017 (Fig.4 (d) and 4 (e)). But in 2018, the minimum of this debris was observed in September in the GF. In contrast for debris between 0.5-2 mm, seasonal variations were similar in both forests (Table 2) with minimums in June 2017 (Fig.4 (f)).

These results show that the evolution of litter accumulated on the ground does not parallel rainfall. Whatever the forest type, there is a layer of litter on the forest floor throughout the year, with a leaf peak in March corresponding to the rainy period.



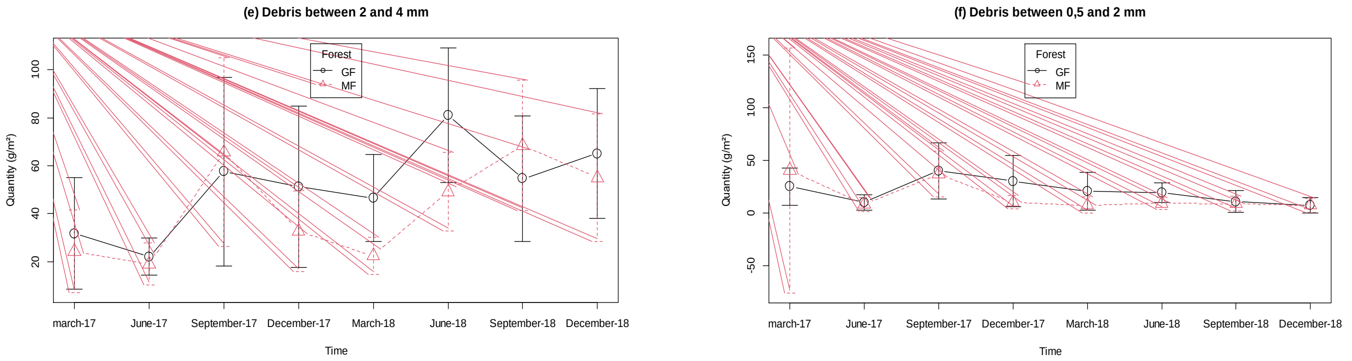


Figure 4: Monthly variations in the quantities of litter accumulated on the ground (a, b, c, d, e and f)

Table 2: Table of analyses of variance of the monthly amount of different litter components accumulated on the ground in relation to harvest period, forest and harvest period-forest interaction, in the two forest types

Components	Treatments	Sum Sq	df	F-value	p-Value
Leaves	Forest	13382	1	85.6122	< 0.001
	Period	58521	7	53.4858	< 0.001
	Forest x Period	4133	7	3.7778	< 0.01
	Residuals	34075	218		
Woody organs	Forest	1	1	0.0005	0.98
	Period	32750	7	1.9737	0.05
	Forest x Period	40100	7	2.4166	< 0.05
	Residuals	516768	218		
Reproductive organs	Forest	6402	1	03.0253	< 0.001
	Period	5956	7	3.9909	< 0.001
	Forest x Period	4835	7	3.2393	< 0.01
	Residuals	46480	218		
Debris ≥ 4mm	Forest	191885	1	43.8277	< 0.001
	Period	255192	7	8.3268	< 0.001
	Forest x Period	145969	7	4.7629	< 0.001
	Residuals	950062	218		
Debris 4-2mm	Forest	4808	1	7.7816	< 0.05
	Period	63179	7	14.6080	< 0.001
	Forest x Period	12287	7	2.8410	< 0.05
	Residuals	134691	218		
Debris 2-0.5mm	Forest	1047	1	0.9853	0.32
	Period	27751	7	3.7294	< 0.001
	Forest x Period	5666	7	0.7615	0.62
	Residuals	230678	218		

3.3 Effect of precipitation on soil litter components

The relationship between monthly rainfall and litter components showed that there was no significant correlation between these two variables, except for GF reproductive organs (Table 3). The latter components, have the strongest correlation (-0.76). When precipitation tends to increase, the litter of reproductive organs in the GF decreases (Fig.5).

Table 3: Correlation coefficients between precipitation and different litter components; * $P < 0.05$.

Components	GF	MG
Leaves	-0.452	-0.381
Woody organs	-0.309	-0.547
Reproductive organs	-0.762*	-0.333
Debris ≥ 4 mm	0.166	0.095
Debris 4-2 mm	0.047	-0.095
Debris 2-0.5 mm	0.33	0.31

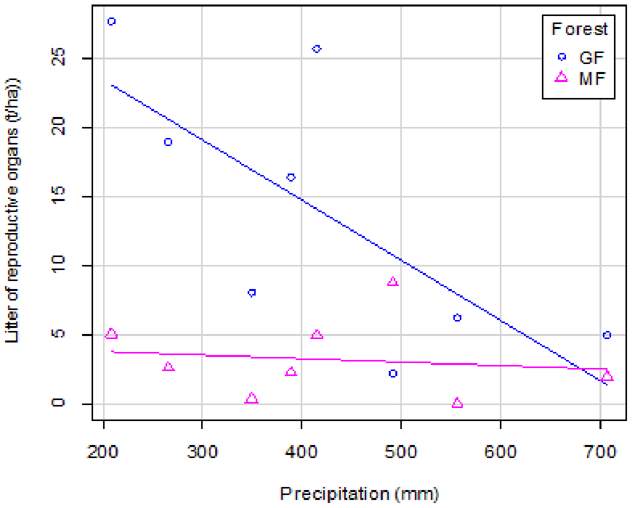


Figure 5: litter of reproductive organs according to rainfall

4.Discussion

4.1 Amount of litter

Results revealed spatial variability in litterfall in relation to forest type. Ground litter was higher under GF (36.96 t/ha/yr) than under MF (25.12 t/ha/yr). These results are in the range of those found by Loumeto (22.21 to 62.52 t/ha/yr) in 2002 [6]. They are high compared to those obtained by Devineau (10 to 13 t/ha/yr) in 1982 [16], Njoukam et al. (20 t/ha/yr) in 1999 [26], Ifo and Nganga (13.8 to 18.2 t/ha/yr) in 2011 [27], Songwe et al. (10.5 t/ha/yr) in 1995 [28], Spain (4.32 to 6.18 t/ha/yr) in 1984 [29]. This difference in storage may be due to the method used. For example, in the study by Ifo and Nganga [27], litter sampling was carried out only twice during two years, i. e. once a year. This is in contrast to our study where sampling was done throughout the two years. Also, in Spain's study [29], debris belonging to the A1 horizon was not considered. Whereas in our study, all litter was collected leaving the soil bare. Compared to other monodominant formations in Congo, the amounts of litter obtained in this study (36.96 t/ha/yr) are lower than those found by Loumeto (56.31 to 68.73 t/ha/yr) [6] in Okoume forest.

The difference in the more abundant litter layer in GF than in MF for both categories (Table1), can be explained by the simultaneous action of the litter fall and decomposition process. Litter storage on the ground is the result of both processes [6], [16]. This suggests that higher litterfall would occur in the GF than in the MF and that decomposition would be slower in the GF than in the MF. These results revealed that among the recognizable organs, the contribution of woody organs in litter to the soil is greater than that of other organs. This is contrary to observations made by some authors [13], [16], in other tropical forest ecosystems, which rather place leaves first in the litter contribution. Climate may be the factor explaining this difference. Indeed, during these last studies in semi-deciduous forest type, there were two dry seasons of duration ranging from 3 to 5 months. The dry season is the period during which deciduous species lose their leaves [19]. In our study, there is only one dry season of two months duration. Regarding debris, the proportion of debris larger than 4 mm is the most important (43.31% to 48.11% of the total weight) in the two forests studied. These results are close to those found by Loumeto [6] in the OCF forest (62% of the total weight), but contrary to those presented by the same author in the rest of the plots studied, which place the 0.5-2 mm fraction in the lead (49% to 51% of the total weight).

4.2 Temporal variations of litter

The peaks in litterfall that occurred almost exclusively during the rainy season show that litterfall accumulation is related to seasonal variations. Although it is recognized that in the tropics, water stress in the dry season is responsible for litter production [17], our results show a high amount of litter in the rainy season. These results are in agreement with those found by authors who have worked on Congolese forests [6], [17], [30]. However, they do not corroborate those found by Bernhard-Reversat [31] who also worked in tropical forest ecosystems. Indeed, this author observed greater quantities of litter in the dry season than in the rainy season. To explain these differences, many factors can be taken into account. In Congo, particularly in Likouala, the dry season is cool with a very high relative humidity of around 96% according to data from the Impfondo weather station. Trees do not need to avoid water stress. In addition, during the rainy season, the winds, storms and thunderstorms that accompany the rains contribute greatly to the accumulation of litter on the ground. Ostertag et al [32], observed the increase of litter stock from 1.2 to 2.5 times the normal stock observed before the hurricane, in six forests of Puerto Rico. However, the monthly evolution of the woody organs storage does not vary according to the seasons.

4.3 Effect of precipitation on soil litter components

No significant correlation was observed between precipitation and the different litter components, apart from the reproductive organs in the GF. Litter storage is related to litterfall, so the factors influencing these two processes are the same. Zank [33] showed that seasonal patterns of litterfall were determined by both the physiological mechanism and environmental variables. Therefore, we can say that the low correlation intensity between precipitation and litterfall, was due to the physiological mechanisms of different species. Therefore, precipitation is not a limiting factor for litter accumulated on the ground.

The strong correlation of reproductive organs in the GF, would therefore be due to the monodominance of the species *Gilbertiodendron dewevrei*. For Zank [33], the relationships with environmental variables in tropical forests depend on the species and components. For they are very diverse forests and formed by many tree species.

5.Conclusion

The results obtained indicate that the quantities of litter on the ground are among the highest values of tropical forests, with annual quantities of 36.96 t/ha and 25.12 t/ha respectively in the *Gilbertiodendron dewevrei* forest and in the mixed forest. The main constituent of this litter on the ground is the decomposing fraction greater than or equal to 4mm corresponding to 48.11% and 43.31% of the total weight, respectively for the *Gilbertiodendron dewevrei* forest and the mixed forest. Of all the undecomposed organs, woody organs are the most dominant.

Through these results, it appears that the type of forest and the periodicity of rainfall, has a significant effect on the total amount of litter. And with regard to its main components, apart from woody organs, the rainy season seems to be the preferred period for abundant litter on the ground of different forests. But, the intensity of correlation between precipitation and litter was low, except for the reproductive organs of the monodominant forest.

Finally, the litter stock observed here is primarily the consequence of litter fall and decomposition processes, and secondarily the consequence of climatic factors but also of phenology. The forests studied provide a significant amount of organic matter to the soil, and it would be interesting to conduct research on the speed and mechanisms of its decomposition, with a view to controlling soil fertility processes, which could constitute a knowledge base for soil management projects in exploited forests.

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