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Research Article
Litter Fall, Standing Litter and Leaves Decomposition Within Urban Tropical Forest of Zoological Park of Brazzaville, Republic of the Congo

Ifo Suspense Averti, Malonga Marini Urielle, Milandou Jodrhy, Madingou Mady Parfait, Mavoungou Naïving, Stevanche Nzingoula and Binsangou Stoffenne

Laboratoire de Géomatique et Ecologie Tropicale Appliquée, Ecole Normale Supérieure, Université Marien N'GOUABI, BP 237 Brazzaville, Congo

Abstract

Background and Objective: Urban forest can play an important role to mitigate global change and regulate local climate of cities. Litter fall and leaf decomposition represent the main pathway for nutrient cycling in forest ecosystems. The aims of this study were to: (i) Evaluate the annual production of litter fall, (ii) Quantify the standing litter stock (iii) and monitor the dynamics of the litter decay. **Materials and Methods:** Litter fall and decomposition were studied in urban forest of Zoological Park of Brazzaville during twelve months. Experimental design has been installed in the urban forest of *parczoologique*. Litter fall was collected every two weeks and litter decay was studied with the technique of litter bag. Eight litter fall traps were installed in the study area. **Results:** An average annual production of 731 g DM m^{-2} $year^{-1}$ was obtained and leaves represent the largest fraction with 63.9% of total litter. Decomposition of leaves was greater in the rainy season, with nearly the loss of 46% of the initial mass, where an average loss of 26% of the initial mass was noted in the dry season. However, it is important to note the influence of plant species in the rate of litter decay. Two species were chosen: *Millettialaurentii* De Wild. and *Antiaristoxicaria* Lesch. Three types of litter were prepared to follow litter decay: one of *Millettialaurentii*, one of *Antiaristoxicaria* and one mixte of (*Millettialaurentii*+*Antiaris Toxicaria*). The most important loss of weight was noted during the rainy season. **Conclusion:** The results showed that the urban forest of Brazzaville is an old forest and transfers an important stock of carbon in the soil component during the litter decomposition.

Key words: Litter fall, decomposition, urban forest, millettialaurentii, antiaristoxicaria

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Corresponding Author: Ifo Suspense Averti Laboratoire de Géomatique et Ecologie Tropicale Appliquée, Ecole Normale Supérieure, Université Marien N'GOUABI, BP 237 Brazzaville, Congo Tel: +242068029720

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Urban forests are ecosystems with trees and others plants in streets, garden parks and spaces surrounding large cities. In recent decades, research has shown that urban trees are an integral part of the environmental quality of cities around the world[1,2]. These trees improve soil quality by participating in the enrichment of soil organic matter through litter fall and decomposition of leaves, fruits and flowers provided by trees[3]. Urban trees and their soils could play an important role in reducing urban runoff frequencies. Similarly, urban areas are often hot spots for air pollution from the automotive industry[4,5].

In both Africa and the Republic of the Congo, the management of intra-urban forest ecosystems has always been one of the major problems of municipal authorities. The forest of the zoological forest, part of patted'oie forest, was classified as a forest reserve in 1938. This forest is actually the only natural intra-urban forest ecosystem of the city of Brazzaville in the Republic of Congo. It counted, at its creation 240 ha, but with the demographic evolution and extension of the city of Brazzaville, it is currently reduced into two natural entities of less than 94 ha[6]. This forest has been the subject of several ecological studies which have focused on the biodiversity and regeneration[7,8], the dynamics and dissemination of diaspores[9] but also studies on the evolution of the areas of these forests[6]. No studies to date have been carried out to monitor the dynamics of leaf litter in the urban forest of Zoological Park. Hence the importance of this study which will make it easier to identify the role that this forest could play in the global context of climate change, including its potential to sequester excess CO_2 into the atmosphere.

Litter fall and leaf decomposition represent the main pathway for nutrient cycling in forest ecosystems[10,11]. Litter falland decomposition rates are influenced by factors such as latitude, elevation, rainfall, seasonal changes, vegetation density and species composition[11-14]. In addition to being habitat for some soil organisms, it is an effective interface between vegetation and soil, proving to be a return of carbon to the soil. Litter has a protective layer function and is put forward when it comes to limiting erosion[15], avoiding soil compaction[16], trapping pollution by retention of toxic metals or micro-pollutants organic[17], reduce losses by drainage (but also by dabbing moisture variations[18] and temperature[19]. In addition, litter is an intermediary between vegetation and soil[20] and is a major substrate for soil microorganisms and influences their activities[21].

However, the amount of organic matter in a forest soil depends on the equilibrium between litter production and the rate of decomposition of this litter[22].

Litter decomposition directly affects the dynamics of forest ecosystems as a source or sink of carbon, by releasing CO_2 and indirectly by improving nutrient availability and consequent changes in net primary production[23]. The rate of litter decomposition is largely a determining factor for productivity of the forest ecosystems as plant nutrients became available for recycling within the system during litter decomposition can account for 69-87% of the total annual requirement of essential elements for the forest plants[24].

Data on litter fall quantities are important for estimating carbon stocks entering the soil compartment[25]. The overall objective of this study was to understand the functioning of urban forest ecosystems in the context of climate change through the dynamics of litter systems. The specifics aims were: (i) To evaluate the litter fall production during the study period, (ii) Quantify the standing litter stock present on the ground and (iii) Evaluate the dynamics of litter decay.

MATERIALS AND METHODS

Presentation of the study area: The forest of the Zoological Park of Brazzaville is located in the center of Brazzaville's city closed to Maya Maya Airport and "MassambaDébat stadium" (Fig. 1). The forest of the zoological park belongs to the domain of Lower Guinea and the Congolese-Zambésien transition sector of the District of La Léfini[26] whose forests are mostly mesophilic. The natural forest is dominated by *Millettialaurentii* De Wild[27].

The climate of Brazzaville is of the Congolese Bas type[28]. It is characterized by annual averages of temperature of approximately 25°C and annual thermal amplitude oscillating from 4-6°C (Fig. 2). March and April are the hottest months; the months from June to September, marking the dry season, are cool, July and August are the freshest. The rains are spread out from October to May and the average rainfall is of approximately 1200 mm $year^{-1}$. This rainy and hot season knows a deceleration of precipitations in January and February. The maximum of rain were observed in March-April and in November-December (Fig. 2)[29,30].

The relative humidity is higher than 70%, whereas an absolute minimum is observed in August and September and a relative humidity minimum in February and March. As for evaporation, it presents a relative minimum in June and an absolute maximum in August and September. The monthly averages over ten years (1999-2008) showed that the insolation presents two maximum in March and May (164 and 175 h) and a minimum in June (124 h). The annual average lies between 1100 and 1800 h for the same period[31,32]. The soils

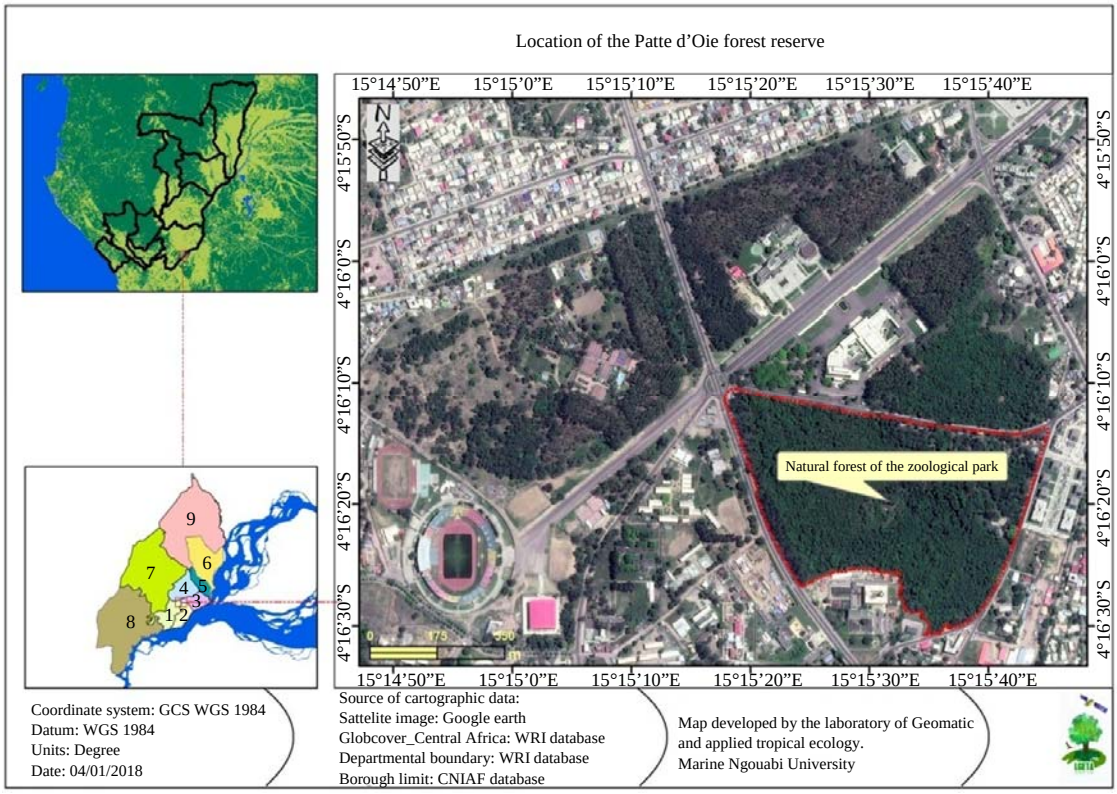

Fig. 1: Geographical location of the natural forest of the zoological park

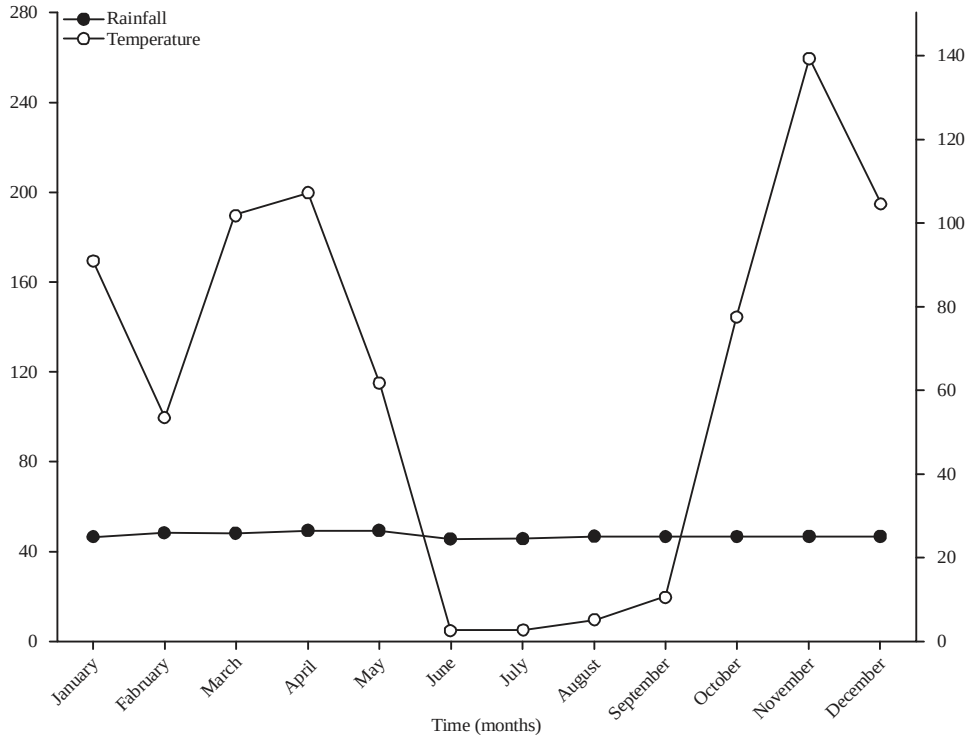

Fig. 2: Ombrothermic Diagram of the Brazzaville's city from 1960-2014, ANAC Brazzaville

are ferralitic, strongly desaturated and impoverished. They are low in exchangeable and very permeable bases because of the sandy substrate which allows the migration of the solutions of the ground.

Litter fall sampling: The measurements of the litter fall were estimated by randomly placing eight litter fall traps in all the study area, each trap measuring 50 cm×50 cm with 2 mm nylon mesh to catch the litter and located 50 cm above the ground. Litter was collected from the traps at two-week intervals for from August, 2016 to 17 August, 2017. The collected litter samples were brought to the laboratory, separated into leaf and non-leaf components and oven-dried at 70°C for four days to constant mass, using an electronic balance (CS200, Ahaus 0.1 g accuracy).

Litter standing crop sampling: Litter standing crop in the study area forest was measured using a metal 50 cm×50 cm frame. All dead leaves, stems, bark, fruits, flowers, seeds and other debris were collected. Litter standing crop sampling was collected four times during the studying period from August, 2016 to 17 August, 2017. The first sample was taken on 07/20/2016, the second in 10/31/2016, the third collecting of soil litter was done in 12/12/2016 and the last one 03/04/2017.The various components of the litter were separated (litter leaves, barks, stems, debris) and oven-dried at 70°C during four days to constant mass, using a balance.

Litter decomposition experiment: Mesh litter bags containing leaves were placed into random locations within the plots and retrieved them after varying lengths of time to quantify litter decomposition rates. The experiment was repeated two times, one experiment in the dry season from august to earlier october2016. The second experiment was done during the rainfall season from December to March and the leaves of the most dominant tree species in their respective stands were put into the litter bags[33]. The litter bags were made of 2 mm nylon mesh, sized 20×20 cm. In the secondary forest each litterbag contained, 10 g of pure litters of *Milletialaurentii* and in the gallery forest 10 g of pure litters of *Antsiaristoxicaria* the leaves for the experiment were sourced from recently fallen *Antsiaristoxicaria* and *Milletialaurentii* within the study plots. About 10 g of mix litter of both two kinds of litter cited above.

A total of 144 nylon-net bags (2 mm mesh) of 20×20 cm were prepared for each experiment. Forty-eight of each types of litter were placed in the forest of "Patted'oie" to follow the litter decay dynamics. Eight bags of each type of litter were collected once every two weeks during three months. This was repeated 3 times as mentioned it above. After recovery from the forest, the bags were placed in individual polythene bags and brought to the laboratory. The bags were opened and the litter materials were air dried initially, brushed to remove adhering soil particles and finally dried at 70°C for four days to constant mass, using an electronic balance.

The mass loss over time was fitted using a negative exponential model (Olson[34]):

$$K = \left[-\ln\left(\frac{m}{m_0}\right) \right].t^{-1}$$

Where:

m_0 = Original mass of litter
m = Amount of litter remaining after time t
t = Time (year)
K = Decomposition rate (year^{-1})

The time required for 50 and 95% mass loss was calculated as $t_{50} = 0.693/k$ and $t_{95} = 3/k$, respectively.

Statistical analysis: R statistically software was used for statistical analysis. Linear regression analyses were performed to test the relationship between decomposition and environmental factors. Linear Model.1 <- lm(weight ~ season +species, data=decay) to evaluate the significant factors explains the loss of mass weight during the decomposition. Significant effect of environmental factor was revealed when Pr<0.0001. Also we test if the sum of litter fall was different among.

RESULTS

Litter fall: The most significant production litter fall was noted in the months of September 2016 with a total litter fall production of 1259.64 g DM m^{-2} whereas the weakest production was recorded in the month of August, 2017 with a production of 321.32 g DM m^{-2}. This study revealed that the production of litter fall in dry season was more significant than the litter fall production during the rainy season (Fig. 3). However, an average annual production of 731 g DM m^{-2} year^{-1} was calculated for the studying period.

In addition, the different components of the litters fall have a seasonal production which varies one month with another with different percent of leaves rates (Fig. 4, 5).

August 2016 was that which showed the highest rate of leaves fall whereas January 2017 and May 2017 showed the

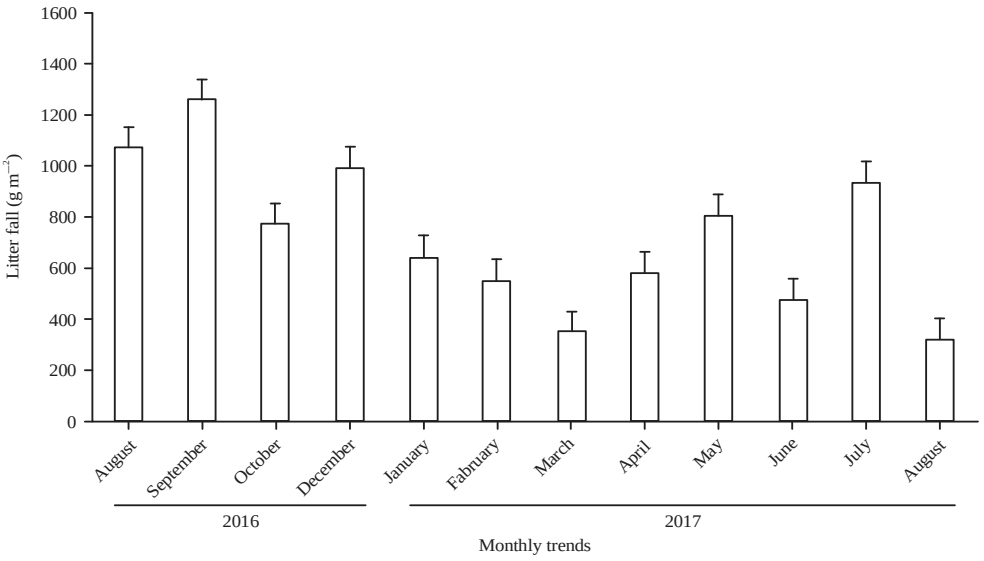

Fig. 3: Monthly variation in litter production in the zoological park forest

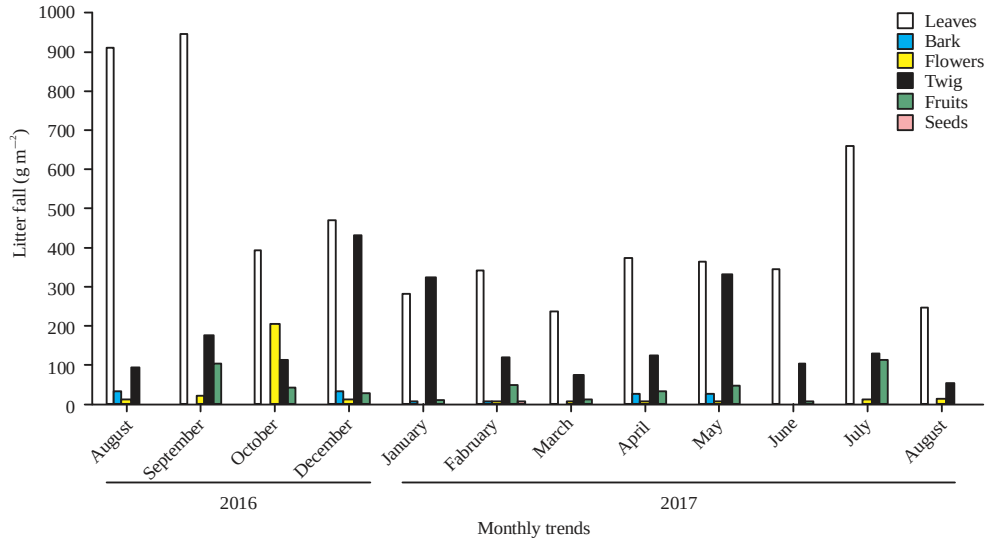

Fig. 4: Production of the different litter compartments

weakest rates of leaves in the total litter fall with 44.52 and 45.44%, respectively. Multiple comparisons of means: Turkey contrast applied to litter fall data revealed a significant difference of litter fall by month, specially between September 2016 and June 2017, September 2016 and mars 2017 (Pr = 0,006). However when litter fall data was gathered between season (dry and rainy), no significant production of litter was noted (Pr = 0.0892). Between the four plots of collected data, significant differences in production were noted between P4-P1, P4-P2, P4-P3, Pr<0.001.

Litter amount on forest floor: The amounts of standing litter on forest floor were collected four times during the period of study. The amounts of litter were 1271.06 g DM m^{-2} in July 2016, 1216.03 g DM m^{-2} in October 2016, 980.38 g DM m^{-2} in December 2016 and 612.86 g DM m^{-2} in March, 2017. The fraction composed by the fine debris of litter was the most important component of standing litter on soil in comparison with the amounts of the others fraction of litters: leaves, twigs, seeds, etc.

Litter decay: The loss of litter weight have shown different dynamic of decomposition during the first experiment during the dry season from August, 2016 until October, 2016 and during the rainy season from January, 2017 to March, 2017. For the first experiment, during the first two weeks, the litter lost

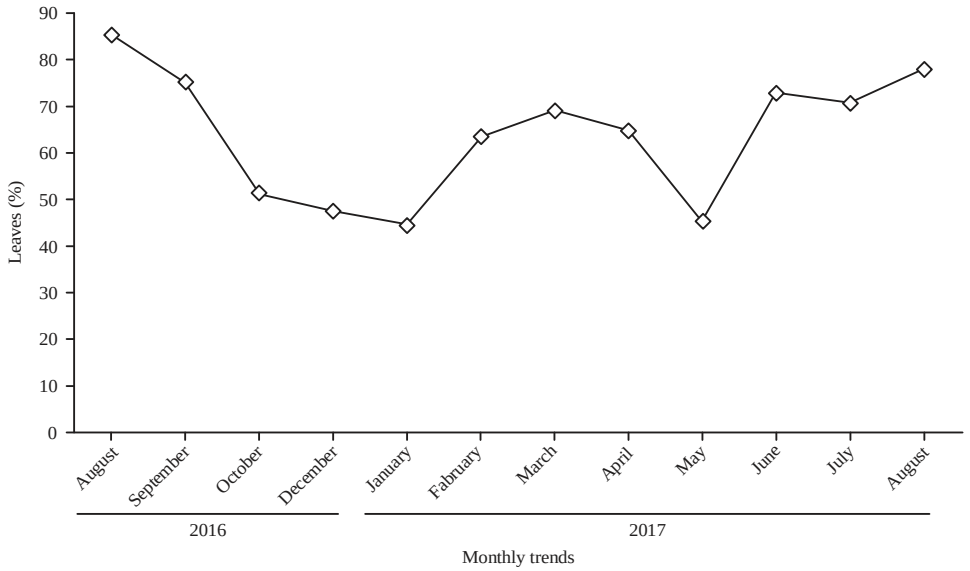

Fig. 5: Trends of percent of leaves fall in total litter fall during study period

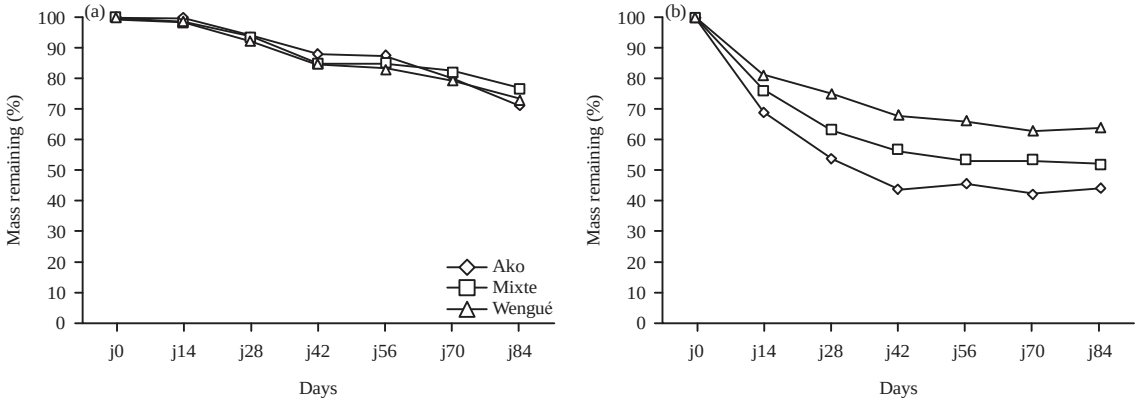

Fig. 6(a-b): Mass remaining in percent of different type of litter decomposition in the forest of Zoological Park of Brazzaville. (a) Litter de composition samples installed during rainy season and (b) Litter decomposition samples installed during the second experiment during the dry season

0.2% for all the types of litter bag *Antiaristoxicaria* Lesch., Mixed litters and *Millettialaurentii* De Wild.,litter. After 4 weeks of decomposition monitoring, *Antiaristoxicaria* Lesch. litters had lost 6% of their initial weight, while the mixed and *Millettialaurentii* De Wild. litters had lost 4.6 and 6.3%, respectively. After 3 months of study, *Antiaristoxicaria* Lesch. litters lost 2.89 g (28.9%) compared to 2.68 g (26.8%) for *Millettialaurentii* De Wild. litter. Mixed litter only lost 2.31 g (23.1%) over the same period. During the second experiment, all type of litters lost their weights, but to varying degrees. Two weeks after the litter bags were deposited, *Antiaristoxicaria* Lesch. litters had lost 30% of the initial mass, while the mixed and *Millettialaurentii* De Wild. litters had lost 24 and 19% of the initial mass, respectively. After three months, *Antiaristoxicaria* Lesch. litters lost 56% of their initial mass compared to 48 and 36% for both mixed and *Millettialaurentii* De Wild. litters. These two experiments revealed the effect of the season on the total rate of decay of litters in the forest of the Brazzaville Zoological Park (Fig. 6). ANOVA test (weight ~ season) was applied on our data. The effect of season the litter decomposition in the one hand was observed and in the other hand species influenced also the rate of decomposition of the different species ($p<0.05$). Time elapsed on the ground had a significant impact on the decomposition of litter ($p<0.05$). Season was really a major factor of the litter decomposition (Fig. 7) in this study area.

Fig. 7: Effect of seasons on the means of final loss weight of litter decay in the experimental study

DISCUSSION

The most significant production litter fall was noted in the months of September, 2016 with a total litter fall production of 1259.64 g DM m^{-2} whereas the weakest production was recorded in the month of August 2017 with a production of 321,32 g DM m^{-2}. Litter fall in forest ecosystems is influenced by the environmental factors (climate, edaphic parameters, water in soils, etc.) and biotic factors. It plays a very important role in the recycling of bio elements and the maintenance of balance in tropical forest ecosystems[35].

Current study showed that the natural forest of the zoological park of Brazzaville undergoes the same influences as other large forest masses in the Republic of the Congo[11,22]. In fact, large litter fall was observed during the dry season on the one hand, but also on the other hand during the rainfall season which are usually accompanied by very strong winds in and around Brazzaville's city.

However, in comparison with results obtained in the Republic of the Congo by Koubouana *et al.*[7], who obtained an average annual production of 1063 and 1097 g DM m^{-2} $year^{-1}$ in the gallery forest and the secondary forest of the Lesio respectively, litter fall production obtained in this study was low, a difference of about 300 g DM m^{-2} $year^{-1}$ between both sites. It is very interesting to compare these two results, because the forests of the Lesio-Louna is about 100 km in the north of Brazzaville and are made up of the same type of forest that has long existed in the city of Brazzaville before its degradation.

A comparison with the international database showed that the production of litter fall in the urban forest of Brazzaville was closed to what others researchers noted in their study[36-39]. But the mean production of litter in our study was high in comparison to what Kang *et al.*[36] and Martius *et al.*[40] noted in their study.

Litter production can be explained by the age of the main trees within the plots where the traps were installed, phenology of species, the spatial distribution of large trees inside the urban forest, the relationship with the environmental factors like wind, season and hydric stress of plants. Trees inventories showed that, large trees do not cover the entire urban forest of the Zoological Park of Brazzaville, this can explain the unequal repartition of litter fall. However, It should be noted that rainfall data collected less than 200 m from this urban forest in the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) station indicated a good watering of this area. Indeed, the annual rainfall recorded over the last ten years indicates an average precipitation around 1400 mm in the city of Brazzaville.

The influence of the dry season in the fall of litters was observed in tropical region during the dry season by Wang *et al.*[41] and Goma-Tchimbakala *et al.*[42]. However, this differs from observations made by other authors which observed peaks of litter production during the rainy season[43,44] The most important production in September during the dry season in our study can be explained by phenology of species but also by the deficit of water in the top soil in that period of the year. Urban forest of the Zoological Park of Brazzaville is a semi-deciduous forest as revealed by the ground truth as well as the articles published by Liao *et al.*[45]. Further work on *Millettialaurentii* De Wild shows that this species exhibits highly seasonal leaf and reproductive phenology. Leaf fall and the appearance of new leaves occur twice a year, respectively during dry seasons and early rainy seasons[43].

The leaves accounted for 63% of the total litter production in the study area. This production is low in comparison withwhat observed in the literature in other types of forests in the Republic of the Congo. Goma-Tchibakala and Bernhard-Reversal[38] notedin their study that the leaf fraction represented 89% in the primary forest at *TerminaliaSuperba* and in the plantation of 49 yearsold. Koubouana *et al.*[7] noted a percentage of leaves that ranged from 95-98% of total litter fall production. Also many authors obtained a percentage of leaves higher that what our results shown[46,47]. But our results was closed to what Yang *et al.*[32] and Cattanio *et al.*[47] obtained in their study. Lebret *et al.*[48] observed in a beech plantation that the proportions of leaves in litter fall decreased with the age of plantation. The leaves represented in their study 90% of the total fallout in a young stand and 70% in the old plot.

Percentage of leaves in the total litter fall reveals the importance of this fraction in the functioning of a forest in general and of the tropical ecosystems particularly, since foliar litters contains bio-elements that are rapidly recycled during the first stage of litter decomposition and made it available to the trees by the fine roots present in the top soil horizon. Older

forests allocates more production to fruits, flowers and seeds and have more branch production than younger forests. This leads us to conclude that the urban forestof Brazzaville is an old forest.

Litter decomposition: Decomposition of leaves was greater in the rainy season, with nearly the loss of 46% of the initial mass, where an average loss of 26% of the initial mass was noted in the dry season. The balance between litter inputs and heterotrophic litter decomposition influences the amount of carbon stored in the forest floor. In the Congolese rainforests and other latitudes, several authors noted the effect of rainfall and thus soil moisture on litter decomposition[11,22,49]. It is important to note that three factors influence the rate of litter decomposition: environmental condition, litter quality and soil biota. These factors are known to control litter decomposition processes[50,51].

Water, one of the environmental factors works by promoting the release of hydro soluble substances from litters[14] and promotes the recovery of the life of the soil fauna, the first element of the chain during the degradation of litters[52].

During dry season, the lack of water in top soil forest would promote the migration of microbial flora to the depths of the litter layer[53]. This phenomenon reduces the exposure of litters to decomposers. Moreover, Thurow[54] observed that during the dry season there was a decrease of microbial activity due to water deficiency in litter system. Thus the decay of litters during the dry season is essentially the result of the macro fauna of the soil including the termites which constitute one of the most abundant agents during this period. Theses can explain the difference in terms of rate of litters decomposition noticed between dry season and rainy season.

CONCLUSION

Current study helps to understand that urban forest have a high production of litter fall with a percentage of leaves indicated that this forest is not a young but an old forest. However litters decomposition varies following the season of the year, with high rate of decomposition during the rainy season and lowest in the dry season. This forest could play an important role in mitigation in the context of global change.

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SIGNIFICANCE STATEMENT

Urban forest of Brazzaville decreased significantly from 240-90 ha the last 70 years because of human activities. But this forest continue to play an important role to mitigate the cause of climate change according to the litter fall obtained. This study could open up further research in the field of Eco physiology: foliar photosynthesis, soil plant and atmosphere relationship, the turnover of fine root, etc.

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