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Litterfall, Accumulation and Decomposition in Forest Groves Established on Savannah in the Plateau Teke, Central Africa

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ABSTRACT

The carbon budget of marginal forests that developed on the savannah in the Plateau Teke has not yet been studied despite increasing evidences of their spatial expansion. Measurements of litter fall, litter amount on forest floor and leaf litter decomposition was undertaken, on three plots in a Gallery Forest (GF) and three plots in a hill-slope forest clump (HF). The aim of the study was to study the dynamic of litter in two types of forest groves. Litterfall was collected biweekly for two years and averaged 1063 g m^{-2} y^{-1} in GF and 1097 g m^{-2} y^{-1} in HF, with leaves accounting for more than 95% of the total litterfall. The amount of litter on the floor was estimated twice within each plot and averaged 1824 g m^{-2} in GF and 1381 g m^{-2} in HF. The relative mass remaining after seven months of decomposition assessed in litterbags was 40% in GF and 33% in HF in 2007 and 44 and 53% in the 2008, with a strong impact of dry season. Despite differences in forest structure and species composition, litterfall, litter accumulation and decomposition rates were similar between the two types of forest groves.

Key words: Litter decomposition, litterfall, residence time, plateau teke, forest grove, congo

INTRODUCTION

Leaf litter production and decomposition are two important processes which provide the main input of organic matter in the soil and which regulate the patterns of nutrient cycling in forest ecosystems contributing to the maintenance of soil fertility and productivity of forest ecosystems (Weltzin *et al*., 2005; Goma-Tchimbakala and Bernhard-Reversat, 2006; Pandey *et al*., 2007; Ukonmaanaho *et al*., 2008; Wang *et al*., 2008). Furthermore, it is known that differences in vegetation composition alter the rates of both litter input and decomposition, via the activities of faunal and microbial activities (Polyakova and Billor, 2007). Therefore, an improved understanding of these basic ecosystem processes is desirable to better understand the dynamics of soil carbon in mosaic vegetation systems.

The vegetation of Central Africa is largely composed of the Congo drainage basin and contiguous humid closed-canopy forests and less well known, large areas of savannah and forest-savannah mosaics often composed of forest groves either along the river bank (gallery forest) or resulting from ancient local human activities (Schwartz *et al*., 2000). These are highly dynamic ecosystems, with some evidences that recently the forest is encroaching into the savannah area (Delegue *et al*., 2001; Favier *et al*., 2004; Mitchard *et al*., 2009). One of the largest areas of savannah-forest mosaic is the Plateau Teke, also known as the Plateau Bateke, covering 12000 km^{-2} of the Republic of Congo (also known as Congo-Brazzaville), Gabon and

Republic Democratic of Congo (RDC). The climate, with annual rainfall of approximately 2100 mm, and a relatively short dry season (2-4 months), suggests there should be humid closed-canopy tropical forest on the plateau. The predominance of savannah in this region results from a combination of frequent fires, poor sandy soils and possible slow rebound of the vegetation from the drier conditions that occurred over the last glacial maximum (Vincens *et al*., 1999).

Quantifying the litter dynamics of the different forest types that are found on the Plateau Teke would provide basic parameters and additional insights into the functioning of these forest ecosystems. Most studies measuring litterfall dynamics and litter decomposition in central Africa, including Congo-Brazzaville, have been carried out in forest plantations, often studying non-native species (Bernhard-Reversat, 1993; Goma-Tchimbakala and Bernhard-Reversat, 2006). Very few studies have been conducted in natural environments (Schwartz, 1993; Goma-Tchimbakala and Bernhard-Reversat, 2006) and none that we know dealt with forest groves in savannah-forest mosaic systems.

Here, we report litter production, litter amount and leaf litter decomposition in two types of forest groves on the Teke Plateau in the République du Congo, one gallery forest on the banks of the Louna river and one hill-slope forest clump. We hypothesized that accumulation of organic matter on the forest floor will depend on the forest type through differences in both litterfall and decomposition.

MATERIALS AND METHODS

Study sites: The study sites are localised at Iboubikro (3°11'S, 15°28'E), 140 km north east of Brazzaville on the Plateau Teke. The average annual rainfall is 2100 mm (2006-2008) with a marked dry season from June to September (Fig. 1a) and an annual average air temperature of 26°C. The soil is a deep acidic sandy arenosol with clay content varying from 0.3 to 7.6% (Schwartz and Namri, 2002).

The two studied forest groves were a Gallery Forest (GF) with many individuals of *Colletoecema dewevrei* (De Wild.) Petit. [Rubiaceae] and *Eriocoelum microspermum* (De Wild.) Radlk. [Sapindaceae] and a hill-slope forest clump (HF) dominated by *Musanga cecropioides* R. Br. [Cecropiaceae] and *Macaranga barteri* Mull.Arg. [Euphorbiaceae]. Three plots of 40 m × 40 m were delimited in each forest types. All plots were within 300 m of each other. The height of the canopy was approximately 20-26 in GF and 15-21 m in HF. Tree density was 640 stems ha^{-1} in GF and 119 stems ha^{-1} in HF (diameter at breast height above 0.1 m) and the basal area was, respectively 17 and 7 m^2 ha^{-1}.

Litterfall: Aboveground litterfall were estimated by randomly placing three litter traps per plot. Litter traps of 50 × 50 cm were made with 2 mm nylon mesh to catch the litter, and were installed 50 cm above the forest floor. Litter was collected from the traps at two-week intervals for two years from October 2006 to December 2008. The collected litter samples were brought to the laboratory, separated into leaf and non-leaf components, oven-dried at 70°C for four days and weighed using an electronic balance (0.1 g accuracy).

Amount of litter: The amount of litter on the forest floor was collected with a 50 × 50 cm metal frame. All dead leaves, stems, bark, fruits, flowers, seeds and other debris were collected. Three samples were first collected in each plot at random location in March 2007 and in May 2008. The various components of the litter were separated, oven-dried at 70°C for four days and weighted.

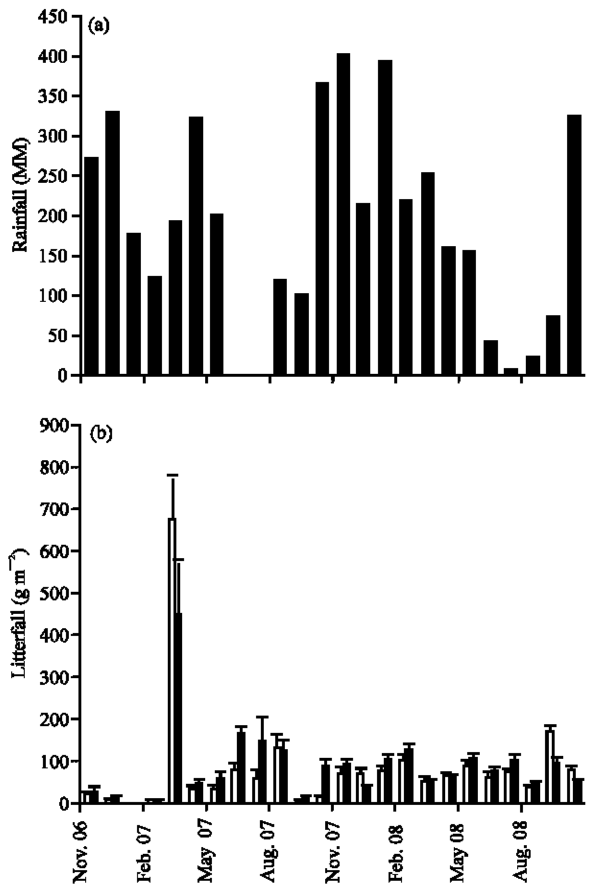

Fig. 1(a-b): Seasonal courses of (a) monthly rainfall in Iboubikro site and (b) litterfall in the gallery forest (open bars) and the hill-slope forest (closed bars) with vertical bars representing the SE of the mean of 9 litter traps per forest

Litter decomposition experiment: Leaf decomposition of the most dominant tree species of both forests (*C. dewevrei* in GF and *M. cecropioides* in HF) was studied using litterbags made from 2 mm nylon mesh, sized 20 × 20 cm. The litterbags were filled with 10 g of leaf litter. The litter bags were installed in November 2007 for the first experiments and in June 2008 for the second one. The first experiment ended in June 2008 and the second one ended in December 2008.

Twelve bags were set up in two plots in HF and in GF in the second experiment and in three plots in GF in the first experiment. Two bags from each plot were retrieved at six occasions at 1 to 2 month intervals. After collection, the bags were placed in individual polythene bags and brought to the laboratory. The bags were opened and the litter materials were air dried, brushed to remove adhering soil particles, dried at 70°C for four days and weighted.

Soil water content and soil temperature: Soil Water Content (SWC) in the first 0-10 cm and soil temperature at 10 cm depth were randomly measured every month (except in February and April 2008 due to logistic problems) in all plots (n = 6 per plot) using a soil moisture sensor (HMS 9000 connected to a Microterm 4800 data logger, Microterm, France). Monthly rainfall data has been provided by the Gorilla sanctuary base (John Espinall Foundation) nearby the experimental site.

Data analysis: Means are given with their Standard Errors (SE). Analysis of variance was performed to test significant differences in annual litterfall and in litter amount between forest types, plots (nested within forest types) and years as well as their interactions (GLM procedure of SAS software). We are aware that plots were pseudo replicates but the study of additional sites was not feasible because of logistic constraints. Analysis of variance was also performed to test differences in leaf remaining mass between forest types and sampling date (decomposition experiments).

RESULTS

Rainfall, soil water content and soil temperature: The 2008 dry season was longer that the 2007 dry season, with, respectively two and three consecutive months with rainfall below 50 mm (Fig. 1a). Soil water content varied according to the season (Fig. 2a). In the 2008 dry season, minimal SWC was 6.2% in GF and 4.7% in HF. In the wet season, maximal SWC was 11.2% in GF and 9.5% in HF. Soil temperature varied with the season with slightly lower soil temperature in the dry season than in the wet season (Fig. 2b) as expected because of a cloud induced decrease in global radiation during the dry season in this area.

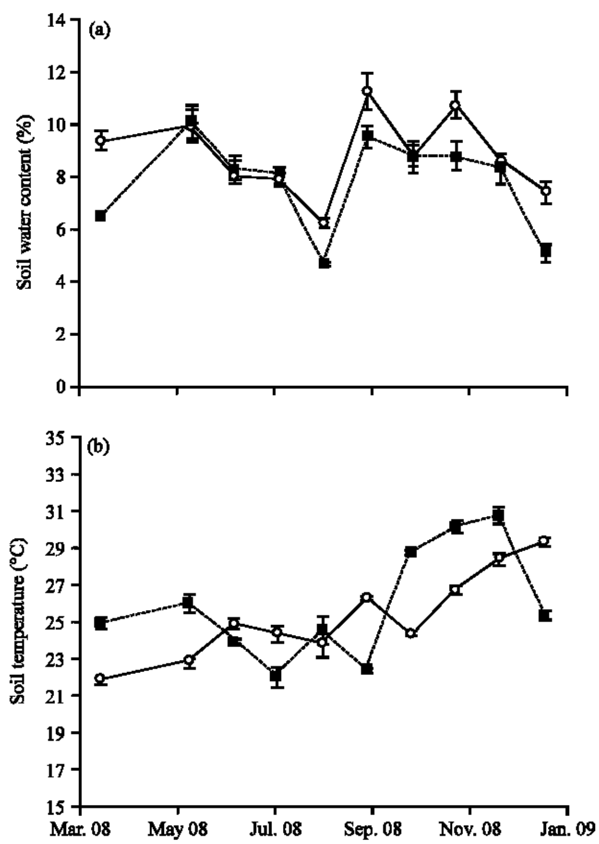

Fig. 2(a-b): Seasonal courses of (a) soil water content in the top soil (0-10 cm) and (b) soil temperature at 10 cm depth in the gallery forest (open circle) and the hill-slope forest (closed square) with vertical bars representing the SE of the mean of 18 measurements per forest

Table 1: Total aboveground annual litterfall and leaf annual litterfall [1]($g\ m^{-2}\ y^{-1}$) and total aboveground litter amount and leaf litter amount on the floor ($g\ m^{-2}$) in the Gallery Forest (GF) and the hill-slope forest (HF)

		Litterfall ($g\ m^{-2}\ y^{-1}$)		Litter amount ($g\ m^{-2}$)	
Forest type	Year	All	Leaf	All	Leaf
GF	Y1	1180±88	1165±87	2470±193	162±18
	Y2	1044±57	1028±57	1177±135	212±44
HF	Y1	1254±170	1178±125	1730±248	109±22
	Y2	1040±70	1033±68	1032±109	309±46
ANOVA					
Forest (df = 1)		1.22	0.93	6.21	0.46
Plot (df = 2)		4.25*	4.87*	1.35	0.44
Year (df = 1)		3.30	3.18	31.34***	12.32***
Forest x Year (df = 1)		0.16	0.00	2.80	4.39*

Degree of freedom. F ratio followed by *, ** and *** are significant at 0.05, 0.01 and 0.001, respectively, [1]Value are means of 9 replicates per forest ± SE. Analyses of variance (F ratio) for litterfall and litter amount as affected by forest type, plots nested within forest type and year.

Litterfall: The mean annual litterfall from November 2006 to October 2008 was 1063±44 $g\ m^{-2}\ yr^{-1}$ in GF and 1097±90 $g\ m^{-2}\ yr^{-1}$ in HF. The difference between the two forest types was not significant across the two years (Table 1). Litterfall was lower in year 2 compared to year 1 for both sites (8% in GF a nd 15% lower in HF) but the difference was not significant ($p = 0.079$, Table 1).

Litterfall exhibited a strong temporal variability, consistent across the two forest types (Fig. 1b). Almost half of annual litterfall occurred in March in 2007 with 672 $g\ m^{-2}$ in GF and 445 $g\ m^{-2}$ in HF. This was likely associated with a major windstorm that has been reported by local peoples.

Litter collected in the litter trap was dominated by leaves. The mean annual percentage of leaves on total litterfall is was 99% in GF and 96% in HF and this was consistent across years.

Litter amount: The amounts of litter on soil in March 2007 were 2470±193 $g\ m^{-2}$ in GF and 1730±1355 $g\ m^{-2}$ in HF while it was significantly lower in May 2008 (1177±135 and 1032±109 $g\ m^{-2}$ in GF and HF, respectively, $p<0.001$, Table 1). There was no difference in aboveground litter amount between both forest types. On average, leaf accounted for 10 and 22% of the total aboveground litter.

Litter decomposition: In both forests, the loss of litter mass was relatively fast during the first experiment from November 2007 until June 2008, during the wet season (Fig. 3a) with no difference between the two forests ($p = 0.77$). During the first two months, the litter lost one fourth of it initial mass. In contrast, the loss of mass was very limited during the first two months following the beginning of the experiment started in June 2008 at the beginning of the dry season, until the beginning of the rainy season in September (Fig. 3b). There was a significant difference between the two sites with higher mass loss in GF than in HF across all sampling date ($p = 0.011$) which might be related to higher SWC in GF (Fig. 2a).

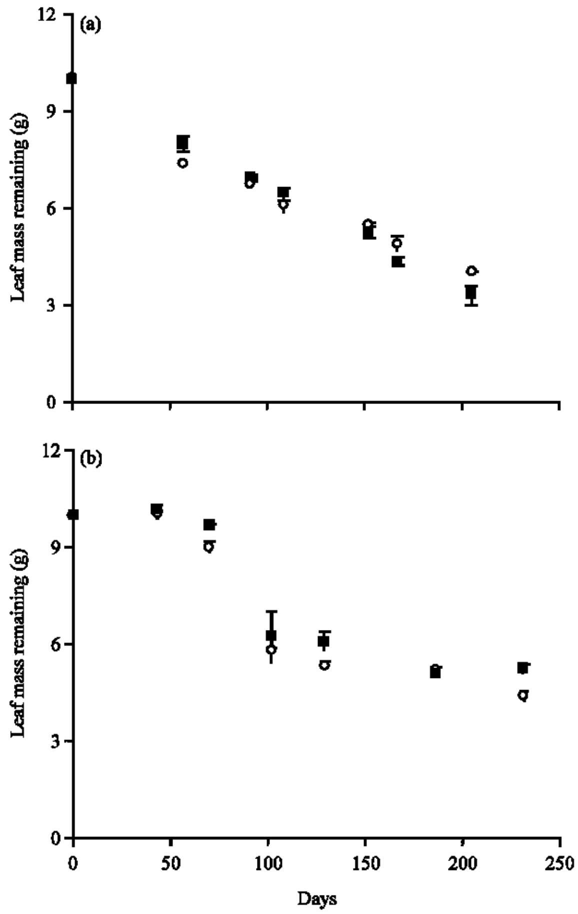

Fig. 3(a-b): Litter decomposition in gallery forest (open circle) and in hill-slope forest (close square) during the 1st experiment (a), litterbag installed in December during the wet season) and during the 2nd experiment (b), litterbag installed in June at the beginning of the dry season) with vertical bars representing the SE of the mean of 4 to 6 litter bags per forest

DISCUSSION

Litterfall in forest ecosystems is determined by climatic conditions, species composition, successional stage, soil fertility and over shorter timescales, weather phenomena (Vogt *et al.*, 1986; Sundarapandian and Swamy, 1999; Ostertag *et al.*, 2003). Despite differences in species composition and successional stage, the mean annual litterfall in the present study, was not significantly different for the gallery forest compared to the hill-slope forest. The mean annual litterfall obtained in both forests was within the range of published data for tropical evergreen forest and tropical plantations (Lowman, 1988; Njoukam *et al.*, 1999; Goma-Tchimbakala and Bernhard-Reversat, 2006).

Environmental factors played an important role in the production of litterfall in the Teke Plateau during the period of our experimentation. There was a lower litterfall in the second year of monitoring compared to the first, highlighting inter-annual variability in litter production. Nearly 56% (GF) and 35% (HF) of the annual litterfall in the first year was produced during March 2007. Local people reported a windstorm at that time which most likely accounts for the anomalous litter input. Other authors have also observed this effect (Ostertag *et al.*, 2003) observed it in six forests of Puerto Rico in which the litterfall increased by 55 to 93% immediately following a windstorm compared with the amounts taken during a normal collecting period. We noted also that the amount of litter on soil collected just after the windstorm was 1.6 times higher compared to the amount collected 14 months after. This unpredictable natural phenomenon highlights the importance of undertaking long-term sampling for over several years. Many authors have reported the effect of season on litterfall in tropical region, with greater litterfall in the dry season (Valenti *et al.*, 2008) but we did not observed any marked seasonal pattern of litterfall in our site.

The proportions of leaves in total aboveground litterfall may provide a good indication on the successional stage of tropical forests. This is because older forests allocate more production to fruits, flowers and seeds and have more branch production than younger forests. Leaves normally account for less than 70% of aboveground litterfall in old forests (Njoukam *et al.*, 1999; Lebret *et al.*, 2001). The much higher contribution of leaves in our study (96-99%) might indicate that the forest groves on Teke Plateau we studied are rather young. This is indeed corroborated for the hill-slope forest plots that are dominated by two pioneer species (*M. cecropioides* and *M. Barteri*). The gallery forest is dominated by *C. dewevrei* and *E. microspermum* which are characteristic of swamp forests of Central Africa. Swamp forests are thought to encounter more frequent blow downs that maintained them in a more juvenile stage because of shallow rooting pattern in waterlogged soils (Battaglia and Sharitz, 2006; Ferry *et al.*, 2010).

Climatic conditions (e.g., soil water content, temperature, etc) affect litter decomposition (Tripathi *et al.*, 2006; Pandey *et al.*, 2007). An important loss of litter dry mass in the first weeks of decomposition occurred when the experiment started in the wet season, while we noted a much slower decomposition of litter when the experiment started in the dry season. High soil moisture during the rainy season therefore enhanced the rates of litter decomposition in both forest groves. Several authors have noted the effect of the rainfall on litter decomposition in tropical forests (Bernhard, 1970; Devi and Yadava, 2007). This is because rainfall stimulates the growth of both bacteria and fungi (Clein and Schimel, 1993; Keith *et al.*, 1997). Additionally, the leaching action of rainfall releases water-soluble substances from decomposing litters (Bernhard-Reversat *et al.*, 2003). On the opposite, the decomposition decreases during the dry season most likely as a result of retarded activity of soil organisms (Tripathi and Singh, 1992). The decrease of soil water content causes the migration of the flora towards the deepest layer of litters, reducing the exposure of the litters to the microbial flora (Garay *et al.*, 1986). The difference we observed between the two types of forest groves during the second experiment might be related to the slight difference in soil water content with higher SWC in the gallery forest than in the hill-slope one, rather than to species-related differences.

The lack a marked difference in litter input and decomposition between the two forest groves accounted for the similarity in litter accumulation on the forest floor. This is in agreement with results obtained in a chronosequence of secondary forests showing that canopy closure, rather than species composition, appears to be the factor explaining litter inputs and decomposition (Ostertag *et al.*, 2008). The fact that the amount of litter on the floor was not at steady state because of high inter annual variability of litterfall precluded estimation of mean residence time of carbon on the forest floor. However, the large decrease in litter amount between March 2007 and May 2008 (1293 g m^{-2} in GF and 698 g m^{-2} in HF) despite a substantial input between these two dates (809 g m^{-2} in GF and 1126 g m^{-2} in HF) suggests a rapid cycling of aboveground litter with a residence time of about one year.

In conclusion, despite differences in species composition and forest structure (tree density and basal area), there is no substantial differences in the accumulation of aboveground litter on the forest floor in two different types of forest groves that developed on the Plateau Teke. This was explained by similar litter inputs which are characteristic of rather young forests and similar leaf litter decomposition that seems to be mainly driven by seasonal changes in soil water content. Present results have highlighted high temporal variability of aboveground litterfall in relation with climatic events. Longer-term measurements would undoubtedly help us arrive at a more accurate assessment of litterfall. Accumulation of carbon on the forest floor in these expanding forest groves as compared to native savannah where aboveground litter input is offset by annual burning will be critical in the frame of carbon accounting programs in Central Africa.

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