Litter Decomposition and Nutrient Dynamics in Tropical Rainforests of Ebom, Southwestern Cameroon: Effects of Logging-Disturbed

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Abstract: The impact of logging on litter decomposition and nutrient release was poorly understood in tropical rainforests. Litter decomposition *in situ* and nutrient dynamics of selected four tree species, Bubinga (*Guibourtia tessmannii* (Harms) J. Leonard), Ngon (*klainedoxa gobonensis* Pierre ex Engl.), Asseng (*Musanga cecropioides* (Dunal) A. Rich) and Akui (*Xylopia aethiopiaca* R. Brown ex Tedlie) were compared in undisturbed and logging sites of Ebom tropical rainforest, Southwest Cameroon. After 14 weeks of field experiment, dry mass remaining varied from 43.82% in *G. tessmannii* to 79.82% in *M. cecropioïdes* of initial dry mass in undisturbed site, and from 13.36% in *G. tessmannii* to 81.84% in *M. cecropioïdes* in the logging site. Decomposition rate constants (k % per week) ranged from 0.02 in *M. cecropioides* to 0.14 % per. week in *G. tessmannii* in undisturbed forest and from 0.04 % per week in *X. aethiopiaca* to 1.7 % per week in *G. tessmannii* in logging forest. In undisturbed forest, litter of *G. tessmannii* was rich in initial Nitrogen (N), Magnesium (Mg), Potassium (K) and Phosphorous (P) contents, and poor in initial Calcium (Ca) content. Conversely, litter of *M. cecropioides* was rich in initial N and Ca contents, and poor in Mg, K and P while that of *K. gabonensis* was poor in initial N content. Apart from Sodium (Na), all the other nutrients were released from decomposing litter 14 weeks after incubation in undisturbed site with mean released rate between 84.82% for K and 5.41% for P. In both sites, litter decomposition and nutrient dynamics of *G. tessmannii* were fastest while that of *M. cecropioides* was lowest and those of the other species intermediate. Initial nutrient content of all species was generally higher in logging site than in undisturbed one, except Ca content in litter of *M. cecropioides*. Litter decomposition and nutrient releases were similar in logging and undisturbed sites, excepted for *G. tessmanni* where litter decomposition and nutrient release were higher in logging than undisturbed site. The high turnover of litter and nutrients in logging site suggest that logging activities have little impact on litter decomposition and nutrient dynamics.

Keywords: Litter decomposition, nutrients dynamics, logging, tropical rainforest, cameroon.

1. INTRODUCTION

The tropical rainforest of Cameroon cover averagely 40% of the national territory in the south part [1]. They are subject of degradation, particularly reduction of habitats and biodiversity. Recent estimations of indicated that at least 0.14% of these forests disappear annually between 1990 and 2000, due to slash-and-burn agriculture and logging activities [2]. This information differs from estimates of FAO and OIBT [3], which, taking into account the national territory and all forest vegetation , assessed the deforestation rate at 1.02 % for 2005-2010. Thus, the actual most probable alternative way to degradation and enabling in the same time sustainable exploitation of these forests is their sustainable management. On of the aspects to take into account in the sustainable forest management is the nutrient cycling, including plant litter decomposition process and nutrient dynamics.

Litter decomposition is a great importance in determining the functioning of forest ecosystem in tropical areas. The nutrient release from decomposing litter plays a significant role in nutrient cycling and maintaining the productivity of forest ecosystems, as well as the regeneration of seedlings [4, 5]. Numerous factors, including resource quality, decomposer community and climate have been recognized to strongly influence plant litter decomposition rates. The initial content of N, lignin, P, and the C/N, C/P, lignin/N ratios [6, 7, 8] or litter toughness and thickness [9, 10, 11] influence litter decomposition process according to regions. The most climate factors taken into consideration are probably moisture and temperature. Moisture is considered as a preponderant factor in the regulation of litter decomposition [12, 13]. But some studies have shown that temperature constitutes a dominant climatic factor ([14, 4]). In contrast, other studies have carried out that temperature and moisture interact in natural conditions and the effects of these interactions on litter decomposition rates are important than individual effects [15].

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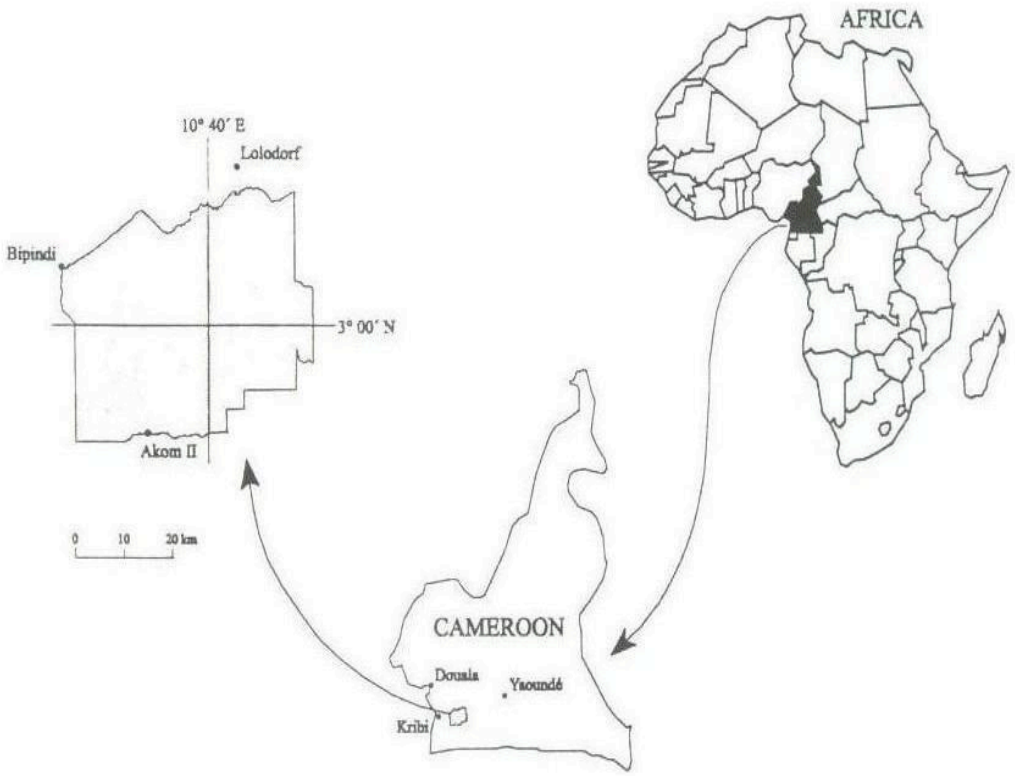

Figure 1: Location of TCP research area in southwest Cameroon [27].

Other variables that affect litter decomposition process and nutrients release in the tropical rainforests are disturbances ([16, 17]). Natural or artificial gaps resulting from logging are considered as a disturbance, which alter the environmental conditions, such as temperature, availability of light, nutrients and moisture to plants ([18, 19]). These changes affect the flora and fauna composition and influence the plant litter decomposition process [20]. In West and Central Africa, an estimated 0.43% of the rain forest are deforested annually, mainly for agricultural purposes [21], while logging operations are estimated to affect another 0.7% [22]. The present-day human induced disturbances are generally more frequent and more intense than the natural disturbance regime during the last few millennia. As a result, a shift in species composition and diversity, and functioning is likely to occur [23]. The growing pressure on tropical rain forest functioning requires the design (and implementation) of effective conservation strategies and sustainable forms of forest use. Few studies have been carried out to understand the effects of logging activities on litter decomposition process in tropical rainforests ([16, 24, 25]). The purpose of this study is to determine the impact of logging activities on plant litter decomposition and nutrient release in tropical rainforest of Ebom, southwest Cameroon.

2. MATERIALS AND METHODS

2.1. Study Sites

The experiment was conducted in Ebom undisturbed forest, within the Tropenbos Cameroon Programme (TCP) research area, which is located in the western portion of the Atlantic Biafrean forest of south Cameroon, lying within the Congo-Guinea refuge (Figure **1**). The experimental sites are located at 3º05'N and 10º41'E, with elevation of ~440 m. The bedrock is composed of Precambrian metamorphic as well as old volcanic rocks [26]. The soil is very clayey (35-70%) and strongly acidic [27]. The climate is humid tropical with four seasons: a long dry season (from mid-November to mid-March) and a short one (mid-May to mid-August) and a short rainy season (mid-March to mid-May) and a long rainy season (mid-August to mid-November). Mean annual rainfall is about 2100mm and mean annual temperature is 22.9°C [27]. The portion of forest selected for experiment was characterized by the absence of recent natural or human disturbance. Relevant characteristics of these sites like location, rainfall data and soil physico-chemical characteristics are presented in Table **1**. Vegetation consists of evergreen forest rich in caesalpiniaceae [28], characterised by tall trees that reach heights of about 60m. Tree density was about 521 trees per hectare,

Table 1: Physico-Chemical Characteristics of the Ebom Rainforest[1]

Variables	Data
Location	3°05'N, 10°41'E
Elevation (m a.s.l.)	440
Rainfall (mm)[2]	2115.3
Relief intensity (m)	moderate (30-80)
River density	moderate
Vegetation	lowland forest
Soil types	Ultisols/Oxisols (infertile)
Clay (topsoil, 0-10cm) (%)	20-50 (clayey)
sandy (%)[3]	40-60
pH (water)[3]	4.7
Carbon (%)[3]	4-8
Nitrogen (%)[3]	0.25-0.50
C/N	10
Available P (ppm)	12-26
Total P (ppm)[3]	150-400
K (meq/100g of soil)[3]	0.1-0.9
Mg (meq/100g of soil)[3]	0.4-1.6
Ca (meq/100g of soil)[3]	0.5-4
Al (meq/100g of soil)[3]	0.5-6

[1] Source: van Gemerden and Hazeu [27].

[2] Annual mean of rainfall collected from 1996 to 2000.

[3] topsoil (0-10cm depth).

basal area of about 29.84m^2ha^{-1} and diameter classes ranged from 9.39 to 150cm, with a mean of 21.34cm [29]. At some places in the forest Bantou people practice shifting agriculture with short fallows [30], while Banyeli Pygmee live from gathering and hunting. Many non-timber forest products like bushmeat, honey, mushrooms, fruits, leaves, seeds and roots are harvested [31].

Two sites with a same soil type were selected in the experimental area in the catchments of Bibo'o Minwo near Ebom: one in undisturbed forest at 15km away in the north of Ebom, characterized by the absence of recent natural or human disturbance. The vegetation consists of evergreen forest rich in caesalpiniaceae, with four strata and one closed canopy [32]. Tree density was about 521 trees per hectare with a basal area of 29.84$m^2.ha^{-1}$. Diameter classes ranged from 9.39 to 150cm, and a mean DBH of 21.34cm. The other site is located at Ebom in the disturbed part of forest due to logging activities, which stopped since 1996. The vegetation of this site is dominated by pioneer species, particularly Musanga (*Musanga cecropioides* R. Brown ex. Tedlie). Tree density, the basal area and the mean DBH are respectively 417 trees per hectare, 28.48$m^2.ha^{-1}$ and 22.91cm; the diameter classes ranged from 9.20 to 141.72cm. The annual litter production is 9.07 t. ha^{-1} [29].

2.2. Litter Selection

In this study, only freshly-fallen leaf litter of four contrasting and dominant species was selected (Table **2**). There are including *Guibourtia tessmannii* (Harms) J. Leonard, (Caesalpiniaceae), *klainedoxa gobonensis* Pierre ex Engl., (Irvingiaceae), *Xylopia aethiopica* (Dunal) A. Rich, (Annonaceae) and *Musanga cecropioides* R. Brown ex Tedlie, (Cecropiaceae). The first two species belong to climax tree species, while the other are pioneer species dominating degraded forest such as *M. cecropioides* with 60 trees per hectare. *Xylopia aethiopica* is classified as a Riverine species. The litter samples were collected from twenty litter traps previously put in each site, during the litterfall experiment [29], shorted by species and dried in the oven at 60C. Because of the absence of *G. tessmannii* in the logging site, its leaf litter comes only from undisturbed site.

Table 2: Density (trees/ha), Basal Area (BA, in m^2ha^{-1}) and Leaf Litterfall ($kg.ha^{-1}$) Collected in Undisturbed and Logging Sites of Tropical Rainforest of Ebom, Southwest Cameroon

Family	Species	Undisturbed site				Logging site		
		Density	BA	Quantity[1]	Quanti-ty[2]	Density	BA	Quantity[2]
Caesalpiniaceae	*G. tessmannii* (Harms) J. Leonard	1	1.77	227.24	230.24	0	0	34.16
Irvingiaceae	*K. gabonensis* Pierre ex. Engl.	7	1.57	176.06	204.15	4	1.39	273.17
Cecropiaceae	*M. cecropioides* R. Brown ex. Tedlie	6	0.83	208.38	210.05	60	2.84	217.87
Annonaceae	*X. aethiopica* (Dunal) A. Rich	1	0.10	93.75	94.28	10	2.21	234.54

[1]Litterfall from January to December 2000 and

[2] from February 2000 to January 2001. *Guibourtia tessmannii, Klainedoxa gabonensis, Musanga cecropioides* and *Xylopia aethiopica.*

2.3. Litter Decomposition Experiment

Litterbag method was used in evaluating litter decomposition rates ([33, 34]). They consist of nylon material with a 2-mm mesh size and they were different sizes according to litter type to avoid compression of material. The choice of the litterbags and mesh sizes was based on other studies in tropical forests [12]. A total of 60 litterbags (5 sampling dates x 3 replications x 4 species) were filled with 5 ± 0.01g of litter and placed on top soil of each site, from January to April 2001. Three litterbags per species were collected at 2, 4, 6, 9 and 14 weeks intervals, brought to the laboratory in Kribi to discard all the roots, fauna, and soil particles. The dry mass of the samples in each litterbag was determined after it was oven dried at 60°C to constant mass. To determine the initial dry mass and nutrient content, three supplementary litter samples of each species were weighed and dried at 60°C to constant mass. The residual mass percentage in each litterbag was determined using the following equation: $(DM_t/DM_0) \times 100$, where DM_0 is the initial dry mass and DM_t the residual dry mass at time t.

2.4. Chemical Analysis

All the samples were transformed into powder through a *Micro Hammer Mill Culatti* grinder equipped with a 1mm link filter and were analysed. The samples were first mineralised by passing the powder through a furnace at 550°C for 40mn. The ashes were recollected with a diluted HNO_3 solution for nutrient analyzing: Ca and Mg were determined by atomic absorption spectrophotometer; K and Na by flame spectro-photometer; P by vanado - molybdate colorimeter. N analysis was done by the Kjeldhal method and its titration by sulphuric acid at 0.01N.

2.5. Statistical Analysis

The decomposition rate constant (k) was estimated, using the simple negative exponential decay function [35]:

$$DMR = 100e^{-kt}$$

Where DMR is the litter dry mass remaining at time t.

The amount of nutrient remaining express in percentage of initial quantity was calculated from the following equation [36]:

$$QR = (C/C_0)*(DM_t/DM_0)*100$$

Where QR is the amount of nutrients remaining (%); C and C_0 are respectively the nutrient content at time t and t_0 or initial time; DM_t and DM_0 are dry mass at time t and t_0.

Before performing any statistical analysis, all variables were tested for normality and if necessary (usually) were transformed. The comparison of dry mass remaining (DMR) at the end of incubation (at 14 weeks), as well as the nutrient remaining among species was carried out by using ANOVA, followed by *Scheffe*'s test at 5%, if ANOVA was significant. A multiple comparison among the decay rate constants (k) was also carried out using the *T'method* [37].

The quantity of nutrient at the last incubation time (after 14 weeks of incubation) was compared to those measured in the initial litter for each species (*Student* t test). The loss of nutrients was calculated as the difference between the initial absolute amount and the final one of each nutrient (mg), while the same difference was also expressed as the percentage of the initial amount (%). These tests were conducted through SX software (*statistix, version 4.0, Analytical software* 1992).

3. RESULTS

3.1. Litter Mass Loss Dynamics

At the end of incubation time, the dry mass remaining of the four litters varied from 43.82 in *G. tessmannii* to 79.82% of initial dry mass in *M. cecropioïdes* in undisturbed site, and from 13.36 to 81.84% respectively for the same species in logging site (Table 3). The difference between species was significant in the two sites. The comparison of means by *Scheffe* test at 5% level showed that loss in dry mass was significantly the highest in *G. tessmannii* (56.18 and 86.64%) and the lowest in *M. cecropioïdes* (20.18 and 18.16%) respectively in undisturbed and logging sites. However, the later species did not significantly differ from *X. aethiopica*. *K gabonensis* has an intermediate position in the two sites. The coefficients of variation (CV) were higher for *G. tessmannii* in the two sites and for *K. gabonensis* in logging site, suggesting high variability between replicates.

The average loss in dry mass of all the litters including was higher in logging site (45.22 ± 31.56) than undisturbed one (33.3 ± 16.51), although the difference between the two sites was not significant ($t=0.67$, $P>0.05$). The CV of the corresponding average dry mass remaining were high in undisturbed (0.50) and logging (0.70) sites. Similarly the dry mass loss of

Table 3: Litter Dry Mass Remaining (DMR) in Percentage of Initial Dry Mass and Coefficient of Variation (CV) after 14 Weeks of Incubation Time in Undisturbed and Logging Forest of Ebom, Southwest Cameroon. Standard Deviation in Parenthesis

Species	Undisturbed Site		Logging Site		t *Student*
	DMR (%)	CV	DMR (%)	CV	
G. tessmannii	43.82 (18.92)b	0.432	13.36 (7.09)b	0.531	3.09*
K. gabonensis	65.48 (3.45)ab	0.053	47.18 (20.96)ab	0.444	1.61ns
M. cecropioides	79.82 (5.30)a	0.066	81.84 (6.67)a	0.082	0.41ns
X. aethiopica	77.68 (5.28)a	0.068	76.76 (8.33)a	0.109	0.16ns
F	7.68**		19.38**		

*P<0.05; ** P<0.01 and ns: non significant.

each species was higher in logging site than in undisturbed one, with the exception of *M. cecropioïdes* (Table **3**). Despite this apparent difference, the two sites did not significantly differ according to the litter mass loss, except for the *G. tessmannii* litter.

The dynamics of DMR varied also according to plant species and site (Figure **2**). A part from G. tessmanni, the three other plant species did not show a fast mass loss at the beginning of the litter incubation *in situ* in undisturbed site. The dry mass loss in logging site was faster than that of undisturbed one, although this difference between the two sites tended to die down with the time course of litter decomposition excepted *G. tessmanni*.

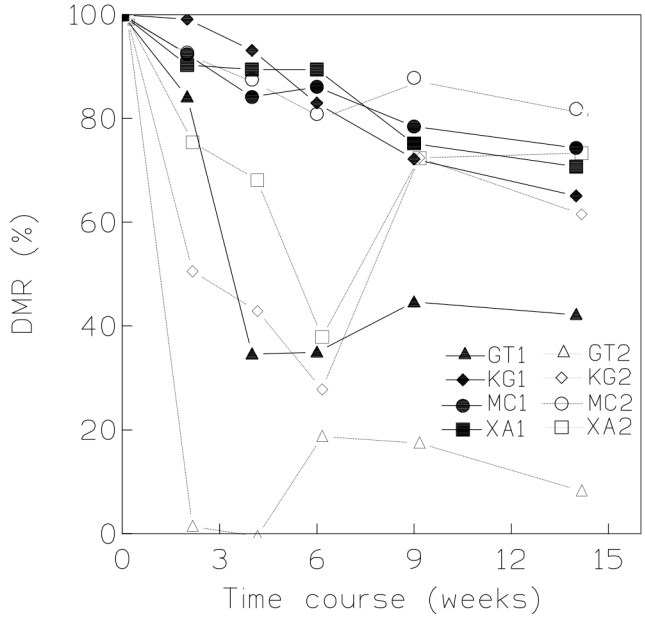

Figure 2: Litter dry mass remaining (DMR) dynamics during 14 weeks of field incubation times in undisturbed (1) and logging (2) sites of Ebom rainforest of Southwest Cameroon.

Guibourtia tessmannii (GT), *Klainedoxa gabonensis* (KG), *Musanga cecropioides* (MC) and *Xilopia aethiopica* (XA).

3.2. Litter Decomposition Rate Constants

The simple exponential function was used to determine the litter decomposition rate constants (Table **4**). The coefficients of determination, despite their high variation between plant species were highly significant for undisturbed site. The values of the litter decomposition constants were ranged from 0.02 to 0.14 week^{-1} in the undisturbed site. The litters of *G. tessmannii* showed the fastest decomposition (0.14 week^{-1}) and that of *M. cecropioides* the slowest (0.018 week^{-1}). In contrast, the coefficients of determination of adjustment were not significant in the logging site, except for *G. tessmannii* and *X. aethiopica* (Table **4**). The simple exponential model was not convenient to the litter decomposition of *K. gabonensis* and *M. cecropioides* 14 weeks after incubation. The two sites differed according to the litter decomposition constant. *G. tessmannii* and *X. aethiopica* exhibited the higher litter decomposition constant in logging site than in undisturbed site.

3.3. Nutrient Loss in Decomposing Litters

Nutrient contents of initial litters varied between species in the two sites (Table **5**). The N and K contents were significantly the highest in *G. tessmanni*i respectively 17.01 and 7.59mg/g, and the lowest in K. gabonensis for N (9.17mg/g) and in *M. cecropioides* for K (0.89mg/g). Conversely, the Ca content was the highest in *M. cecropioides* (2.72mg/g) and the lowest in *G. tessmanni*i (0.67mg/g) in the undisturbed site. Similar to undisturbed site, N, Ca and K contents in the initial litters were significantly differed between species in the logging sites (Table **5**), but, the N and K contents were significantly the highest in *M. cecropioides* respectively 20.30 and 8.80mg/g, and the lowest in K. gabonensis for N (9.38mg/g) and in *X. aethiopica* for K (4.88mg/g). Conversely, the Ca content was the

Table 4: Simple Exponential Equation (DMR = 100*e^{-kt}) Describing Changes in DMR (in % of the Initial Mass) with Incubation Time (in Weeks). Standard Error in Parenthesis

Species	Undisturbed Site		Logging Site	
	K ($week^{-1}$)	R^2	K ($week^{-1}$)	R^2
G. tessmannii	0.140 (0.021)a	0.726	1.697 (1.685)a	0.824
K. gabonensis	0.028 (0.002)b	0.849	0.088 (0.024)	0.292
M. cecropioides	0.018 (0.003)b	0.561	0.018 (0.005)	0.121
X. aethiopica	0.022 (0.002)b	0.871	0.041 (0.008)b	0.552

R^2: coefficient of determination.

Table 5: Nutrient Contents (mg/g) in Initial Litters of Undisturbed and Logging Sites of Ebom Forest. Standard Deviation in Parenthesis

Species	Undisturbed Site						Logging Site						Student's t (between the Two Sites)					
	N	Ca	Mg	K	Na	P	N	Ca	Mg	K	Na	P	N	Ca	Mg	K	Na	P
GT	17.01 (0.26) a	0.67 (0.26) b	0.46 (0.26)	7.59 (0.26) a	0.006 (0.0026)	0.74 (0.26)	17.01 (0.26) a	0.6 (0.26) b	0.46 (0.26)	7.59 (0.26) a	0.006 (0.0026)	0.74 (0.26)	-	-	-	-	-	-
KG	9.17 (0.84) c	2.59 (0.84) a	0.14 (0.13)	5.67 (0.84) a	0.007 (0.008)	0.45 (0.44)	9.38 (0.84) d	2.03 (0.84) b	0.15 (0.84)	6.56 (0.84) ab	0.006 (0.005)	0.46 (0.45)	0.25 ns	0.66 ns	0.01 ns	1.05 ns	0.12 ns	0.01 ns
MC	12.25 (0.16) b	2.72 (0.16) a	0.06 (0.016)	0.89 (0.16) b	0.005 (0.005)	0.34 (0.16)	20.30 (0.16) a	1.47 (0.16) b	0.19 (0.016)	8.80 (0.16) a	0.013 (0.0016)	1.05 (0.16)	51.7 5***	8.04*	8.36*	50.85 ***	5.14*	4.56*
XA	10.57 (0.46) bc	1.83 (0.46) bc	0.25 (0.24)	1.89 (0.46) b	0.005 (0.0046)	0.40 (0.39)	13.30 (0.46) c	6.78 (0.46) a	0.65 (0.46)	4.88 (0.46) b	0.025 (0.0046)	0.66 (0.46)	5.90*	10.7 **	0.86 ns	6.47*	4.32 ns	0.56 ns
F	91.34 ***	6.94*	0.24ns	77.85 ***	0.07ns	0.25 ns	73.99 ***	59.36 ***	0.45 ns	21.60 **	6.30 ns	0.47 ns						

GT: *Guibourtia tessmannii*; KG: *Klainedoxa gabonensis*, MC: *Musanga cecropioide*s and XA: *Xylopia aethiopica*;. *P<0.05; ** P<0.01; *** P<0.001 and ns: non significant.

highest in *X. aethiopica* (6.78mg/g) and the lowest in *G. tessmanni*i (0.67mg/g). The other nutrient contents were not significantly different between species in the two sites.

The nutrient contents of the initial litters differed significantly between undisturbed and logging sites only for *M. cecropioides* (Table **5**). N, Ca, K were significantly higher in logging site than undisturbed site for *X. aethiopica*, while all the nutrient contents for *M. cecropioides* were significantly higher in logging site than undisturbed one, except Ca which was inversely significantly lower in logging site than undisturbed site.

After fourteen weeks of incubation *in situ* all the nutrient contents were averagely released, except Na in undisturbed site and Ca, Mg and Na in logging site (Table **6**). The three last nutrients continued to be immobilized in litters. The nutrient losses ranged from 18.49 for K to 0.12mg for P, with corresponding rates of 84.82 and 5.41% of initial amount in undisturbed site. These losses varied from 1.51mg for P to 24.20mg for N, with corresponding rates of 42.66 and 33.15% of initial amount in logging site. The loss order of nutrients was the following: K > Mg > Ca > N > P in undisturbed site and K > P> N in logging site.

Individually, all the species did not have the same patterns as far as the nutrient release was concerned (Table **7**). In the undisturbed site, the litter of *G. tessmannii* released all the nutrients apart from Na during the fourteen weeks of incubation. In contrast, the litter of *X. aethiopica* released three nutrients and the other litters four nutrients. Apart from N in *X. aethiopica*, four nutrients (N, Ca, Mg and K) were released in each of the three specie with the following orders: Mg > K> Ca in *X. aethiopica*, K > Mg > Ca > N > P in *G. tessmannii*, K > Ca > N > Mg in *K. gabonensis* and Mg > K > Ca in *M. cecropioides*. In contrast there is no net tendency of nutrient release in logging forest, except K was released by all the species and P released by *G. tessmannii* and *K. gabonensis* species.

Table 6: Average Values of Gain and Loss (+/-) of the 4 Litter Nutrients after 14 Weeks of Field Litter Incubation Calculated from Initial Litter to 14 Weeks of Decomposition. Standard Deviation in Parentheses

Nutrients		Undisturbed Plot	Logging Plot	t *Student*
N	Initial quantity (mg)	55.80 (3.92)	73.00 (3.63)	2.12*
	Final quantity (mg)	41.10 (6.69)	48.80 (10.40)	1.01ns
	Gain (+) or loss (-) (mg)	- 14.70	- 24.2	
	%	26.34	33.15	
Ca	Initial quantity (mg)	8.58 (0.60)	13.00 (0.34)	1.11ns
	Final quantity (mg)	3.78 (0.31)	16.50 (3.60)	5.41***
	Gain (+) or loss (-) (mg)	- 4.80	+ 3.50	
	%	55.94	26.92	
Mg	Initial quantity (mg)	1.11 (0.08)	1.81 (0.07)	1.76ns
	Final quantity (mg)	0.36 (0.09)	2.07 (0.35)	5.18***
	Gain (+) or loss (-) (mg)	- 0.75	+ 0.26	
	%	67.57	14.36	
K	Initial quantity (mg)	21.80 (2.00)	32.5 (1.59)	2.17*
	Final quantity (mg)	3.31 (0.58)	9.91 (1.92)	3.51**
	Gain (+) or loss (-) (mg)	- 18.49	- 22.59	
	%	84.82	69.51	
Na	Initial quantity (mg)	0.03 (0.003)	0.06 (0.002)	2.90*
	Final quantity (mg)	0.08 (0.01)	0.13 (0.03)	1.43ns
	Gain (+) or loss (-) (mg)	+ 0.05	+ 0.07	
	%	166.66	116.67	
P	Initial quantity (mg)	2.22 (0.20)	3.54 (0.18)	3.11**
	Final quantity (mg)	2.10 (0.40)	2.03 (0.38)	0.21ns
	Gain (+) or loss (-) (mg)	- 0.12	- 1.51	
	%	5.41	42.66	

*P<0.05; ** P<0.01; *** P<0.001 and ns: non significant.

The average loss of nutrients were generally higher in undisturbed than in logging site, except for N (33.15 > 26.34%) and P (42.66 > 5.41%) with release rates higher in logging than undisturbed sites (Table **6**). The order of nutrient loss in logging site (K>P>N) was different from that of undisturbed site (K>Mg>Ca>N>P). An individual analysis of species showed that compared to undisturbed site, there was no net tendency of nutrient loss or gain in logging site (Table **7**). After 14 weeks of litter incubation *in situ*, there was release of K and immobilization of Na in all the litters.

The nutrient dynamics during 14 weeks of incubation *in situ* varied according to the species and nutrient (Figure **3**). Ca and K decreased with incubation time for all the species, while P and N were immobilized in the litters, except in the litter of *G. tessmannii* that released these two nutrients from the beginning of incubation time. Mg and Na did not show net patterns. Their dynamics varied according to species.

4. DISCUSSION

4.1. Comparison of Litter Decomposition Model between Undisturbed and Logging Sites

The coefficient of determination of fitting of DMR to simple exponential model was highly significant (P<0.01) for all the litters in the undisturbed site and not significant for *M. cecropioides* and *K. gabonensis* in the logging site for the simple reason that dry mass loss of the two species during time course of decomposition did not fit to the simple exponential function. This finding would explain by the slow decomposition (18.16%) or short-term of

Table 7: Gains and Loss (+/-, in mg) of Litter Nutrients after 14 Weeks of Litter Decomposition, Calculated between Nutrient Quantity of Initial Litter and 14 Weeks of Field Incubation. Standard Deviation in Parenthesis

Nutrients		Undisturbed site					Logging site				
		GT	KG	MC	XA	F	GT	KG	MC	XA	F
N	Qi	78.4 (3.20)	44.00 (5.50)	55.00 (1.80)	46.00 (3.50)	49***	79.5 (3.49)	44.00 (3.5)	93.6 (5.17)	60.40 (0.85)	53**
	Qf	28.70(12.40)	37.40 (1.97)	48.10 (3.19)	50.00 (3.40)	7*	7.62 (4.04)	50.60 (22.5)	57.6 (4.70)	66.30 (6.38)	14**
	+/-	- 49.7	- 7.6	- 6.90	+ 4.0		-71.88	+ 6.60	- 36.00	+ 5.90	
	%	63.39	17.27	12.55	8.70		90.42	15	38.46	9.77	
Ca	Qi	3.10 (0.12)	12.40 (1.55)	12.10 (0.40)	7.97 (0.60)	66***	3.11 (0.14)	9.54 (3.6)	6.79 (0.38)	30.80 (0.43)	266***
	Qf	0.83 (0.36)	4.89 (0.26)	4.46 (0.30)	4.92 (0.38)	118***	3.45 (1.83)	17.4 (7.75)	17.7 (1.44)	23.50 (2.26)	13**
	+/-	- 2.27	- 7.51	- 7.64	- 3.05		+ 0.34	+ 7.86	+ 10.91	- 7.30	
	%	73.23	60.56	63.14	38.27		10.93	82.39	160.68	23.70	
Mg	Qi	2.12 (0.09)	0.67 (0.08)	0.27 (0.01)	1.09 (0.08)	280***	2.15 (0.09)	0.70 (0.02)	0.88 (0.05)	2.95 (0.04)	449***
	Qf	0.38 (0.16)	0.59 (0.03)	0.03 (0.002)	0.43 (0.03)	23**	0.48 (0.26)	1.49 (0.66)	3.33 (0.27)	2.25 (0.22)	28***
	+/-	- 1.74	- 0.08	- 0.24	- 0.66		- 1.67	+ 0.79	+ 2.45	- 0.70	
	%	82.08	11.94	88.89	60.55		77.67	112.86	278.41	23.73	
K	Qi	35.00 (1.40)	27.00 (3.38)	14.50 (0.50)	8.28 (0.62)	105***	35.5 (1.56)	30.8 (5.30)	40.50 (2.24)	22.20 (0.31)	48**
	Qf	2.51 (1.08)	3.79 (0.20)	3.13 (0.21)	3.82 (0.26)	3ns	2.22 (1.18)	8.81 (3.92)	18.40 (1.50)	7.30 (0.70)	32**
	+/-	- 32.49	- 23.21	- 11.37	- 4.46		- 33.28	- 21.99	- 22.10	- 14.9	
	%	92.83	85.96	78.41	53.86		93.75	71.40	54.57	67.12	
Na	Qi	0.03 (0.001)	0.03 (0.003)	0.03 (0.007)	0.02 (0.002)	16**	0.03 (0.001)	0.03 (0.00)	0.06 (0.003)	0.11 (0.002)	608***
	Qf	0.03 (0.01)	0.07 (0.004)	0.09 (0.006)	0.14 (0.01)	81***	0.02 (0.01)	0.13 (0.06)	0.07 (0.01)	0.26 (0.02)	37***
	+/-	0.00	+ 0.04	+ 0.09	+ 0.12		- 0.01	+ 0.10	+ 0.01	+ 0.15	
	%	0.00	133.33	300	600		33.33	333.33	16.67	136.36	
P	Qi	3.37 (0.15)	2.10 (0.30)	1.49 (0.01)	1.67 (0.15)	51***	3.45 (0.15)	2.16 (1.02)	4.85 (0.27)	2.99 (0.04)	62***
	Qf	1.70 (0.76)	2.27 (0.15)	2.06 (0.14)	2.37 (0.15)	2ns	0.50 (0.27)	1.64 (0.73)	2.06 (0.17)	3.27 (0.31)	22**
	+/-	- 1.67	+ 0.17	+ 0.57	+ 0.70		- 2.95	- 0.52	- 2.79	+ 0.28	
	%	49.55	8.10	38.26	41.92		98.66	24.07	57. 53	9.36	

Qi and Qf are the nutrient amounts of initial and final litter (mg). Gain and loss (+/-) of nutrients expressed in mg and in percentage.

decomposition for *M. cecropioides* and high variability between replicates for *K. gabonensis* (high standard deviation and CV). In fact, Wieder and Land [38] suggest that litter types with a large labile fraction will show exponential decay, while decay of those with a small labile fraction will be linear. Thomas [39] also obtained an extremely good fit (R^2 = 0.99) to a linear model of pine needle decay with a slow decomposition (48% mass loss). In other side, Taylor and Parkinson [40] have shown that after 16 weeks of incubation in microcosms, litter decomposition of aspen (*Populus tremuloides* Michx) exhibited linear decay.

In the logging site, most of the litterbags were invaded by mesofauna, particularly ant species at the second weeks after litter incubation and they

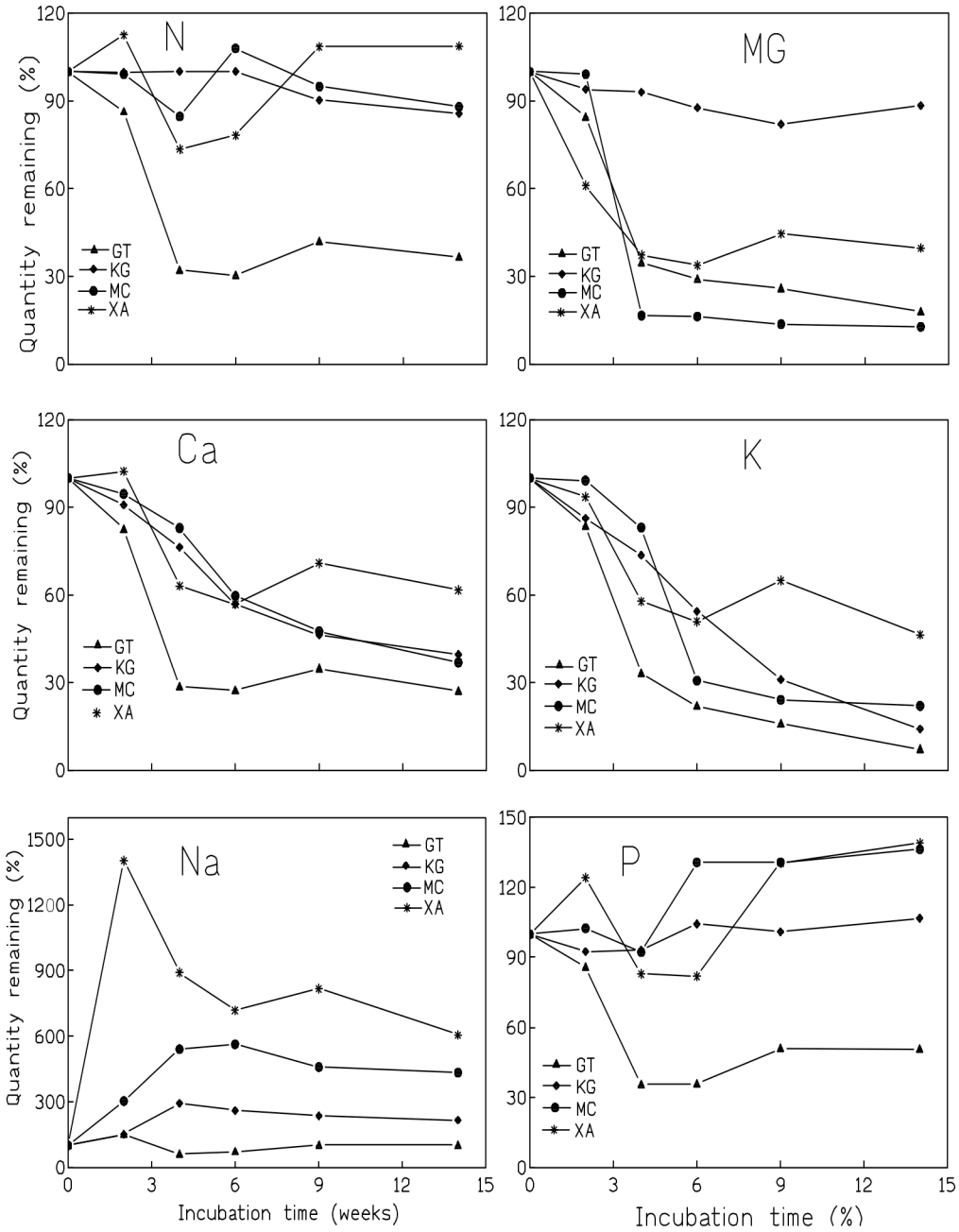

Figure 3: Nutrient dynamics of four litters during 14 weeks of field incubation time in undisturbed site of Ebom rainforest of Southwest Cameroon.

Guibourtia tessmannii (GT), *Klainedoxa gabonensis* (KG), *Musanga cecropioides* (MC) and *Xilopia aethiopica* (XA).

contributed significantly to breakdown of litter and to the loss of their fragments, but in disorganized manner. Similar observations were reported by Ibrahima [34] on litter decomposition of four Mediterranean species in four sites using two types of litterbags, small (0.5mm) and medium (1mm) mesh sizes. One of the four sites was characterized by the absence of soil mesofauna such as earthworm. His results have revealed that the variability between replicates at each sampling date increases with time course of incubation, except in two cases: the litters enclosed in litterbags with small mesh size and those incubated in site characterized by the absence of soil mesofauna. In these cases, the coefficients of variation (CV) between replicates were low. According to the same author, the litterbags with small size have probably limited the soil fauna in the litterbags and prevented the loss of fragments of litters from litterbags. In the site where the soil mesofauna was not much, their action was low, and this appears to explain why the CV remained low in this site.

4.2. Comparison of Litter Decomposition Process between Undisturbed and Logging Sites

Numerous studies in the tropical rainforest have shown that the litter decomposition process was significantly lower in disturbed forest by logging or agriculture than in undisturbed one. Ewel [41] has found that the litter decomposition was 10 to 18% lower in disturbed forest than in undisturbed one. These results are similar to those of Brouwer [24] in the Guyana tropical rainforest developed on infertile soils (Oxisols/Ultisols). Maheswaran and Gunatilleke [42] have also reported that the litter decomposition was considerably lower in disturbed fernland forest than in adjacent undisturbed rainforest zones. Ritter [43] has shown that after 1 year of decomposition, litter mass loss was significantly higher in the closed forest or small gap (17 m of diameter) than in the large gap (30 m of diameter) in a Danish beech (*Fagus sylvatica* L.) forest. The alteration of physical conditions of the area and the destruction of fauna and flora due to logging activities were the reasons used to explain these differences [41, 24, 16]. The temperature and sunlight radiations were higher in the forest gaps than in closed forest. The combination of higher and more stable moisture with higher and more stable temperature may be the main causes of higher biological activity, which lead to higher litter decomposition in undisturbed forest or small gaps. In contrast, in the open forest gaps, lower litter decomposition rate was attributed to a higher exposure of the forest floor to incoming radiation and wind [44].

Other explanations reported in the literature to justify the difference between the disturbed and undisturbed forests according to litter decomposition are the degradation of plant roots density and their associated mycorrhiza which play an important role in the litter decomposition ([24, 45]) and the forestry succession [46]. In the gaps created by the logging, the felling of trees and the soil damage lead to the death of plant roots and associated mycorrhiza. Onguene [47] has reported that the number of spores and mycorrhiza associated to roots were lower in logging site (skid trails and landing) than in natural forest. These plant roots and their associated mycorrhiza will only be restored after numerous years. Similarly, Brouwer [24] has shown that the colonization of litterbags by fungi and roots decrease from natural forest towards to disturbed forest, and the loss of dry mass of plant litters in the same way.

Our results on the fine roots invading the litterbags contradict with those of Brouwer [24]. We have observed that the density of fine roots and the number of ant species in litterbags were higher in logging site than in undisturbed site. our results have indicated that the litter decomposition was significantly faster in logging site than in undisturbed site for *G. tessmannii* and did not significant different between logging and undisturbed sites for the other species. These results supported the finding of Chaćon and Dezzeo [48] in the Gran Sabana of Venezuela forest. They have reported that there was no significant difference between primary forest and disturbed forest by the fires according to 1 year litter decomposition, with mass loss of 31% and 25% of initial mass respectively. Ritter [43] has also shown that after 1 year of litter decomposition, there was no significance difference between the small gap (17 m of diameter) and closed forest in a Danish beech (*Fagus sylvatica* L.) forest. Likewise, low litter decomposition rate was found in clear-cut areas (1-97 ha) or in large gaps (30 m diameter) than under closed canopy [43]. This was suggested that litter decomposition rate was related to size of gaps.

The fastness of litter decomposition in logging site compared to undisturbed site or the no significant difference of litter decomposition in the two sites in this study can be explained in part by the long-term gap formation or age of gaps and the rapid litter turnover in logging site. Bauhus *et al*. [49] have carried out that no changes in litter decomposition were found in gap area 8 years after gap formation. In our study site, the logging activity stopped in 1996 according to the field assistant, Mva Marcel (Pers. Comm.). Fines *et al*. [50] reported also that this forest site was included in the oldest permission of logging during the 1985-1997 periods. Six or seven years after logging, the site was then abandoned and no disturbance was occurred. The sites of forestry practices (skid trails, timber landings and logging roads) were already invaded with pioneer vegetation, in particular *M. cecropioides*, about 60 trees.ha^{-1} [29, 27] have shown that the community Xylopia-Musanga that characterizes disturbed zones developed five years after disturbance. In the lowland rainforest of Cameroon, the vegetation in logging gaps recovered quickly through secondary succession. Plant density and basal area of logging plots were comparable to old growth forest after only five years, and species composition took only 14 years to recover [51]. Logging site is in broad stage of restoration of its soil and organisms, and expresses by an important increase of fine root production and higher turnover value of litter in logging site than undisturbed site. In fact, Ibrahima *et al*. [29] have found for the same period of study and the same site turnover values of litter were 2.63 and 2.68 in undisturbed and logging sites

respectively. The increase fine roots biomass and rapid turnover in logging site justified the no-significant difference between the logging and undisturbed sites. Litter quality, which also affects decomposition rates, did not differ between sites in the present study for *G. tessmannii* (same fresh litter material used for all litterbags) and can be excluded as factor or has lesser important.

4.3. Comparison of Nutrient Loss in Decomposing Litters between Undisturbed and Logging sites

The litter types were differed according to nutrient release. There was no nutrient immobilization in decomposing litter of *G. tessmannii*, where nutrient loss varied from 93 (K) to 0% (Na). Conversely, there was immobilization at least one nutrient in decomposing litter of the other species. Furthermore, the initial N and P contents were higher in *G. tessmannii* than in the other three species and suggesting that the difference between species can partly explain by difference of initial N and P contents. In fact, the immobilization or release of nutrients from decomposing litter is determined by the level of initial nutrient content. If the litter is rich in nutrient contents, the decomposer organisms find enough nutrients for their energy, and the nutrient release from decomposing litter is fast, like in the case *G. tessmanni*. If in contrast, the initial nutrient contents is low, a large quantity of nutrients are immobilized for microbial growth and the nutrient release from decomposing litter is low [52]. However it can be noticed that the physical characteristics of litter, not studied here, might be also one of the cause of differences between species.

In general the nutrient contents of initial litter were higher in logging site than undisturbed, except Ca, Na and all the nutrients of *G. tessmannii*. The litter of the later species came only from undisturbed site, and this account for the absence in difference between the two site in this species. Despite the fact that this species comes only from one site, the nutrient losses were higher in logging site than undisturbed site. This finding indicates that different biological function of logging site were more intense 6 or 7 years after logging stop. Conversely to undisturbed site, there was no net tendency of losing or immobilization of nutrients during the 14 weeks of litter decomposition in logging site.

CONCLUSION

After 14 weeks of litter incubation *in situ*, litter decomposition and nutrient release were significantly highest in *G. tessmannii*, lowest in *M. cecropioides* and intermediate in the other two species. Litter decomposition process and nutrient release were higher in the logging site than undisturbed site for *G. tessmannii* or not significantly differed between the two sites. The results can be explained by the fact that the impact of logging on litter decomposition process was either low, or 6 to 7 years after logging the biological and ecological functions of logging site were in great part restored. This information need to be completed by studies of the root, forest floor, etc to contribute in the sustainable management of the tropical rainforests in general and those of Southern Cameroon in particular.

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