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# Patterns of Leaf Litter Decomposition as Related to Litter Traits in the Sudano-Guinea Savannahs of Ngaoundere, Cameroon

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author AI designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author PS managed the analyses of the study. Author AAMAM managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Litter decomposition processes are poorly studied in the savannahs. Leaf litter decomposition of the twenty-four contrasting plant species including trees, shrubs and grass species, was studied in the sudano-guinea savannahs of Ngaoundere, Cameroon. The litterbag technique was used to assess litter mass loss and single exponential model was adopted to estimate decay rate constants. Initial litter thickness varied from 0.02 to 1.11 mm, area from 4.27 to 245.89 $mm^2$, sclerophyllous index from 0.01 to 1.75 $mg.mm^{-2}$, density from 0.21 to 87.50 $mg.mm^{-3}$, and specific mass area from 0.57 to 185.46 $mm^2.mg^{-1}$. Litter cellulose content varied from 3.79 to 11.84%; lignin from 2.84 to 8.12%, NDF from 21.35 to 80.41%, and total phenolic compounds from 0.47 to 17.76%. During the 52 weeks of the field experiment, mean dry mass remaining of litter samples was significantly between 8.05 and 75.22% of initial litter dry mass for *C. papaya* and *C. regidus* respectively. Litter decomposition rate constant (k) significantly ranged from 0.003 (*C. regidus*) to 0.121 $\%.week^{-1}$ (*C. papaya*). Litter mass remaining (LMR) was positively related to thickness ($R^2$ =

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0.605, P<0.01), Sclerophyllous index ($R^2$ = 0.446, P<0.05), Specific mass area ($R^2$ = 0.569, P<0.001), lignin ($R^2$ = 0.631, P<0.01) and phenolic compounds ($R^2$ = 0.618, P<0.001). The litter decomposition rate constant (k) was negatively related to thickness ($R^2$ = 0.602, P<0.01, n=12), Sclerophyllous index (0.542; P<0.05), Specific mass area (0.419; P<0.05) and phenolic compounds (0.530; P<0.01). It can be concluded that litter decomposition is affected by plant species diversity, plant groups and physico-chemical traits of litters in the sudano-guinea savannahs of Ngaoundere, Cameroun. These preliminary results would contribute to understanding the mechanism of litter decomposition in general and in these savannahs in particular.

*Keywords: Litter decomposition; decay rate; plant species diversity; sudano-guinea savannahs; Ngaoundere; Cameroon.*

## 1. INTRODUCTION

In the Sudano-guinea savannahs of Adamawa, where the local population derives most of their livelihood from livestock, agriculture and, to a lesser extent, forest products, the social and environmental situations are worrying for this population [1,2]. These traditional anthropogenic activities were already enough to carry out the seeds of the destruction of the natural environment, with the practices of wildfires, uncontrolled logging, the increase of non-timber forest products for trade and traditional medicine [3,4].

Human activities, natural hazards and the extention of cities at the expense of savannahs, due to the demographic pressure, the poorly adapted traditional practices of agriculture and the related ecological disturbances have led to a more or less complete disappearance of arable land reserves and a significant decrease in agricultural and forestry production [3,5,6]. Production systems based on traditional agriculture can no longer satisfy population demands [7]. In this context, cropping systems must integrate judicious soil management in order to improve and maintain their productivity. Therefore, the addition of organic or mineral fertilizers could help to meet the nutrient requirements of crops [8]. However, organic fertilizers are poorly used because agriculture is not systematically integrated with livestock and mineral fertilizers are inaccessible to average farmers [9]. It is therefore necessary to find other ways to increase agricultural production and diversify farmers' sources of income while protecting the natural environment. The most accepted alternative currently is agroforestry [10]. One of the functions of this technique is the maintenance or improvement of soil fertility through the introduction into production systems of plant species whose litter is an important source of organic matter and nutrients.

Decomposition and mineralization of these litters are key processes in which organic matter and nutrients are incorporated into the soil and provide a reserve of available nutrients for plants and soil biological activity [11]. According to Swift et al. [11], litter decomposition rate is mainly controlled by three groups of factors: soil organisms such as microorganisms and invertebrates, litter physico-chemical traits such as N, Lignin, phenolic compounds, NDF, litter thickness, density and specific mass area, and environmental conditions, especially climate to temperature and humidity, and soil type [12,13]. The importance of each variable varies with the study sites, the type of litter and the ecosystems considered [11]. The understanding of these processes and the factors that control them is an essential step for the selection of plant species to domesticate in the Sudano-guinea savannahs of Adamawa.

Despite their importance in the sustainable management of Ngaoundere savannahs, very little information exists on litter decomposition processes, except those on the effects of litterbag mesh size on the litter decomposition of agroforestry species [14], on leaf litter leaching of nine agroforestry species [15,16], on litter decomposition of J*atropha curcas* L. and *J. gossypifolia* L. along altitudinal gradient [13] and on synergistic effects of earthworms and soil microorganisms one litter decomposition in sudano-guinea savannahs of Ngaoundere, Cameroon [17]. All these studies were carried out for a short period, at most 24 weeks, with few species. In this study, contrasting litters of 24 species were used to determine the patterns of litter decomposition of sudano-guinea savannahs of Ngaoundere in long-term. The objectives of the present work were to determine 1) the best

model estimating litter decomposition rate constant (k), and 2) the effects of litter physico-chemical traits, and 3) biological groups of plant species on litter decomposition in the Adamawa region.

## 2. MATERIALS AND METHODS

### 2.1 Study Site

The study site located in Adamawa region (6-8N, 12-15E, altitude 1200 m asl). This geographical situation gives at this region a humid climate according to Suchel [18], with one dry season (November - March) and one rainy season (April - October). The rainy season extends from July to September, registering maximum amounts in August. The dry season stretches from November to March. The mean annual rainfall is about 1500 mm, with a variation coefficient of 9.8. The mean annual temperature is approximately 22°C and the mean relative humidity about 69% [19]. The seasonally arid situation of Adamawa region is due to the influence of the Harmattan (dry wind) which recalls the harsh climatic conditions of the Sudano-sahelian regions, while its rainfall and its thermal amplitude recall the humid subequatorial regions [20]. The ferralitic soils are the dominant type [21], with rich clay (40-60%), low organic matter (less than 1%), low soil exchange capacity from 15 to 20 meq/100g and the pH about 4.7 to 5.6 [22]. Hydromorphic soils are found in the marshy depressions. The vegetation of Ngaoundere savannahs is constituted of meadows, shrubby and woody savannahs, with predominance of *Daniellia oliveri* and *Lophira lanceolata* [23] Degraded fallow lands and savannahs occasionally used as grazing land and composed of *Acacia hockii* and *Afzelia Africana* [23]. The vegetation aspects are maintained by zoo-anthropic factors such as wildfires and grazing [24].

The experimental site is located at the University of Ngaoundere (7°26' North, 13°31' East and altitude 1114 m) situated at the village Dang, about 15 km from North of Ngaoundere city. Plot was chosen under canopy of trees including *mangifera indica* L. (Anacardiaceae) and *Daniellia oliveri* (Rolfe) Hutnch and Dalz (Caesalpiniaceae).

### 2.2 Leaf litter Selection

In this study, only fresh fallen leaf litters of twenty-four socio-economic and contrasting plant species of the Sudano-guinea savannahs of Ngaoundere were used. The experiment involved twelve deciduous broad-leaved including seven trees (*Combretum molle*, *Lannea schimperi*, *Lophira lanceolata*, *Senna javanica*, *Terminalia glaucescens*, *Terminalia macroptera* and *Vitex doniana)* and five shrubs (*Chromolaena odorata*, *Hymenocardia acida*, *Mucuna stans*, *Protea madiensis and Tithonia diversifolia)*, six evergreen board-leaved including five trees (*Carica papaya*, *Dacryodes edulis*, *Psidium gajava, Syzigium guineense* var. *guineense* and *Uapaca togoensis*) and one shrub (*Callistemon regidus*), one semi-deciduous shrub (*Securidaca longepedunculata*), five grasses (*Aframamum latifolia*, *Pseudarthria hookeri, Hyparrhenia involucra*, *Imperata cylindrica* and *Pennisetum purpureum*). The biological characteristics of these species are found in Table 1. The distribution area of *Syzigium guineense* var. *guineense, Vitex doniana* and *Dacryodes edulis* is forest gallery, while others species is savannahs land, fallows or degraded forests. The twenty-four plant species play a great socio-economic role in the area. They are a source of income, food, firewood, medicinal products and soil fertility indicators for the farmers of this region [24-28].

### 2.3 Litter Decomposition Experiment *in situ*

New litterfall samples were collected directly from forest floor in the Ngaoundere humid savannahs, next to the University of Ngaoundere, during maximum leaf fall period (November 2006 – January 2007). This period corresponds to dry season and soil was very dried. Grasses have been cut to the ground. No leaching occurred from new litter which was sorted, air-dried and stored in the laboratory before use.

A study was conducted *in situ* in the savannahs near the University of Ngaoundere. A litterbag technique was used according to Bocock and Gilbert [29] method, and consisted of nylon material with a 2 mm mesh [11]. The bags were of different sizes according to litter type to avoid compressing the material and thus creating artificial conditions in the litterbags. The choice of the litterbags and mesh size was based on previous studies of litter decomposition [30]. The 2 mm diameter mesh is considered by Sundarapandian and Swamy [31] to be small enough to prevent litter loss and large enough to allow access to mesofauna such as some earthworms and termites. In total, five hundred

and seventy-six (576) litterbags (24 species x 8 sampling dates x 3 replications) were each filled with 7±0,01g of the leaf litter and placed on soil top, during 52 weeks. The litterbags were lightly covered with vegetation litter to avoid destruction litterbags by animals. The experimental design was a randomized complete block with species as treatment. Three litterbags per species were collected at 2, 4, 6, 10, 16, 24, 36, and 52 weeks intervals, brought to the laboratory where all roots, fauna, and soil particles were manually removed from the litter samples. The dry mass of the litter samples in each litterbag was determined after it was oven-dried at 60°C to constant mass for 48h.

To determine initial dry mass, three other litter samples of each species not including in the above mentioned were weighed and dried at 60°C to constant mass. The litter dry mass remaining was calculated per sample date and species. To avoid fragmentation, leaf-litter was moistened again, spread out and then the corresponding leaf areas were measured using a planimeter (Area meter, MK2). Specific area mass (SM) or area per unit mass was calculated from their dry area and mass. The Sclerophyllous index (SI) was also calculated from their dry mass and area. Thickness was measured on the same leaf litter by calliper. Leaf litter density was calculated from their dry mass, area, and thickness.

## 2.4 Chemical Analysis

The initial litters were analysed chemically after passing through a cyclone mill with a l-mm mesh. Ash content was measured after combustion in a muffle furnace at 550°C for 3h. The concentrations of phenolic compounds, cellulose, lignin and NDF were respectively determined by Dubois et al. [32] method, by Folin-Ciocalteu reagent [33], by colometric method [34] and by van Soest's [35] and detergent method.

## 2.5 Statistical Analysis

The oven dried litter mass remaining will hereafter be denoted as LMR. The LMR values for each species were fitted to four mathematical models communly used, assuming that the litters were composed of one, two, or three compartments with different rates of decomposition [36]:

$$LMR = Ae^{-k_1 t} \quad \text{Eq1}$$

$$LMR = Ae^{-k_1 t} + C \quad \text{Eq2}$$

$$LMR = Ae^{-k_1 t_1} + Be^{-k_2 t_2} \quad \text{Eq3}$$

$$LMR = Ae^{-k_1 t} + Bt + C \quad \text{Eq4}$$

Where, A, B and C are the compartments of water soluble and resistant substances (lignin and other compounds). $k_1$ and $k_2$ are the decomposition rate constants over time t for compartments A and B respectively, and LMR is expressed as a percentage of the initial mass and the time in weeks. Best model was selected according to high coefficient of determination and low standard deviation or error. A multiple comparison among the fitted decomposition constants (k) was carried out using the *T' – method* [37].

Before forming any analysis, all variables were tested for normality and if necessary, log transformed. Using a one-way ANOVA, following by *Scheffe*'s mean comparison test at 5% (if ANOVA was significant), we compared LMR among litter types (or species). *Student* t test was also used to compare LMR at 4 and 52 weeks of incubation *in situ*. Pearson's correlation coefficients were used to determine relationships between decomposition rate constants (k), LMR at 4 and 52 weeks and physico-chemical traits of initial litter. These tests were conducted through software package SX for DOS, version 4.0. (Statistix, 1992).

# 3. RESULTS

## 3.1 Initial Litter Traits

Five physical traits of initial leaf litter (thickness, area, sclerophyllous index, density and specific area mass) of 23 species, except *A. latifolium*, have been determined (Table 2). These plant species differed significantly ($P < 0,001$) among them according to each physical trait. Their mean thickness varied from 0.02 mm in *P. purpureum* to 1.11 mm in *T. macroptera*, their area from 4.27 in *C. regidus* to 245.89 $mm^2$ in *T. macroptera*, their sclerophyllous index from 0.01 in *T. diversifolia* to 1.75 $mg.mm^{-2}$ in *P. purpureum*, their density from 0.21 in *D. edilus* to 87.50 $mg.mm^{-3}$ in *P. purpureum*, and their specific area mass from 0.57 in *P. purpureum* to 185.46 $mm^2.mg^{-1}$ in *T. diversifolia*.

The litters also differed significantly ($P<0.01$) in each of their four chemical traits (cellulose, lignin, NDF and total phenolic compounds) which have been detremined in 20 species, except *C. odorata*, *P. purpureum*, *P. gojava* and *T. glaucescens* (Table 2). Their cellulose content varied from 3.79 in *A. latifolia* to 11.84% in *V.*

*doniana;* lignin from 2.84 in *S. g. guineense* to 8.12% in *V. doniana*; NDF from 21.35 in *S. g. guineense* to 80.41% in *V. doniana*; and total phenolic compounds from 0.47 in *V. doniana* to 17.76% in *A. latifolia*.

### 3.2 MSR at 4 and 52 Weeks of Incubation *in situ*

The litter dry mass remaining (LMR) varied significantly (P <0.05) among species at 4 and 52 weeks of incubation (Table 3). LMR ranged from 47.03 in *C. papaya* to 96.94% in *S. g.* var. *guineense* 4 weeks after incubation, and 8.05 in *C. papaya* to 76.22% in *C. regidus* 52 weeks after incubation. That is, a litter mass loss corresponding to 52.97 and 3.06% at 4 weeks after incubation and 92 and 23.78% after 52 weeks of incubation in the same species. For all species, LMR after 4 weeks of incubation were significantly different from those after 52 weeks of incubation, with the exception of *A. latifolia* and *L. schimperi* (Table 3). For the latter species, the standard deviations were large, suggesting that the deviations of the values around the averages were high.

### 3.3 Selection of the Best Litter Decomposition Models and Decay rate Constant

To compare the litter decomposition rate constants (k) in different species, we needed to find the mathematical function that fitted the data best. Among the tested functions, the equation Eq2 and Eq4 did not adjust to the LMR of all litters, in particular *L. lanceolata* and *S. g.* var. *guineense* for model Eq2 and *C. odorata*, *P. gojava*, *T. glaucescens* and *U. togoensis* for equation Eq4 (Table 4). On the other hand, the simple (Eq1) and double (Eq3) exponential functions fitted well to the LMR of all litters with highly significant coefficients of determination. The double exponential function had coefficients of determination generally higher than those of the simple exponential model (Table 4), but the parameters (A, B, $k_1$ and $k_2$) of the model were not generally significant, because most of the standard errors of these parameters were higher than the estimated parameters. The simple exponential function was therefore adopted to fit the LMR of the litters (Fig. 1) because the coefficients of determination were significant and the parameters of the regression model were well estimated with low standard errors for all litters.

The litter decomposition rate constant (k) differed significantly among species (Fig. 2). It ranged from 0.003 to 0.120 $week^{-1}$. The litter decomposition rate constants of *C. papaya* (0.121 $week^{-1}$) and *T. diversifolia* (0.119 $week^{-1}$) were the highest. That of the litter of *C. rigidus* (0.003 $week^{-1}$) was the lowest and did not differ significantly from those of *D. edulis* (0.006 $week^{-1}$) and *H. acida* (0.006 $week^{-1}$). *C. papaya* and *T. diversifolia* had litter decomposition rate constants 2 to 40 times higher than those of other species, particularly of *C. rigidus*.

### 3.4 Relationships between Physico-Chemical Traits of Initial Litter, LMR and k

Relationships between initial litter traits and their LMR at 4 and 52 weeks of litter decomposition were determined (Figs. 3, 4 and 5). Positive and highly significant correlations (P <0.01) between sclerophyllous index ($R^2$ = 0.568), NDF ($R^2$ = 0.523) and phenolic compounds ($R^2$ = 0.598) and LMR at 4 weeks of incubation (LMR4) were found (Fig. 3). Similarly, LMR at 52 weeks of incubation (LMR52) were positively and significantly correlated with the three physical traits of litter: the thickness ($R^2$ = 0.605, P <0.01), the sclerophyllous index ($R^2$ = 0.446; P<0.05) and specific area mass ($R^2$ = 0.569, P <0.001) (Fig. 4a) and two chemical traits: lignin ($R^2$ = 0.631, P <0.01) and phenolic compounds ($R^2$ = 0.618, P <0.001) (Fig. 4b). On the other hand, the litter decomposition rate constant (k) was negatively and significantly correlated with the three physical traits of the litter: thickness ($R^2$ = 0.602, P <0.01), Sclerophyllous index ($R^2$ = 0.542, P <0.05) and Specific area mass ($R^2$ = 0.419; <0.05) and one chemical trait, phenolic compounds ($R^2$ = 0.530, P <0.01) (Fig. 5).

## 4. DISCUSSION

### 4.1 Initial Litter Traits

The litter studied came from a varied range of plants, *i.e.*, grasses, shrubs, trees and broad-leaved deciduous and evergreen, and native and exotic plant species. The physical traits within the initial litters studied ranged from 0.02 to 1.11 mm for thickness, from 0.04 to 2.46 $mm^2$ for area,

**Table 1. Leaf litters of 24 studied species**

| Species | Families | Code | Statut | Habitat | Guilde |
|---|---|---|---|---|---|
| Broad-leaved deciduous trees | | | | | |
| *Combretum molle* R. Br. Ex G. Don | Combretaceae | CM | N | Savannah | |
| *Lannea schimperi* (Hochst. Ex A. Rich.) Engl. | Anacardiaceae | LS | N | Various | |
| *Lophira lanceolata* Van Tigh. Ex Keay | Ochnaceae | LL | N | Savannah | |
| *Senna javanica* L. | Fabaceae | SJ | E | Pre-forest | |
| *Terminalia glaucescens* Planch. Ex Benth. | Combretaceae | TG | N | Savannah | |
| *Terminalia macroptera* Guill. & Perr. | Combretaceae | TM | N | Savannah | |
| *Vitex doniana* Sweet | Verbenaceae | VD | N | Forest gallery | Shad tree |
| Broad-leaved deciduous shrubs | | | | | |
| *Chromolaena odorata* (L.) King & Robinson | Asteraceae | CO | E | Clearing | Pioneer |
| *Hymenocardia acida* Tul. | Hymenocardiaceae | HA | N | Savannah | |
| *Mucuna stans* Welw. ex Baker | Fabaceae | MS | N | Savannah | |
| *Protea madiensis* Oliv. | Proteaceae | PM | N | Savannah | |
| *Tithonia diversifolia* (Hemsl.) A. Gray | Asteraceae | TD | E | Open Savannah. | Pioneer |
| Broad-leaved semi-deciduous tree | | | | | |
| *Securidaca longepedunculata* Fres. | Polygalaceae | SL | N | Savannah | |
| Broad-leaved evergreen trees | | | | | |
| *Carica papaya* L. | Caricaceae | CP | E | Planted | |
| *Dacryodes edilus* (G. Don) H. J. Lam. | Burseraceae | DE | N | Forest gally | Shad tree |
| *Psidium guajava* L. | Myrtaceae | PG | E | Planted | Pioneer |
| *Syzygium guineense* var. *guineense* (Willd.) DC. | Myrtaceae | SG | N | Forest gallery | Shad tree |
| *Uapaca togoensis* Pax | Euphorbiaceae | UT | N | Forest gallery | Shad tree |
| Broad-leaved evergreen shrub | | | | | |
| *Callistemon rigidus* R. Br. | Myrtaceae | CR | E | Planted | |
| | | | | | |
| Grasses | | | | | |
| *Aframomum latifolia* K. Schum. | Zingiberaceae | AL | N | Grassland | Pioneer |
| *Hyparrhenia Involucrata* Stapf. | Poaceae | HI | N | Grassland | Pioneer |
| *Imperata cylindrica* (Linnaeus) Palisot de Beauvois | Poaceae | IC | N | Grassland | Pioneer |
| *Pennisetum purpureum* Schum. | Poaceae | PP | N | Grassland | Pioneer |
| *Pseudarthria Hookeri Wright & Arn.* | Fabaceae | PH | N | Grassland | Pioneer |

*Statut: Native (N) and exotic (E)*

from 0.01 to 1.75 $mg.mm^{-2}$ for sclerophyllous index, from 0.21 to 87.50 $mg.mm^{-3}$ for density and from 0.57 to 185.46 $mm^2.mg^{-1}$ for specific area. Regarding the initial organic compounds, they varied from 3.79 to 11.84% for cellulose content, from 2.84 to 8.12% for lignin content, from 21.35 to 80.41% for NDF content and from 0.47 to 17.76% for phenolic compound content. Mapongmetsem [38], used seven types of litters of Adamawa savannahs with a thickness varying between 0.12 and 0.36 mm, area between 0.19 and 1.26 $mm^2$, sclerophyllous index between 0.27 and 1.05 $mg.mm^{-2}$, density between 0.67 and 14.21 $mg.mm^{-3}$. He also found out cellulose content ranged from 1.26 to 3.28%, lignin content from 1.05 to 5.37% and phenolic compound content from 1.48 to 7.48%; Anguessin et al. [13], using jatropha leaf litters with thickness varying between 0.21 and 0.36 mm, area between 108.64 and 246.40 $mm^2$, sclerophyllous index between 0.045 and 0.051 $mg.mm^{-2}$; Bayala et al. [39], using deciduous leaves with cellulose between 16.26 and 18.90%, lignin between 15.74 and 20.78% and polyphenol content between 5.51 and 5.91%. Compared with that of other litter decomposition studies, the range of variation in initial physical and chemical traits in the litters in this study was at least of the same order of magnitude, exception of the results of Bayala et al. [39] on cellulose and lignin contents which were higher values than ours. In general, the physico-chemical traits of leaf litters of twenty-four plant species in the soudano-guinea Savannahs of Ngaoundere were within the range of published data [13,17,38,39,40,41].

## 4.2 Mass Loss at 4 and 52 Weeks of Incubation

Litter decomposition varied among study sites and species composition. Indeed, Mapongmetsem [38] reported that mass losses of eight litter types ranged from 10.83 to 41.79% after 1 month (4 weeks) and from 38.00 to 69.85% after 9 months (39 weeks) of field incubation at the similar type of savannah (Sudano- guinea of Ngaoundere) with different litter types. According to Oladoye et al. [42] who worked in the Nigerian savannah, this loss, for *Leucaena leucocephala* litter reached about 32.32% of initial mass after 40 days (≈6 weeks) of field incubation while Jamaludheen and Mohan Kumar [43] found the litter mass loss of nine species ranged from 13 to 35% after 1 month (≈4 weeks) and from 82 to 99% after 12 months (52 weeks) of field incubation in traditional agroforestry systems of Kernataka, southern India. In our study the average litter mass loss varied significantly from 3.06 to 52.97% after 4 weeks and from 23.78 to 92.00% after 52 weeks of litter incubation *in situ*. These values were from the lower to upper range reported in the literature and showed wide spectra of litter mass loss in the Sudano-guinea Savannah of Ngaoundere [14,38], due to existing of various plant species of different behevours in this savannah. It could play an important role in the adaptation mechanism of species of this savannah to eventual and environmental changes, due to natural or anthropogenic pressures, as have shown by Ibrahima et al. [44] in Ebom Tropical Forest.

## 4.3 Mass Loss Dynamics

Numerous mathematical models were found in the literature to describe litter mass loss with time [36,45]. These models vary according to leaf litter traits, short or long-term litter incubation, soil organisms of study sites and laboratory or field experiments [36,46,47]. In our study, depending on the litter type, the four models are well suited to describe the litter mass loss during their decomposition. This suggested that for the studied litters, several models can describe the mass loss dynamics and could be explained in part by a wide range of the initial physico-chemical traits of these species. For example, *T. diversifolia* lost more than 92% of its initial dry mass in one year. This loss corresponds to more than 4.5 times that of *D. edulis* (25.11%). These 2 species differed widely in their physico-chemical litter traits and their ecology. The litter thickness (0.15 mm), sclerophyllous index (0.01 $mg.mm^{-2}$), lignin (5.63%) and phenolic compounds (1.21%) of *T. diversifolia* were 1 to 5 times lower than those of *D. edulis*, which were respectively 0.73 mm, 0.16 $mg.mm^{-2}$, 7.27% and 3.48%. On the other hand, the cellulose content was higher in *T. diversifolia* (9.98%) than in *D. edulis* (6.48%). In addition, *T. diversifolia* is a fast growing pioneer, while *D. edulis* is a slow-growing evergreen shade tree.

To compare litter decomposition rate constants of 24 studied species, the single-exponential decay model, and most commonly used to describe mass-loss with time [45,48] was adopted. Indeed, although the coefficients of determination of the adjustments were weak, it was the only model among the four tested which fitted well for all the litters. On the other hand, the double-exponential model, although had the

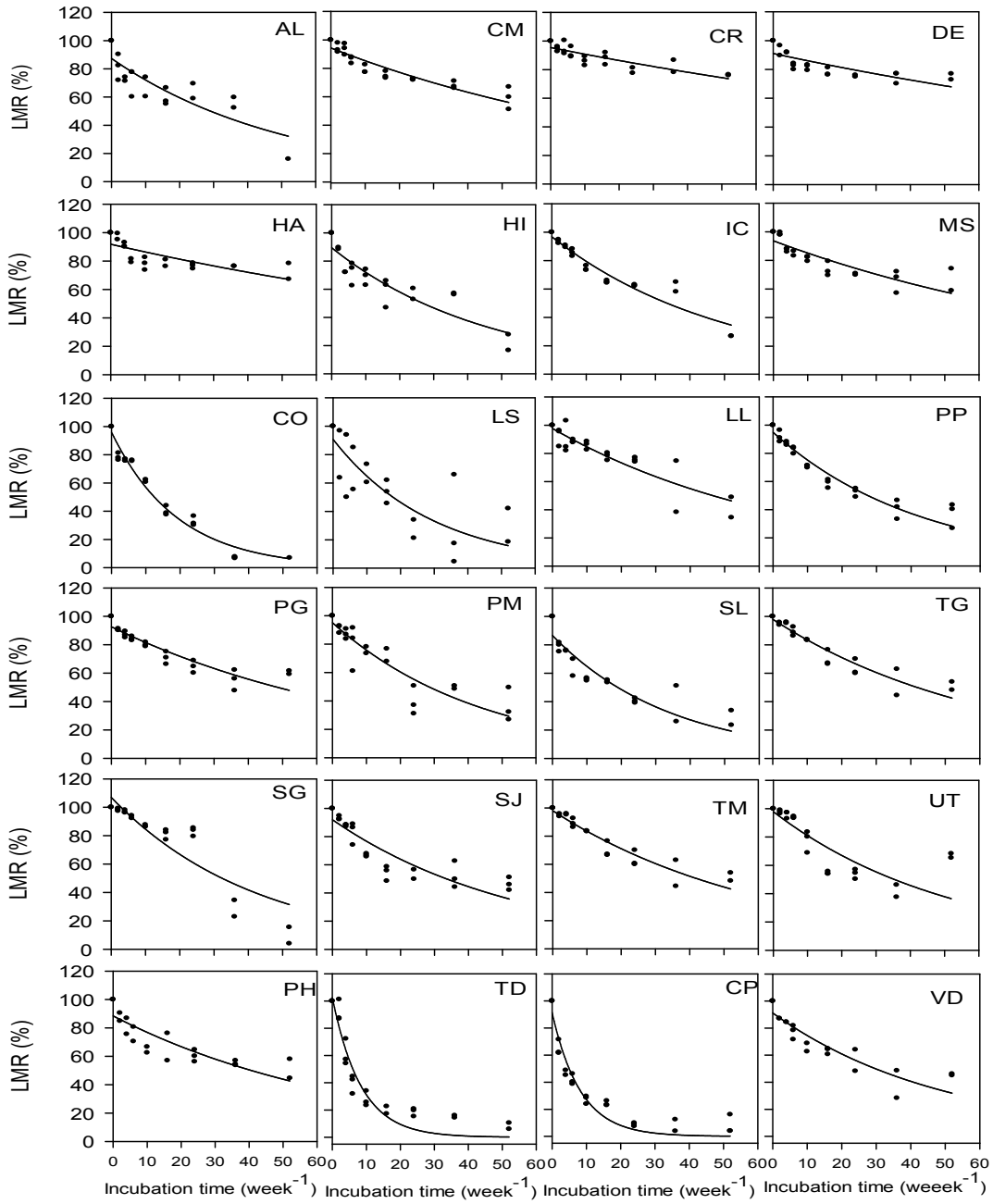


**Fig. 1. Measured values of litter mass remaining (LMR expressed as percentage of original mass) with incubation time, and predicted single exponential decay regression lines (LMR = $Ae^{-k}$) of the 24 types of litter studied**

*A. latifolium (AL), C. molle (CM), C. regidus (CR), D. edulis (DE), H. acida (HA), H. involucra (HI), I. cylindrica (IC), M. stans (MS), C. odorata (CO), L. schimperi (LS), L. lanceolata (LL), P. purpureum (PP), P. gojava (PG), P. madiensis (PM), S. longepedunculata (SL), T. glaucescens (TG), S. g. var. guineense (SG), S. javanica (SJ), T. macroptera (TM), U. togoensis (UT), P. hookerii (PH), T. diversifolia (TD), C. papaya (CP) et V. doniana (VD)*

highest significant coefficient of determination, the three parameters of this model (A, $k_1$ and $k_2$) were estimated with greater error than estimates. In other respects, the coefficients of determination of the single exponential decay model were less than the double exponential decay model, but still quite highly significant. The parameters of this model have been estimated with reasonable standard error.

Litter decomposition rate constant (k) varied among plant species. Indeed, in their study on litter decomposition of a tropical vertisol forest of Lama reserve in Benin, Sabin Guendehou et al. [49] found that the litter decomposition rate constant varied among five plants species (*Afzelia africana*, *Anogeissus leiocarpa*, *Ceiba pentendra*, *Dialium guineense* and *Diospyros mespilifourmis*). Their values ranged from 1.69 to 4.67 $year^{-1}$ corresponding to 0.03 and 0.09 $week^{-1}$. According to Jamaludheen and Mohan Kumar [43], the litter decomposition rate constants of nine multipurpose trees in Kerala, India varied from 0.16 to 32 $year^{-1}$, corresponding to 0.04 and 0.079 $week^{-1}$. Many other studies synthetized by Ibrahima et al. [44] have shown that the litter decomposition rate constant (k) of tropical forests ranged from 0.21 to 8.58 $year^{-1}$, corresponding from 0.004 to 0.17 $week^{-1}$. Our study showed that the decomposition rate constants of leaf litter including the litter of tropical forest as *Dacryodes edulis* were in the lowest to highest part of the range reported in the literature for the litter of plant species of African Savannahs [38,49] and were in the lowest to middle part of the range reported in the literature for the litter of plant species of Tropical forest. In fact, in the present study the decomposition rate constants (k) varied from 0.003 to 0.120 $week^{-1}$, with an average value of 0.027 $week^{-1}$.

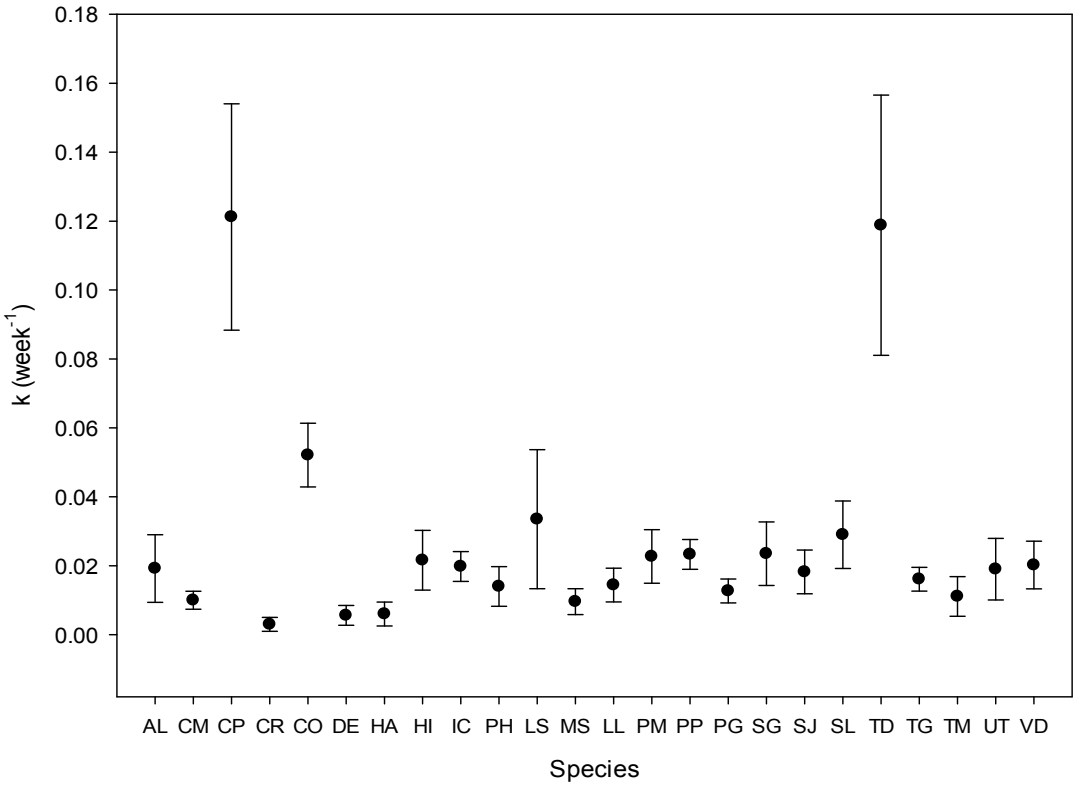


**Fig. 2. Ninety-five percent comparison intervals by the T'-method for litter decomposition constants (k) of 24 studied species during 52 weeks of incubation *in situ***

*A. latifolium (AL),C. molle (CM), C. regidus (CR), D. edulis (DE),H. acida (HA),H. involucra(HI), I. cylindrica (IC), M. stans (MS),C. odorata (CO),L. schimperi (LS),L. lanceolata (LL),P. purpureum (PP),P. gojava (PG),P. madiensis (PM), S. longepedunculata (SL),T. glaucescens (TG), S. g. var. guineense (SG),S. javanica (SJ), T. macroptera (TM),U. togoensis (UT), P. hookerii (PH), T. diversifolia (TD),C. papaya (CP). etV. doniana (VD)*

**Table 2. Initial leaf litter traits of 24 plant species studied. Standard deviation in parenthesis**

| Species | Thickness (mm) | Area ($mm^2$) | IS ($mg.mm^{-2}$) | Density ($mg.mm^{-3}$) | SM ($mm^2.mg^{-1}$) | Cellulose (%) | Lignin (%) | NDF (%) | Phenolic compounds (%) |
|---|---|---|---|---|---|---|---|---|---|
| *A. latifolium* | ND | ND | ND | ND | ND | 3.79 (0.51) e | 4.40 (0.56) abcd | 66.94 (21.71) ab | 17.76 (12.78) a |
| *C. regidus* | 0.22 (0.03) fg | 4.27 (0.56) c | 0.02 (0.003) e | 0.91 (0.11) ef | 50.73 (7.01) c | 9.35 (1.13) abc | 4.06 (0.09) abcd | 62.84 (12.85) ab | 11.28 (0.43) abcde |
| *C. papaya*[1] | 0.44 (0.003) | 48.82 (0.95) | 0.10 (0.01) | 0.23 | 10.00 | 7.16 (0.54) bcde | 5.99 (0.42) abcd | 52.12 (17.16) ab | 4.51 (1.32) defg |
| *C. molle* | 0.62 (0.03) bcde | 42.97 (1.92) bc | 0.18 (0.02) bcde | 0.31 (0.02) f | 59.68 (2.66) c | 9.45 (1.39) abc | 5.83 (0.08) abcd | 63.43 (8.85) ab | 16.11 (13.30) ab |
| *C. odorata*[1] | 0.20 | 38.00 | 0.14 | 0.70 | 7.14 | ND | ND | ND | ND |
| *D. edulis*[1] | 0.73 (0.01) | 42.89 (0.16) | 0.15 | 0.21 | 6.67 | 6.48 (1.95) abcde | 7.27 (2.36) ab | 45.86 (1.48) ab | 3.48 (1.06) efg |
| *H. acida* | 0.40 (0.04) cdefg | 12.63 (0.06) c | 0.16 (0.001) bcde | 0.40 (0.02) f | 66.49 (0.34) c | 5.44 (1.02) bcde | 3.83 (0.55) bcd | 76.43 (12.15) a | 13.54 (9.12) abc |
| *I. cylindrica* | 0.30 (0.10) defg | 26.33 (1.15) c | 0.03 (0.003) e | 1.22 (0.42) def | 29.57 (2.62) c | ND | 6.34 (0.44) abcd | 79.43 (3.78) a | 9.79 (1.23) abcdefg |
| *L. schimperi* | 0.64 (0.03) bcd | 27.21 (2.51) c | 0.26 (0.03) abcde | 0.40 (0.05) f | 41.23 (3.80) c | 7.45 (1.90) abcde | 5.43 (0.01) abcd | 56.38 (12.96) ab | 4.98 (2.83) cdefg |
| *L. lanceolata* | 0.40 (0.03) cdefg | 177.55 (76.16) abc | 0.02 (0.01) e | 0.46 (0.24) f | 65.26 (31.46) c | 6.48 (1.63) bcde | 5.65 (1.30) abcd | 60.63 (23.96) ab | 1.00 (0.12) fg |
| *M. stans* | 0.24 (0.03) fg | 17.46 (0.98) c | 0.07 (0.003) de | 0.32 (0.04) f | 152.60 (1.85) ab | 8.57 (0.01) abcde | 6.51 (0.24) abc | 72.62 (8.83) a | 5.33 (2.49) cdefg |
| *P. purpureum*[1] | 0.02 | 36.26 | 1.75 | 87.5 | 0.57 | ND | ND | ND | ND |
| *P. madiensis* | 0.59 (0.08) bcde | 61.97 (17.15) abc | 0.02 (0.003) e | 0.36 (0.06) f | 48.02 (6.87) c | 8.76 (1.93) abcd | 4.89 (0.06) abcd | 57.51 (18.68) ab | 13.05 (0.39) abcd |
| *P. hookerii* | 0.57 (0.04) bcdef | 70.52 (0.91) abc | 0.14 (0.02) cde | 0.26 (0.03) f | 89.01 (6.88) c | 4.11 (0.3) de | 4.29 (2.68) abcd | 77.73 (6.57) a | 8.71 (5.63) abcdefg |
| *P. gojava* | 0.62 (0.05) bcde | 25.63 (3.47) c | 0.19 (0.02) abcde | 0.32 (0.03) f | 58.25 (7.88) c | ND | ND | ND | ND |
| *S. longepedunculata*[1] | 0.42 (0.02 | 9.65 (0.08) | 0.10 (0.04) | 0.24 | 10.00 | 6.96 (0.54) bcde | 5.43 (1.60) abcd | 66.43 (0.24) ab | 8.18 (0.08) abcdefg |
| *S. javanica* | 0.28 (0.16) efg | 29.00 (1.73) c | 0.02 (0.002) e | 1.09 (0.79) ef | 45.71 (4.17) c | 8.93 (1.40) abcde | 5.59 (1.25) abcd | 61.64 (16.10) ab | 8.79 (2.29) abcdefg |
| *S.g.* var. *guineense* | 0.56 (0.03) bcdef | 29.10 (0.52) c | 0.20 (0.002) abcde | 0.38 (0.02) f | 53.51 (0.96) c | 8.34 (0.19) abcde | 2.84 (0.68) cd | 21.35 (0.17) b | 4.79 (0.35) cdefg |
| *T. glaucescens* | 0.81 (0.03) ab | 75.85 (2.05) abc | 0.20 (0.03) abcde | 0.27 (0.04) f | 54.57 (1.48) c | ND | ND | ND | ND |
| *T. macroptera* | 1.11 (0.05) a | 245.89 (74.66) a | 0.29 (0.11) abcde | 0.26 (0.08) f | 39.03 (11.85) c | 9.30 (1.84) abc | 4.56 (1.76) abcd | 80.41 (4.47) a | 10.76 (4.70) abcdef |
| *T. diversifolia* | 0.15 (0.02) g | 53.24 (22.73) bc | 0.01 (0.002) e | 0.40 (0.14) f | 185.46 (83.09) a | 9.49 (1.10) abc | 5.63 (0.04) abcd | 59.61 (17.14) ab | 1.21 (0.38) fg |
| *U. togoensis* | 0.38 (0.10) cdefg | 176.63 (137.32) abc | 0.29 (0.21) abcde | 0.89 (0.77) ef | 53.04 (41.24) c | 5.38 (1.52) cde | 5.16 (1.18) abcd | 77.23 (10.91) a | 13.25 (10.02) abcd |
| *V. doniana* | 0.72 (0.02) bc | 74.79 (16.47) abc | 0.17 (0.04) bcde | 0.24 (0.06) f | 67.38 (14.84) c | 11.84 (0.17) a | 8.12 (1.12) a | 63.72 (0.63) ab | 0.47 (0.01) g |
| F | 41.88*** | 9.88*** | 14.46*** | 12.78*** | 12.46*** | 5.08*** | 3.04** | 2.63* | 2.18* |

[1]*Excluded species from ANOVA test, because there is only one value. * P= 0.05; ** P= 0.01, *** P= 0.001. Different letters of the same colon indicate that the values were significantly different*

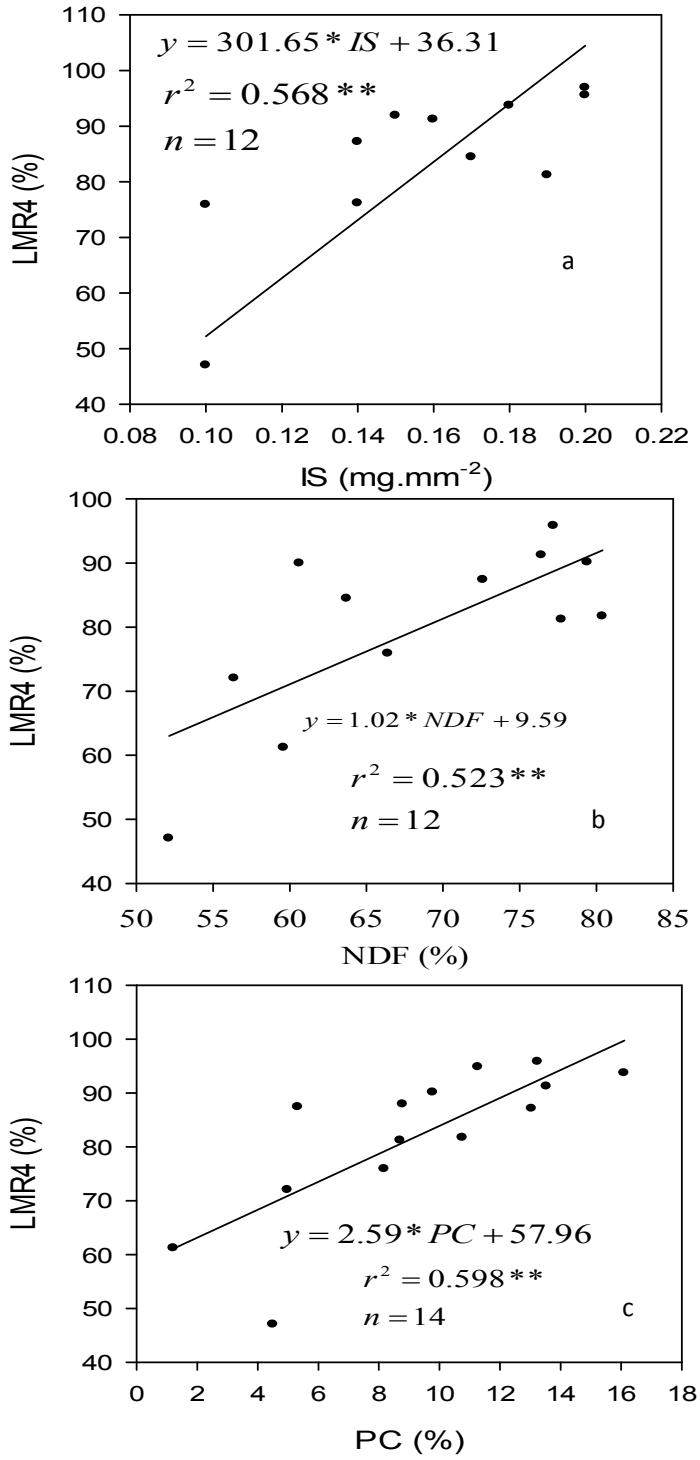


**Fig. 3. Linear regressions between LMR at 4 weeks of incubation (MSR4) and Sclerophyllous index (a), NDF (b) and Phenolic compounds (c). Sample number (n); ** P < 0.01**

**Table 3. Litter mass remaining (%) of 24 studed species at 4 and 52 weeks of incubation *in situ*. Standard deviation in parenthesis**

| Species | 04 weeks | 52 weeks | *Student* t |
|---|---|---|---|
| *A. latifolia* | 72.75 (1.97) abc | 42.55 (37.46) abc | 1.14ns |
| *C. regidus* | 94.83 (4.94) ab | 76.22 (0.39) a | 5.04* |
| *C. papaya* | 47.03 (2.57) c | 8.05 (6.97) c | 7.26* |
| *C. odorata* | 76.17 (0.73) abc | 11.27 (6.01) bc | 20.19*** |
| *C. molle* | 93.73 (3.94) ab | 59.32 (7.92) abc | 6.74* |
| *D. edulis* | 91.90 (0.32) ab | 74.89 (2.93) a | 8.17* |
| *H. acida* | 91.22 (1.69) ab | 72.86 (7.89) a | 4.23* |
| *H. involucra* | 72.11 (0.005) abc | 22.28 (7.88) abc | 8.95* |
| *I. cylindrica* | 90.14 (1.04) ab | 26.78 (0.11) abc | 85.91*** |
| *L. schimperi* | 72.03 (31.00) abc | 30.31 (16.66) abc | 1.68ns |
| *L. lanceolata* | 89.98 (11.59) ab | 53.66 (21.92) abc | 2.54* |
| *M. stans* | 87.40 (1,23) ab | 66.54 (10.86) ab | 3.60* |
| *P. purpureum* | 86.98 (1,19) ab | 36.83 (6.82) abc | 9.70** |
| *P. madiensis* | 87.11 (3,54) ab | 36.21 (11.79) abc | 7.16* |
| *P. hookerii* | 81.21 (7,96) abc | 51.29 (9.49) abc | 3.42* |
| *P. gojava* | 87.18 (2,24) ab | 60.45 (1.64) abc | 14.23*** |
| *S. longepedunculata* | 75.90 (0,26) abc | 28.56 (7.26) abc | 9.22* |
| *S. javanica* | 87.91 (0,76) ab | 46.38 (4.56) abc | 15.55*** |
| *S.g. var. guineense* | 96.94 (1,06) a | 32.23 (39.39) abc | 2.84* |
| *T. glaucescens* | 95.56 (0,51) ab | 51.02 (4.04) abc | 15.46*** |
| *T. macroptera* | 81.71 (4,93) abc | 53.86 (1.76) abc | 7.35* |
| *T. diversifolia* | 61.19 (9,68) bc | 8.28 (3.21) bc | 7.14* |
| *U. togoensis* | 95.82 (2,46) ab | 66.74 (2.15) ab | 13.50*** |
| *V. doniana* | 84.46 (0,03) abc | 45.57 (0.76) abc | 71.95*** |
| F | 7.77*** | 4.17*** | |

** P= 0.05, ** P=0.01 *** P=0.001; ns: not significant. Different letters of the same colon indicate that the values were significantly different*

**Table 4. Coefficients of determination ($r^2$) of the regressions fitted to the four models: single-exponential decay function (Eq1 = $Ae^{-kt}$), single-exponential decay model with asymptote (Eq2 = $Ae^{-kt}$+ B), double-exponential decay function (Eq3 = $Ae^{-k_1 t_1} + Be^{-k_2 t_2}$) and Eq4 = $Ae^{-kt}$ + Bt + C**

| Species | Eq1 | Eq2 | Eq3 | Eq4 |
|---|---|---|---|---|
| *A. latifolia* | 0.7035 | 0.7036 | 0.8074 | 0.8293 |
| *C. regidus* | 0.7081 | 0.7948 | 0.8050 | 0.8051 |
| *C. papaya* | 0.9323 | 0.9655 | 0.9785 | 0.9732 |
| *C. odorata* | 0.9684 | 0.9710 | 0.9684 | ND |
| *C. molle* | 0.8611 | 0.9224 | 0.9339 | 0.9346 |
| *D. edulis* | 0.6019 | 0.9189 | 0.8219 | 0.9193 |
| *H. acida* | 0.5696 | 0.8761 | 0.8783 | 0.8783 |
| *H. involucra* | 0.8016 | 0.8896 | 0.9142 | 0.8870 |
| *I. cylindrica* | 0.9189 | 0.9190 | 0.9283 | 0.9427 |
| *L. schimperi* | 0.6693 | 0.7008 | 0.7008 | 0.7039 |
| *L. lanceolata* | 0.8166 | ND | 0.8166 | 0.8278 |
| *M. stans* | 0.7463 | 0.9017 | 0.9017 | 0.9018 |
| *P. purpureum* | 0.9355 | 0.9712 | 0.9712 | 0.9712 |
| *P. madiensis* | 0.8304 | 0.8583 | 0.8583 | 0.8591 |
| *P. hookerii* | 0.7483 | 0.8952 | 0.9116 | 0.9115 |
| *P. gojava* | 08432 | 0.9383 | 0.9383 | ND |
| *S. longepedunculata* | 0.8404 | 0.9174 | 0.9427 | 0.9412 |
| *S. javanica* | 0.7928 | 0.9349 | 0.9349 | 0.9353 |
| *S. g.* var. *guineense* | 0.8126 | ND | 0.8126 | 0.8986 |
| *T. glaucescens* | 0.9091 | 0.9410 | 0.9410 | ND |
| *T. macroptera* | 0.6487 | 0.8976 | 0.9159 | 0.9170 |
| *T. diversifolia* | 0.9094 | 0.9468 | 0.9471 | 0.9472 |
| *U. togoensis* | 0,6683 | 0,8305 | 0.8305 | ND |
| *V. doniana* | 0,8378 | 0,9150 | 0.9150 | 0.9151 |

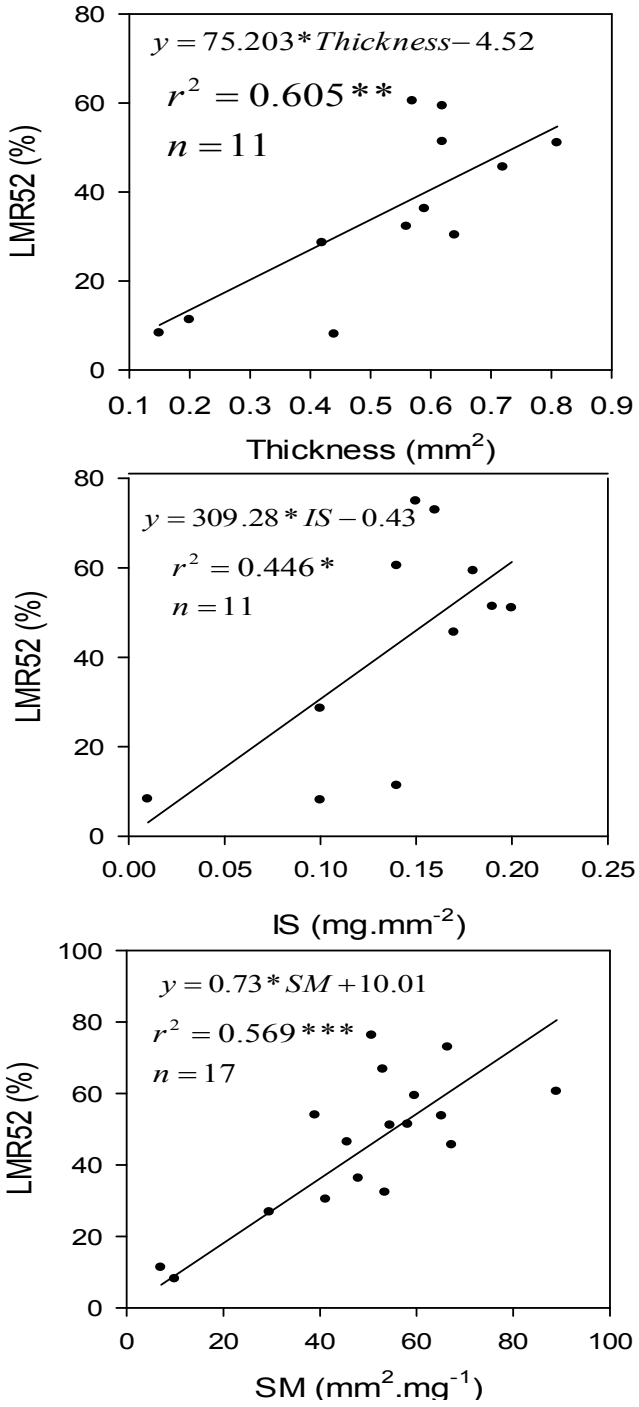


**Fig. 4a. Linear regressions between LMR at 52 weeks of incubation (MSR52) and physical traits of leaf litters (thickness, Sclerophyllous index (IS), SM). Samples number (n); * *P* = 0.05; ** *P* = 0.01; *** *P* = 0.001**

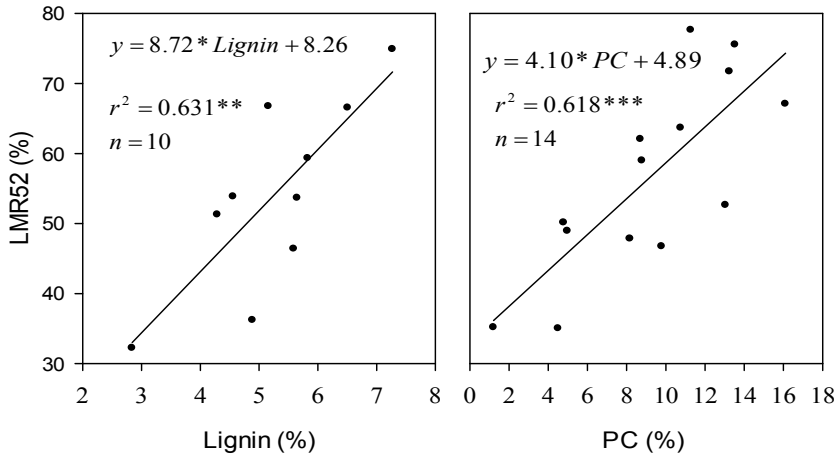


**Fig. 4b. Linear regressions between LMR at 52 weeks of incubation (LMR52) and chemical traits of leaf litters (Lignin and Phenolic compounds). Samples number (n); ** *P* = 0.01; *** *P* = 0.001**

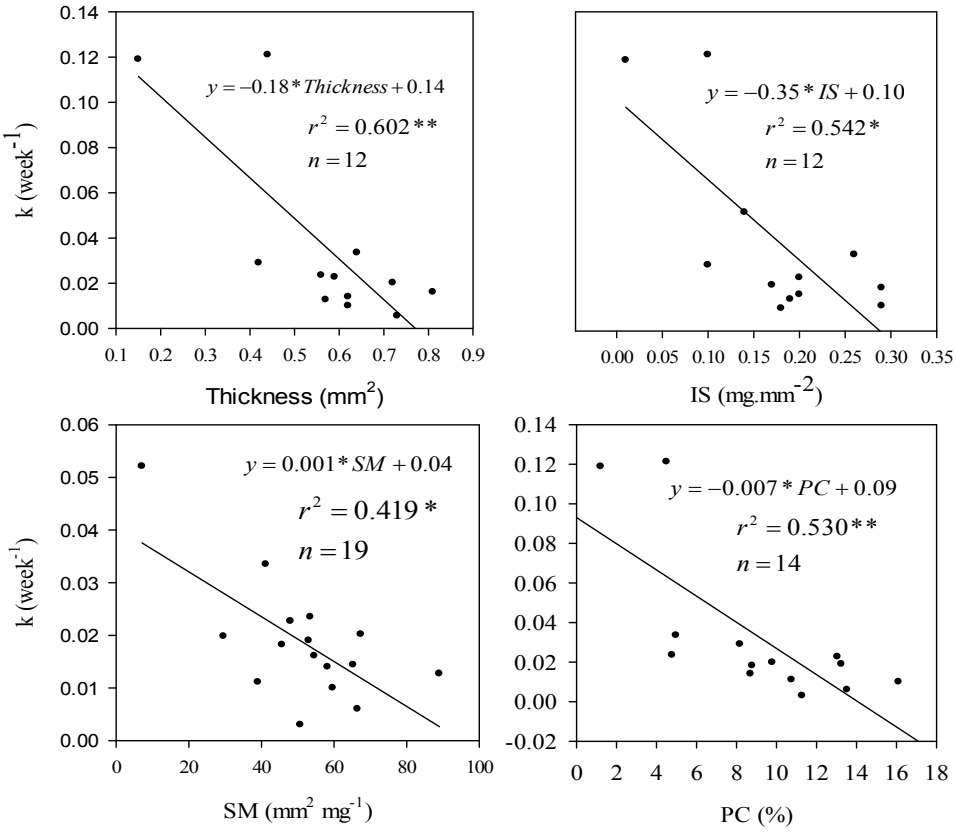


**Fig. 5. Linear regressions between litter decomposition constants (k) and physical litter traits (thickness, IS, SM) and PC. Sample number (n); * *P* = 0.05 and ** *P* = 0.01**

### 4.4 Factors Determining Litter Mass Loss and k

Mass loss and litter decomposition constant (k) were generally influenced not only by the litter physical traits but also by its chemical quality [30,36,38,44,50,51,52]. The parameters retained varied according to ecosystems under consideration. With respect to the litter physical traits such as the thickness, sclerophyllous index and specific area mass (SM), we found that the LMR at 4 weeks of incubation was influenced by the Sclerophyllous index, whereas that at 52 weeks of incubation and the litter decomposition rate constant (k) were both under the dependence of the Sclerophyllous index, the thickness and the specific area mass (SM). Like the physical traits, the litter chemical traits as the phenolic compound content was correlated with the LMR and the litter decomposition constant. Based on these results and those of the previous studies, we can affirm that the rate of litter decomposition of species of Sudano-guinea savannahs of Adamawa was controlled by the litter physico-chemical traits as were shown in this study and those of Mapongmetsem [38], Ibrahima et al. [15], but also by climate [13]) and soil organisms [17]. The importance of these parameters has not yet been studied as Lavelle et al. [53] for Tropical forest ecosystems.

### 4.5 Comparison between Species Groups

The litters in this study can be classified according to their distribution (native and exotic species), their biological type (deciduous and evergreen species), and vegetative type (tree, shrub, and herbaceous). The introduced plant species included the exotic cultivated (*C. papaya*, *D. edulus*, *C. regidus*, *S. javanica*, and *P. gojava*) and alien invasive species as *T. diversifolia* and *C. odorata*. If we exclude grasses with particular characteristics, litter decomposition rate constant (k) and litter mass loss of *T. diversifolia* (0.119 $week^{-1}$ and 91.72%) and *C. odorata* (0.052 $week^{-1}$ and 88.73%), two (2) exotic invasive herbaceous, and those of *C. papaya* (0.12 $week^{-1}$ and 91.95%) were among the highest and that of 2 exotics cultivated, *C. regidus* (0.003 $week^{-1}$ and 23.78%) and *D. edulus* (0.006 $week^{-1}$ and 25.11%), were among the lowest compared to native species of Ngaoundere savannahs. These differences between the native species and these two groups of exotic species can be explained by the physical and/or chemical litter traits as reported by Allison and Vitousek [54] and Godoy et al. [55] comparing the litter decomposition of invasive and native species. Indeed, the 2 exotic invasive species are annual and deciduous species with lower thickness (0.15 and 0.20 mm), sclerophyllous index (0.01 0.14 $mg.mm^{-2}$) and phenolic compound content (1.21%), and higher cellulose content (9.49%). In addition, they are pioneers, fast-growing herbaceous plants adapted to various tropical climatic conditions. In contrast, cultivated exotic species (*C. regidus* and *D. edulus*) are evergreen, with higher litter thickness (0.22 and 0.73mm), density (0.21 and 0.91 $mg.mm^{-3}$), and lignin content (4.06 and 7.23%) and lower cellulose content (6.48 and 9.35%). In addition, they are slow-growing trees adapted to humid climatic conditions in tropical regions. Our results confirm those of the literature. Indeed, Faster litter decomposition from invasive alien species compared to native species has been reported when invaders were $N_2$-fixers and native species were not [56], when nutrient content in the exotic was higher than native one [54] and when the specific leaf area (SLA) of invaders was higher than that of native species [57,58]. By constrast, slower decomposition of invaders alien species leaf litter was found when it had a higher polyphenol content, higher lignin content or higher C/N ratio than native litter [55,59,60].

Some studies have shown that litter decomposition of evergreen species was slower than that of deciduous species [61,62]. However, in our study, the distinction between deciduous and evergreen species concerning litter decomposition was not clear. In fact, evergreen species (*C. regidus* and *D. edulus*) decomposed more slowly than deciduous species. On the other hand, *C. papaya*, which is an evergreen, decomposed very fastly like the deciduous species and had density (0.23 $gm.mm^{-3}$) and phenolic compounds (4.51%) among the lowest such as those of deciduous species. In addition, *C. papaya* is fast-growth species and its litter is very friable in the dry state which breaks easily and increases the contact surface of microorganisms. This explains its litter decomposition was faster than that of the deciduous species and the shift of its behavior with the other evergreen ones.

## 5. CONCLUSION

The 24 leaf litters studied showed a great variety in behaviors in their traits, mass loss, litter decomposition rate constant (k) and equation model describing mass loss dynamics. In fact,

the average litter mass loss ranged significantly from 23.78 to 92.00% after 52 weeks of litter incubation, while the decomposition rate constants (k) ranged from 0.003 to 0.120 week$^{-1}$, with an average value of 0.027 week$^{-1}$. The net difference between litters of evergreen and deciduous species did not seem to appear in our study as shown with litter of *C. papaya* (evergreen species) which decomposed faster than the deciduous ones. These patterns of litter decomposition process were linked to variety of the physico-chemical traits of the leaf litter in the Soudano-guinea savannahs of Adamawa Cameroon. These finding suggested that the litter diversity, species groups and physico-chemical traits of the leaf litter in these savannahs seem to play a major role in leaf litter decomposition.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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