Greener Journal of Agricultural Sciences
Vol. 9(2), pp. 250-258, 2019
ISSN: 2276-7770

DOI Link: http://doi.org/10.15580/GJAS.2019.2.052719103
http://gjournals.org/GJAS

Leaf Decomposition and Nutrient Release in Four Selected Species in Makurdi, Benue State, Nigeria

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ARTICLE INFO

Article No.: *052719103*
***Type*:** *Research*
DOI: *10.15580/GJAS.2019.2.052719103*

Submitted: *27/05/2019*
Accepted: *30/05/2019*
Published: *13/06/2019*

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Keywords: *Litter decomposition; Nutrient dynamics; % carbon; Nutrient accumulation index; Turnover rate; Prosopis Africana; Parkia biglobosa; Daniellia oliveri; Morinda lucida*

ABSTRACT

Leaf decomposition rates in *Prosopis africana, Parkia biglobosa, Daniellia oliveri* and *Morinda lucida* were investigated in Makurdi, Benue State, Nigeria. Decomposition was determined as loss in mass of litter over a period of 8 weeks (January 15- March 15, 2016 and August 15 –October 15, 2016). The exponential decay model W_t / W_0 =$e^{-kd\ t}$. was used to evaluate the percentage mass of litter remaining over time while the time taken for half the initial material to decompose (t_{50}) was evaluated using t_{50}= ln 2/k and the nutrient accumulation index was determined by (NAI = $\frac{\omega tXt}{\omega oXo}$) Leaf decomposition rates (g d^{-1}) varied significantly (p<0.01) with species exposure time with % dry weight remaining ranging from 89.63% to 77.4% in both seasons. *P. africana* (0.0033, 0.0039) had the fastest decomposition rates in both seasons, while *P. biglobosa*, *M. lucida* and *D. oliveri* (0.0017) were slowest in the wet season. Mean projected residence time ranged between 363 and 476 days (wet and dry seasons) across species. Average C: N ratio increased generally across species in both seasons with a net mineralization of nitrogen except in *M. lucida* (0.99) and *D. oliveri* (0.16), while carbon was immobilized except in *P. africana* (0.93) with net mineralization in both seasons. The contributions of selected species in nutrient cycling are implicated in this study, hence their importance in ecosystem management.

INTRODUCTION

Litter decomposition is a major biogeochemical process in nutrient cycling particularly carbon, in forest ecosystems (Perry *et al*., 2008; Aerts, 2006; Shields, 2006; Zhang *et al*., 2008). Litter decomposition is the weight loss due to physical fragmentation (caused by abiotic factors), microbial activity or the leaching of nutrients from plant materials (Werry and Lee, 2005). Several factors controlling decomposition rate have been suggested by different researchers and include temperature, moisture and litter quality (Karberg *et al*., 2008), leaf-dry matter content, leaf toughness, nitrogen and lignin contents (Cornelissen *et al*., 2007) and the decomposer (faunal) community, which in turn is influenced by the tree species (Aponte *et al*., 2012; Dechaine *et al*., 2005). Fallen leaves tend to build up a layer of litter on the floor hence their decomposition becomes an important pathway for nutrients release and recycling back to the

soil (Abugre *et al*., 2011). Consequently, studies on litter decomposition rates are necessary for understanding nutrient dynamics (Karberg *et al*., 2008).

Most studies on litter decomposition are site specific and difficult to extrapolate on spatial scales and considering the diverse vegetation in tropical Africa, it becomes necessary to investigate the decomposition and the pattern of nutrient in some of the woody species. *Prosopis africana, Parkia biglobosa, Daniellia oliveri* and *Morinda lucida* are common species in the Guinea savanna ecosystem and provide important ecological services including nutrient cycling. This study research therefore, investigates the rate of leaf litter decomposition while the specific objectives are; to evaluate the turnover rate, projected residence time for all and half the initial mass to decompose and the nutrient accumulation index in the leaves of the selected species.

MATERIALS AND METHODS

Data Collection

Leaf decomposition rates for all the species were determined as loss in mass of litter over a period of 8 weeks. Senescent leaves were harvested by plucking the leaves directly from the tree since plants are believed to have nutrient re-absorption ability just before senescence (Ocheing and Erftemeijer, 2002). The leaves were rinsed with de-ionized water and air dried for 24 hours, to remove dust particles and placed in litter bags kept under the same tree. Twenty-gram weight (20 g) of senescent leaves from five litter bags of each plant were oven dried at 80 ^{0}C to constant mass and used to determine the mean initial mass of dry leaves in the bags.

Eight litter bags were placed on the soil surface under each plant and tethered with nylon rope. A total of 320 bags were distributed among the eight species (each species in five replicates, each replicate with eight litter bags). A litter bag was collected from each plant (40 litter bags) at 14, 28, 42 and 56 days after initial placement. Thus, a total of 160 bags were retrieved and analysed. After each collection, the litter was gently rinsed (to get rid of soil), oven dried at 80 ^{0}C to constant mass, weighed and finely ground in a mill for nutrient analysis. The experiment was carried out in both wet and dry seasons.

Data Analysis

Graphs of mean mass of litter remaining after time t, as percentage of initial dry mass were obtained for all species. The negative single exponential decay model by Minderman (1968); Olson (2007) and Aldair *et al*. (2010) was used to evaluate the relationship between percentage mass of litter remaining and sampling time for all species using equation (3).

$W_t / W_0 = e^{-kd\,t}$;

Where W_0 = initial dry mass; W_t = mass remaining at time t; K_d = decomposition coefficient in days (d^{-1}) and is derived as follows:

$\text{Log}_e (W_t / W_0) = \log_e {}^{-K_d t}$
$\text{Log}_e (W_t / W_0) = - K_d t$

$K_d = -\ -1/t(\log_e W_t - \log_e W_0)$ $\qquad Kd = -\frac{1}{t} In \left(\frac{Wt}{W0}\right)$

A two-way analysis of variance (ANOVA) (Obi, 2002) was used to evaluate the effects of species and exposure time on the rate of decomposition for all the species, with species and exposure time as the main factors. The time taken for half the initial material to decompose (t_{50}) was evaluated using equation; t_{50}= ln 2/k; where, ln = natural logarithm; K = decomposition rate.

Net changes in nutrients

Nutrient accumulation index (NAI) for each species was calculated in order to establish a net mineralization or accumulation of carbon and nitrogen in the decomposing leaves, using equation NAI= ($\frac{\omega t\, Xt}{\omega o Xo}$) (Harman *et al*., 1986); where, W_t = the dry weight of the leaf litter at time t, X_t = the nutrient concentration of the leaf litter at time t, the initial dry weight of leaf litter and X_0= the initial concentration of nutrient in the leaf litter.

An NAI value of 1.0 indicates that the decomposed leaf litter contains the same mass of the element 'X' when the leaf litter was placed in the litter bag; NAI < 1.0 indicates net mineralization of the element from the decaying leaf litter and NAI > 1.0 indicates net assimilation of the element by the decaying leaf litter.

Relationships between exposure time and nutrient contents (carbon and nitrogen contents) in decomposing leaves were evaluated using correlation and regression analyses.

RESULTS

Leaf Decomposition, Turnover Rate(k_d) and Residence Time(1/k_d)

The average percentages of original dry weight of leaves remaining following exposure for 56 days indicates *D. oliveri* (89.63%, 85.20%) and *P. africana* (81.00%, 77.40%) having the fastest and slowest decomposition in both seasons respectively (figure 1). ANOVA revealed highly significant differences (P<0.01) in decomposition rates and exposure time (days) and a significant interaction (P<0.05) between species and exposure time in both seasons, suggesting that all species were affected in different ways. The average decomposition rate (k_d) in the dry season for all the species was 0.0022 g d^{-1} with *P. africana* having the fastest decomposition rate (0.0033 g d^{-1}) while *P. biglobosa* and *M. lucida* have the slowest decomposition rates (0.0017 g d^{-1}). In the wet season however, the average decomposition rate

was 0.0026 g d^{-1}, with the fastest rate of decomposition in *P. africana* (0.0039 g d^{-1}) while *D. oliveri* had the slowest decomposition rate (0.0017 g d^{-1}) (Figure 2).

The shortest projected residence times($1/k_d$) were observed in *P. africana* (303 and 256 days) in both seasons, while the longest residence times were recorded in *P. biglobosa* and *M. lucida* (588 days) and *Daniellia oliveri* (599 days) in the dry and wet seasons, respectively. The time taken for half of the initial leaf in litter bags to decompose (T_{50}) during the dry season ranged from 210 days in *P. africana* to 407 days in *P. biglobosa* and *M. lucida*; while in the wet season it ranged between 177 days in *P africana* and 415 days in *D. oliveri* (Figure 2)

Nutrient dynamics

Nitrogen content decreased generally with exposure time in both seasons across species except in *Morinda lucida* which showed increase (1.37-1.62) in the dry season and *Daniellia oliveri* (1.44-1.96) in the wet season (Figure 3). Carbon content however, increased in the first 14 days in all the species across seasons, and thereafter decreased progressively (Figure 3). ANOVA revealed highly significant differences ($P<0.05$) in nitrogen and carbon contents. Mean C: N ratio in all the species at the end of study increased generally in both dry and wet seasons. There was net mineralization of nitrogen in all the species in both seasons while carbon showed a net assimilation in the dry season, and a net mineralization in the wet season (Figure 2). There were weak positive relationships ($P>0.05$) between exposure time (days) and nitrogen and carbon contents in the dry season while in the wet season, only carbon showed a positive relationship with exposure time. (Table 1).

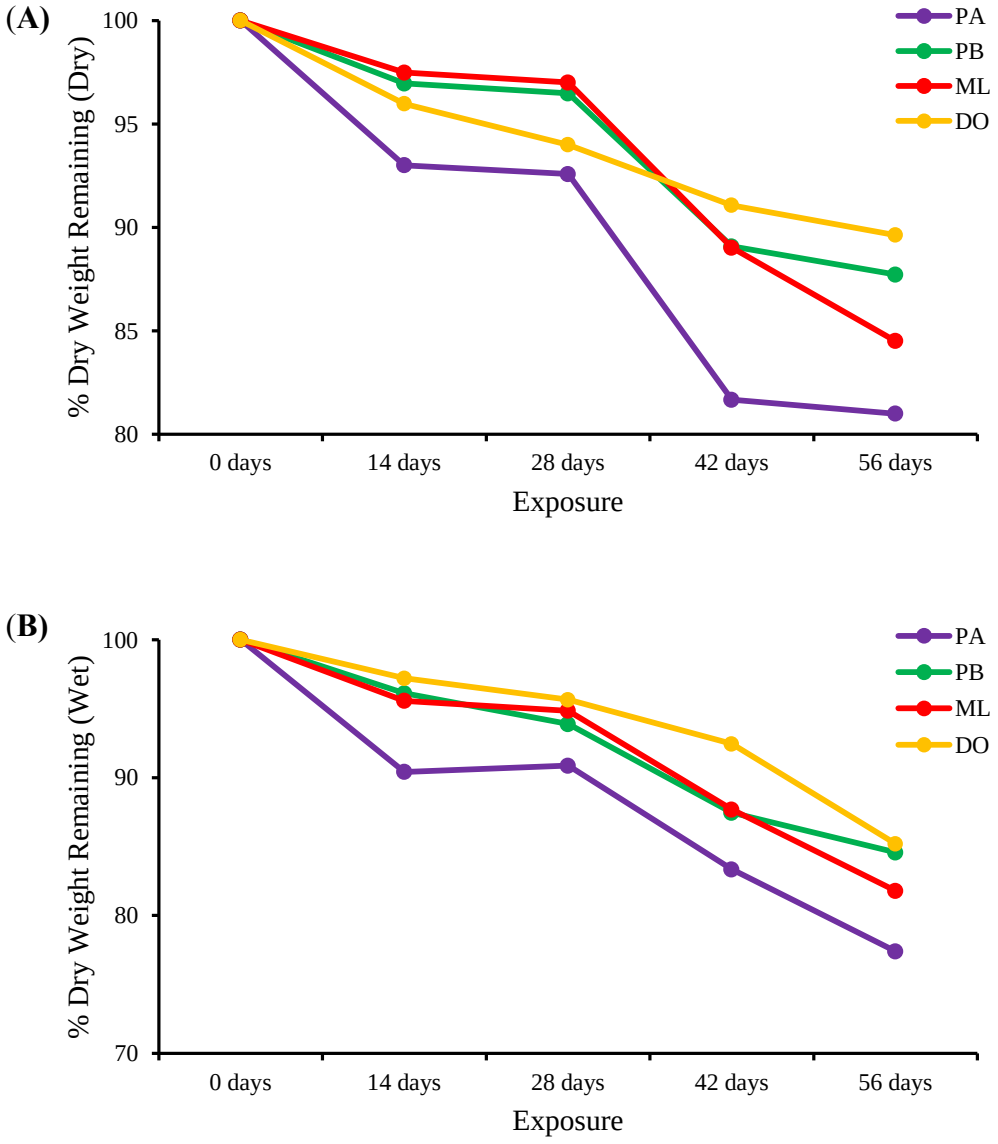

Figure 1. % Dry weight remaining for four species (**A**) Dry season (**B**) Wet season. PA: *Prosopis africana*, PB: *Parkia biglobosa*, ML: *Morinda lucida*, DO: *Daniella oliveri*.

Table 1. Correlation and regression coefficients and equations showing relationship between exposure time and nitrogen and carbon decomposition.

Comparison	Pearson Correlation r	R^2	Strength of Correlation	p value	Equation
Dry					
Exposure time v Nitrogen	0.148	0.022	Weak positive	0.143	y = 1.38+7.5E-3*x
Exposure time v Carbon	0.168	0.028	Weak positive	0.094	y = 24.49+0.8*x
Wet					
Exposure time v Nitrogen	-0.115	0.013	Weak negative	0.256	y = 1.39+-0.01*x
Exposure time v Carbon	0.075	0.006	Weak positive	0.460	y = 24.2+0.28*x

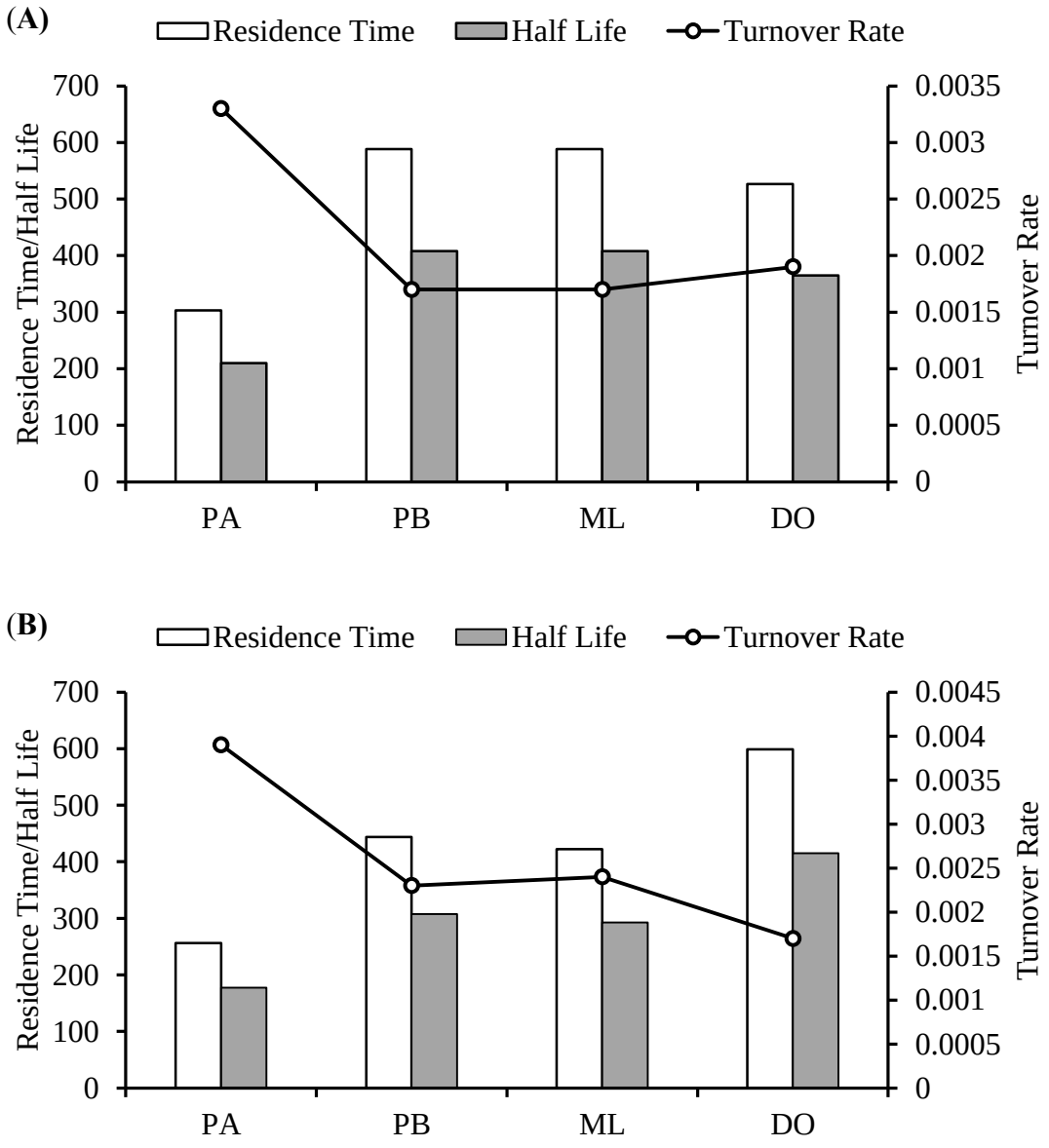

Figure 2. Residence Time, Half Life and Turnover Rate of four species (**A**) Dry season (**B**) Wet season. PA: *Prosopis africana*, PB: *Parkia biglobosa*, ML: *Morinda lucida*, DO: *Daniella oliveri*.

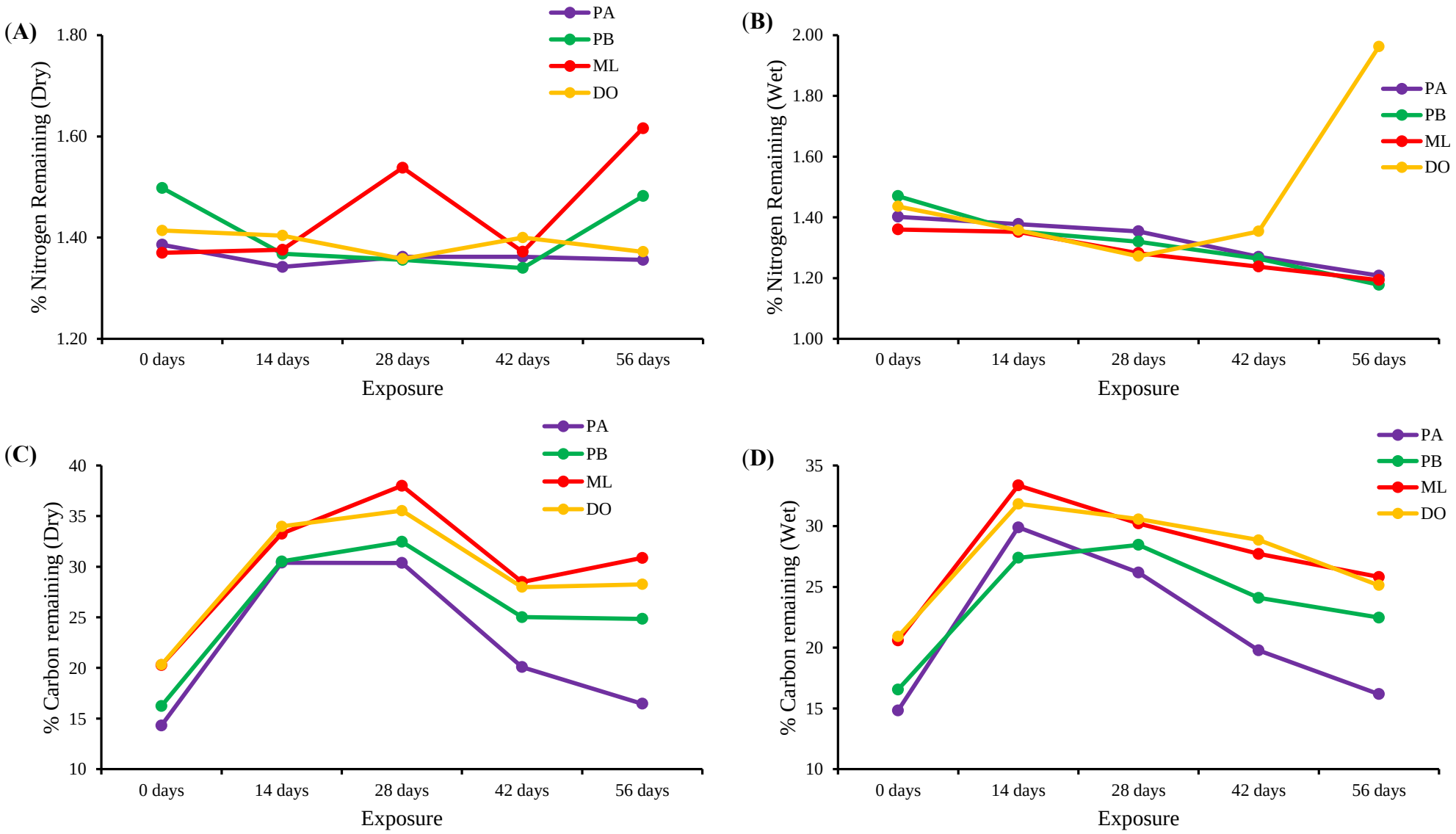

Figure 3. % Nutrients remaining after exposure. (A) Nitrogen (dry) (B) Nitrogen (wet) (C) Carbon (dry) (D) Carbon (wet). PA: *Prosopis africana*, PB: *Parkia biglobosa*, ML: *Morinda lucida*, DO: *Daniella oliveri*.

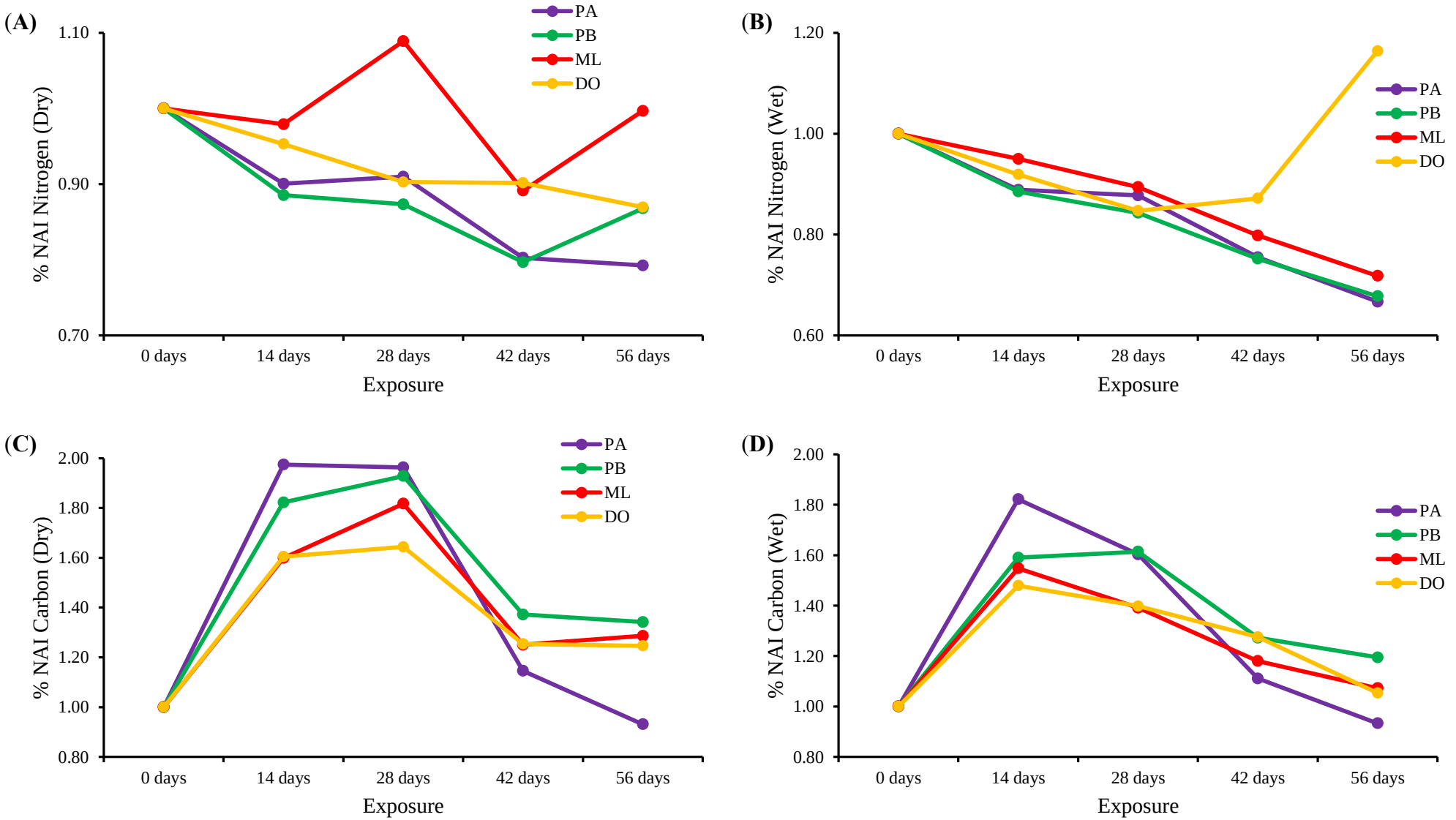

Figure 4. % Nutrient Accumulation Index in the species leaves following exposure. (A) Nitrogen (dry) (B) Nitrogen (wet) (C) Carbon (dry) (D) Carbon (wet). PA: *Prosopis africana*, PB: *Parkia biglobosa*, ML: *Morinda lucida*, DO: *Daniella oliveri*.

DISCUSSION

The variation in decomposition rate among species in both seasons (Figure, 1) is in line with reports by Mitchell *et al*. (2007), Aponte *et al*., (2008), Austin and Vivanco (2006), Sariyildiz and Anderson (2003); who suggested that litter quality and environmental conditions affect decomposition rates. They further explained that, tree species induced changes in soil fertility, microclimate as well as fauna and microbial communities which influenced decomposition on the floor. Negrete-Yankelevich *et al*. (2008), Vivanco and Austin (2008) and Ayres *et al*. (2009) further stated that placing the litter bags under specific canopy instead of other plant cover offers a home-field advantage that enhances a positive litter-environment (soil communities) interaction.

Significant variation ($p<0.01$) in average decay coefficient in both species and exposure time (days), suggests that differences in nutrient and chemical composition in the decomposing leaves are critical factors of decomposition (Table, 1). The mean decay coefficients (k_d) within the study period (0.0022 and 0.0026) in both dry and wet seasons were generally low compared to the estimated mean decay coefficient for most tropical and temperate forests (k=1.8 and k= 0.9) as reported by Toreta and Takeda (1999) and (k>2) in most African forests (Anderson and Swift, 1983). Sariyildiz *et al*. (2005) stated that higher k values (k>1) means rapid nutrient cycling in the ecosystem and a low k value (k<1) indicates a longer time for decomposition to take place. The low mean k values (0.0022 and 0.0026) in this study hereby indicate a slow decomposition of the species leaves and will increase the chance of litter export from the floor (Werry and Lee, 2005), thus affecting nutrient cycling.

Substrate quality which varies with species litter (C: N, N: P ratios, Lignin, Calcium and Magnesium contents) has been highlighted as the main rate determining factors of decomposition (Cornellissen *et al*., 2006; Hobbie *et al*., 2006; Cornwell *et al*., 2008; Gusewell and Gessner, 2009; and Berge *et al*., 2010). Kemp *et al*. (2003) also stressed the significance of litter quality in determining decomposition, saying that short lived species with high nutrients decomposed faster than long lived species with woody and leathery tissues, high nitrogen and carbon rich components (lignin, cellulose).

The slow Decomposition in dry season (November to April) compared to the wet season (May to October) in this study (Figure 2) suggests the possible influence of water on the rate of decomposition. The wet season probably provided adequate moisture which enhanced leaching of soluble materials thus promoting microbial activities (Edu, 2012). Water availability also determines differences in decomposition trend and mass losses as it is limiting for most organisms that affect decomposition, although very high amount of water slows down decomposition rate (Goulden, 2005; Abugre *et al*., 2011).

Litton *et al*. (2011) also reported that warming temperatures increased the rates of litter decay and nutrient release. Laura and Yolanda (2007) demonstrated spatial variability in decomposition and reported that, leaf litter exposed to radiation decomposed faster than those under canopy. Placing the leaves under the tree canopies in this study probably resulted in slow decomposition rate.

The early decomposition in the first 14 days, suggests that some of the labile or rapidly decomposing fractions (sugar, starch or proteins) are water soluble and attracted immediate microbial utilization or leaching that resulted in mass loss in the early phase of decomposition. Gusewell and Gessner (2009), Berg *et al*., (2010) and Abugre *et al*. (2011) explained that availability of limiting elements such as Nitrogen and Phosphorus determines early decomposition where as carbon loss at the late stage is determined by availability of elements required to decompose recalcitrant materials such as lignin in the remaining litter. Consequently, only the slow decomposing tissues (cellulose, lignin,) are left to decompose in the last phase of the experiment.

Nutrient accumulation index (NAI) revealed a net mineralization of nitrogen (except in *Morinda lucida* and *Daniellia oliveri*) while carbon was immobilized in both seasons except in *P. africana*. This result therefore indicates a release of nitrogen from the decomposing leaves into the soil (recycled) while carbon was immobilized (assimilated) probably through microbial population.

CONCLUSION

The initial drop in litter quantity during the first phase of decomposition and the occasional rise in nutrient contents of decomposing litter observed in this study are in line with the general model of litter decomposition which includes initial leaching of nutrients, nutrient immobilization and nutrient release into the soil. Decomposition rate generally increased with exposure time and varies with seasons. There was a net mineralization of nitrogen in both seasons while carbon was immobilized.

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Cite this Article: Okoh T; Edu EA; Ebigwai JK (2019). Leaf Decomposition and Nutrient Release in Four Selected Species in Makurdi, Benue State, Nigeria. Greener Journal of Agricultural Sciences 9(2): 250-258, http://doi.org/10.15580/GJAS.2019.2.052719103**.**