Nutrient dynamics in decomposing litter from four selected tree species in Makurdi, Benue State, Nigeria

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Abstract

Background: Nutrient release during litter decomposition was investigated in *Vitex doniana*, *Terminalia avecinioides*, *Sarcocephallus latifolius*, and *Parinari curatellifolius* in Makurdi, Benue State Nigeria (January 10 to March 10 and from June 10 to August 10, 2016). Leaf decomposition was measured as loss in mass of litter over time using the decay model $W_t/W_0 = e^{-kd\ t}$, while $Kd = -\frac{1}{t}ln(\frac{W_t}{W_0})$ was used to evaluate decomposition rate. Time taken for half of litter to decompose was measured using $T_{50} = \ln ^2/k$; while nutrient accumulation index was evaluated as $NAI = (\frac{\omega t\ Xt}{\omega o Xo})$.

Results: Average mass of litter remaining after exposure ranged from 96.15 g, (*V. doniana*) to 78.11 g, (*S. lafolius*) in dry (November to March) and wet (April to October) seasons. Decomposition rate was averagely faster in the wet season (0.0030) than in the dry season (0.0022) with *P. curatellifolius* (0.0028) and *T. avecinioides* (0.0039) having the fastest decomposition rates in dry and wet seasons. Mean residence time (days) ranged from 929 to 356, while the time (days) for half the original mass to decompose ranged from 622 to 201 (dry and wet seasons). 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.

Conclusion: Slow decomposition in the plant leaves implied carbon retention in the ecosystem and slow release of CO_2 back to the atmosphere, while nitrogen was mineralized in both seasons. The plants therefore showed effectiveness in nutrient cycling and support productivity in the ecosystem.

Keywords: Nutrient dynamics, Litter decomposition, Decay coefficient, Nutrient accumulation index, Turnover rate

Introduction

Litter decomposition is a major pathway in the process of nutrient return to the soil. Several studies on litter decomposition have provided useful information on the rates and pattern of decomposition and nutrient release in various ecosystems and the factors affecting species rate of decomposition (Negrete-Yankelevich et al. 2008; Vivanco and Austin 2008; Ayres et al. 2009). Litter nutrient quality such as nitrogen and lignin content (Aerts 1997), vegetation, and litter types have been suggested as factors affecting litter decomposition (Gholz et al. 2000; Prescott et al. 2000; Cornelissen et al. 2007) as well as

climatic factors such as temperature and precipitation (O'Neill et al. 2003; Karberg et al. 2008). Aponte et al. (2012) stated that, the controlling factors of early decomposition and nutrient release differ from those of slow decomposing litter and build-up of soil organic matter.

Slow decomposition rates result in build-up of organic matter and nutrient stocks in soil; however, fast decomposition rates increase the nutrient availability for plant intake (Isaac and Nair 2005).

The leaf decomposition rate is a measure of the speed at which litter is decomposed in the ecosystem. Residence time gives a measure of how long the litter remains in the ecosystem before decomposition. Nutrient accumulation index indicates if nutrients (nitrogen,

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carbon) are released into the environment (mineralization) or retained (accumulation) in decomposing leaves. Turnover rate indicates mass of litter lost through decomposition since decomposing leaves are trapped in litter bags and excludes other ecological processes that export leaves. Half-life is the time taken for half the mass of the litter to decompose.

Vitex doniana Joris de Wolf (Verbenaceae) is a small to medium-sized tree, 11 m tall; with single bole often slightly fluted at the base (90–160 cm). Leaves are opposite, digitately compound. Inflorescence is axillary cyme up to 10 cm long and 16 cm wide. Flowers are bisexual, zygomorphic, and pentamerous; while the fruit is a drupe with 4, non-endospermous seeds (Orwa et al. 2009). The plant is wide spread in savanna and in wetter areas at lower altitudes, in secondary and dry forests. The fruit and fresh leaves are edible, while medicinal uses include treatment for anemia; the root is used as treatment for gonorrhea. The wood is used for wood fire and charcoal (FAO 1983).

Terminalia avecinnioides (Combretaceae) is a small tree, 7–10 m tall. The plant is wide spread in savanna and in wetter areas at lower altitudes, in secondary and dry forests (FAO 1983). The crown is open and the bark is deeply cracked and corky, dark grey to black. Leaves are alternate, simple, and entire; petiole 1–3 cm long, with blade narrowly elliptical (10–20 cm × 3–7 cm. Inflorescence is a raceme, bearing bisexual flowers, regular, and pentamerous. The plant occurs across West Africa and has several anthropogenic uses such as for chewing stick, wood fire, and as dye (FAO 1983).

Sarcocephalus latifolius (JE Sm.) EA. Bruce (Rubiaceae) is a shrub, with multi stems and open canopy. The leaves are broad, and smooth white flowers are terminal and aggregated into a head-like cyme of small whitish flowers joined by their calyces with a syncarpuous fruit. The plant shows wide distribution in tropical Africa. The fleshy fruits and leaves are edible fodder; the wood is a source of wood fire and the bark yields tannins used in dyeing (FAO 1983).

Parinari curatellifolia (Chrysobalanaceae) is a large, evergreen, spreading tree (20 m) with a single bare stem and rough bark. Leaves are alternate, simple, and dark green on top. Flowers are axillary, bisexual, and pentamerous. Fruits are oval (5 × 3.5 cm) and orange-yellow when ripe. The fruits are edible and are occasionally utilized for the brewing of alcoholic beverages, while the wood provides good source wood fire (FAO 1983).

The highlighted species dominate the vegetation of the study area. The species are widespread in open savanna with moderate rainfall and high temperature. The species thrive naturally on sandy soils and fallow land (Tyowua et al., 2013). The species, among other aforementioned uses, are used for mulching by farmers and, because of their dominant status, understanding their rate of decomposition would therefore provide better insights into their contribution to nutrient cycling. The aim of this research was to investigate litter decomposition and nutrient dynamics in *Vitex doniana*, *Terminalia avecinioides*, *Sarcocephallus latifolius*, and *Parinari curatellifolia*, and the specific objectives were to evaluate the litter turnover rate, residence time, half-life, and the nutrient accumulation index in the leaves of the selected species.
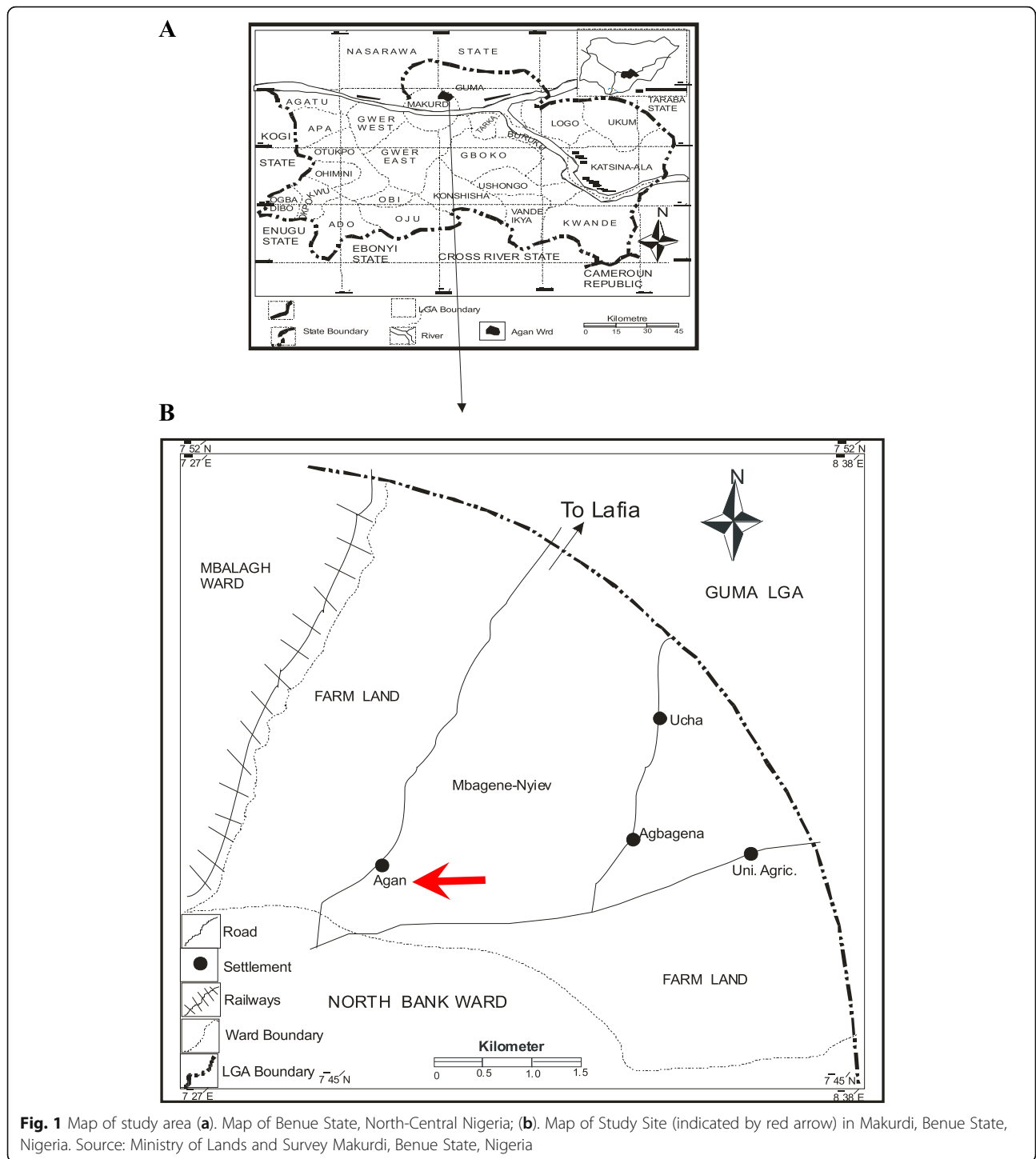
Materials and methods
Study area
The research was carried out at the Agan open forest area of Makurdi, Benue State (January 10 to March 10 and from June 10 to August 10, 2016). The area falls within the Guinea Savanna agro ecological zone of Nigeria (latitudes 70 38′ and 70 50′ North of the Equator and longitude 80 24′ and 80 38′ East of the Greenwich Meridian). The relief is generally low lying, ranging from below 90 to 150 m above sea level. Three soil types (alluvial, clayey loam, and sandy) predominate, with a total land mass of 3,993.3 km^2 and divided by the River Benue into North and South Banks, respectively (Kogbe 1989; Tyowua et al., 2013) (Fig. 1). The region is a tropical area with alternating wet (April to October) and dry (November to March) seasons and an annual average precipitation of 1240–1440 mm. Temperature generally is high during the day especially in March and April, with daily maximum and minimum temperatures between 37 and 16 °C (NIMET 2015, 2016) (Fig. 2). The study area is a hub for agricultural activity and annual bush burning; hence, it is a mixture of natural and human-managed mosaics of different tree and grass species (Tyowua et al., 2013).
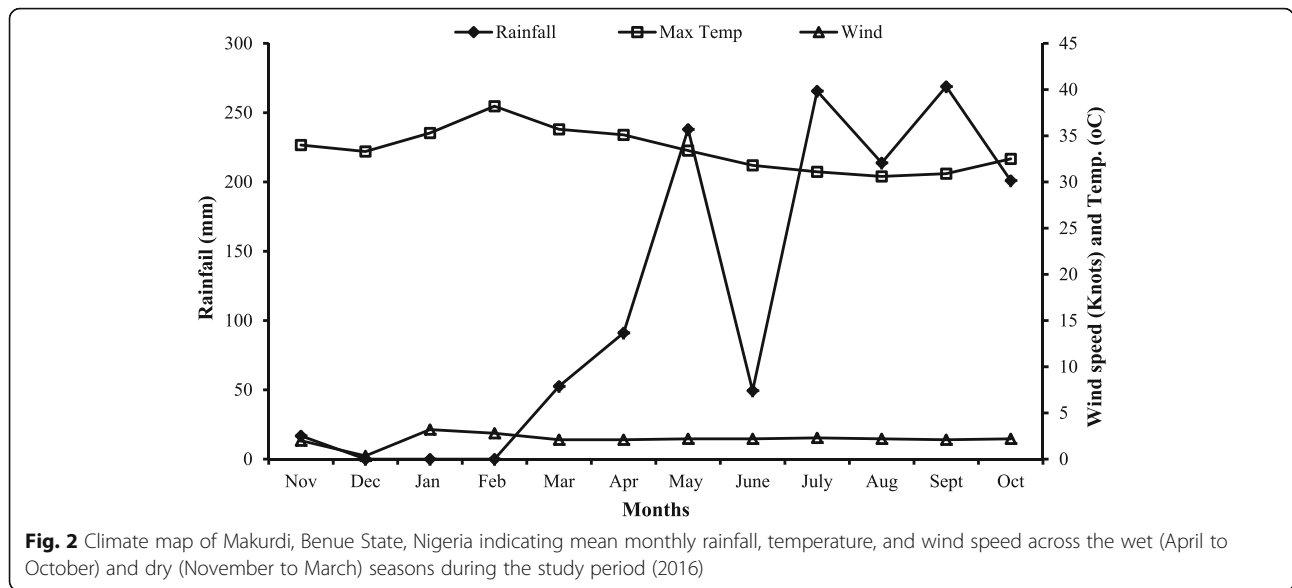
Data collection
The litterbag technique was adopted for evaluating litter decomposition at the soil surface as it allowed for selective entry of microfauna and reduce particle loss during decomposition (Robertson and Paul 1999). Senescent leaves were harvested (plucked) directly from the tree. The leaves were rinsed with de-ionized water and air dried for 24 h, to remove dust particles, and placed in litter bags kept under the same tree. Twenty grams (20 g) of senescent leaves from five litterbags of each plant were oven dried at 80 °C to constant mass and used to determine the mean initial mass of dry leaves in the bags. Eight litterbags (1 mm mesh size) were placed under each plant (on the floor) and tethered with nylon rope. A total of 160 bags were distributed among the four species (each species in five replicates, each replicate with eight litterbags). A litterbag was collected from

Fig. 1 Map of study area (**a**). Map of Benue State, North-Central Nigeria; (**b**). Map of Study Site (indicated by red arrow) in Makurdi, Benue State, Nigeria. Source: Ministry of Lands and Survey Makurdi, Benue State, Nigeria

each plant (20 litterbags) at 14, 28, 42, and 56 days after initial placement. Thus, a total of 80 bags were retrieved and analyzed. After each collection, the litter was gently rinsed (to get rid of soil), oven dried at 80 °C to constant mass, 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 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 the

Fig. 2 Climate map of Makurdi, Benue State, Nigeria indicating mean monthly rainfall, temperature, and wind speed across the wet (April to October) and dry (November to March) seasons during the study period (2016)

equation $W_t/W_0 = e^{-kd\ t}$; where W_0 = initial dry mass; W_t = mass remaining at time t; K_d = decomposition co-efficient in days (d^{-1}) and is derived as follows:

$$\text{Log}_e\ (W_t/W_0) = \text{log}_e\ {}^{-K}{}_d{}^{t}$$

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

$$K_d = -{}^1/t \left(\text{log}_e\ W_t - \text{log}_e\ W_0 \right); \text{Kd} = -\frac{1}{t} In\left(\frac{Wt}{W0}\right)$$

Two-way analysis of variance (ANOVA) was used to evaluate the effects of species and exposure time on the rate of decomposition in all the species, with species and exposure time as the main factors. The time taken for the half of 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 ac-cumulation of carbon and nitrogen in the decomposing

leaves, using equation NA = $\left(\frac{\omega t\ Xt}{\omega o Xo}\right)$. (Harmon 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 assimila-tion of the element by the decaying leaf litter. Relation-ships between exposure time and nutrient contents (carbon and nitrogen contents) in decomposing leaves were determined by correlation and regression analyses (Table [1](#)).

Results

Decomposition rate

Average mass of litter remaining (g) ranged from 96.15 g (*V. doniana*) to 78.11 g (*S. latifolius*) in both seasons re-spectively (Fig. [3](#)). Mean rate of decomposition (k_d) was

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

Comparison	Pearson correlation r	*p* value	Equation
Dry season			
Exposure time v nitrogen	− 0.228	0.022*	$y = 1.47 + - 0.02 \times x$
Exposure time v carbon	− 0.266	0.008**	$y = 30.34 + - 1. \times 17 \times x$
Wet season			
Exposure time v nitrogen	− 0.807	0.000**	$y = 1.52 + - 0.05 \times x$
Exposure time v carbon	− 0.517	0.000**	$y = 31.43 + - 2 \times x$

**p < 0.001 statistically significant at 99% confidence interval; *p < 0.005 statistically significant at 95% confidence interval
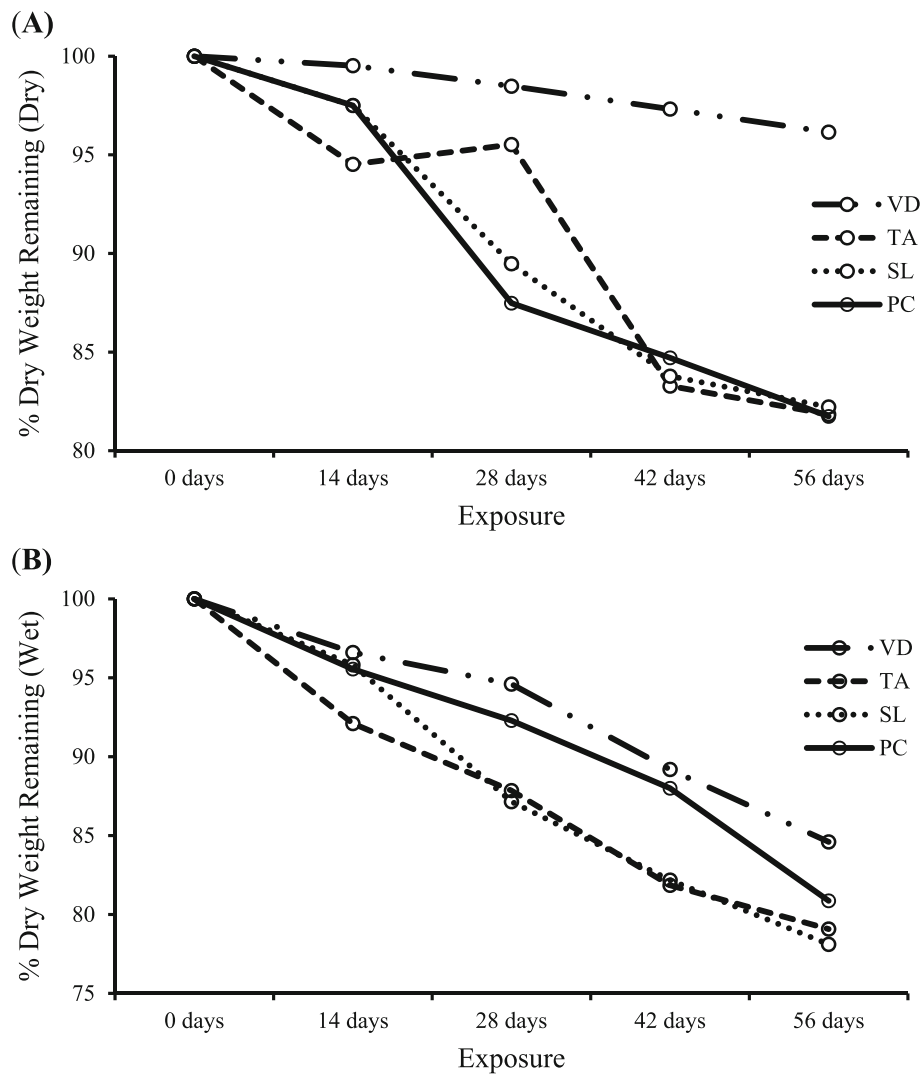
Fig. 3 % dry weight remaining for four species. **a** Dry season. **b** Wet season. VD, *Vitex doniana*; TA, *Terminalia avicennioides*; SL, *Sarcocephalus latifolius*; PC, *Parinari curatellifolia*

faster in the wet season ($0.0030\,g\,d^{-1}$) than in dry season ($0.0022\,g\,d^{-1}$), with *P. curatellifolius* ($0.0028\,g\,d^{-1}$) and *T. avecinioides* ($0.0039\,g\,d^{-1}$) having the fastest rates of decomposition in the dry and wet seasons (Fig. 4). 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 (Table 1).
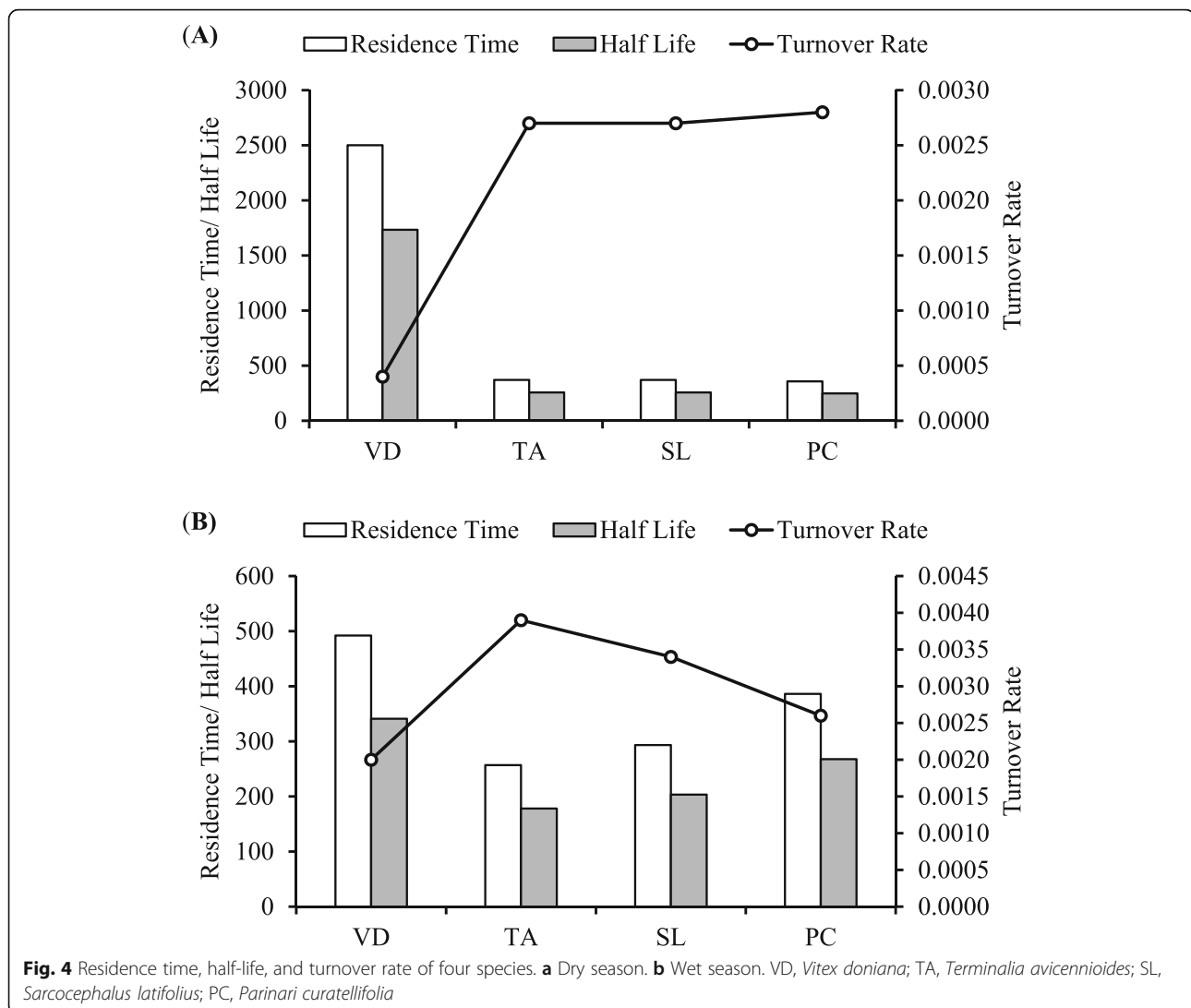
Turnover rate
Turnover rates in the dry season ranged from 0.0027 (*T. avecinioides*) and 0.0004 (*V. doniana*) and from 0.0039 (*T. avecinioides*) and 0.002 (*V. doniana*) in the wet season. Mean projected residence time ranged from 2500 days (*V. doniana*) to 357 days (*P. curatellifolius*) in the

dry season and from 491 days (*V. doniana*) to 256 days (*T. avecinioides*) in the wet season (Fig. 4). The minimum time (days) taken for half the original mass of litter to decompose (half-life) varied between 1732 days (*V. doniana*) and 178 days (*T. avecinioides*) in dry and wet seasons respectively.

Nutrient dynamics
Carbon and nitrogen contents were generally higher in the dry season than in the wet season (Fig. 5). Nutrient accumulation index (NAI) generally revealed a net mineralization of nitrogen while carbon was immobilized in both seasons respectively (Fig. 6). There were negative relationships ($p < 0.001$) between exposure time (days) and nitrogen and between exposure time and carbon contents in both seasons (Table 1).

Fig. 4 Residence time, half-life, and turnover rate of four species. **a** Dry season. **b** Wet season. VD, *Vitex doniana*; TA, *Terminalia avicennioides*; SL, *Sarcocephalus latifolius*; PC, *Parinari curatellifolia*
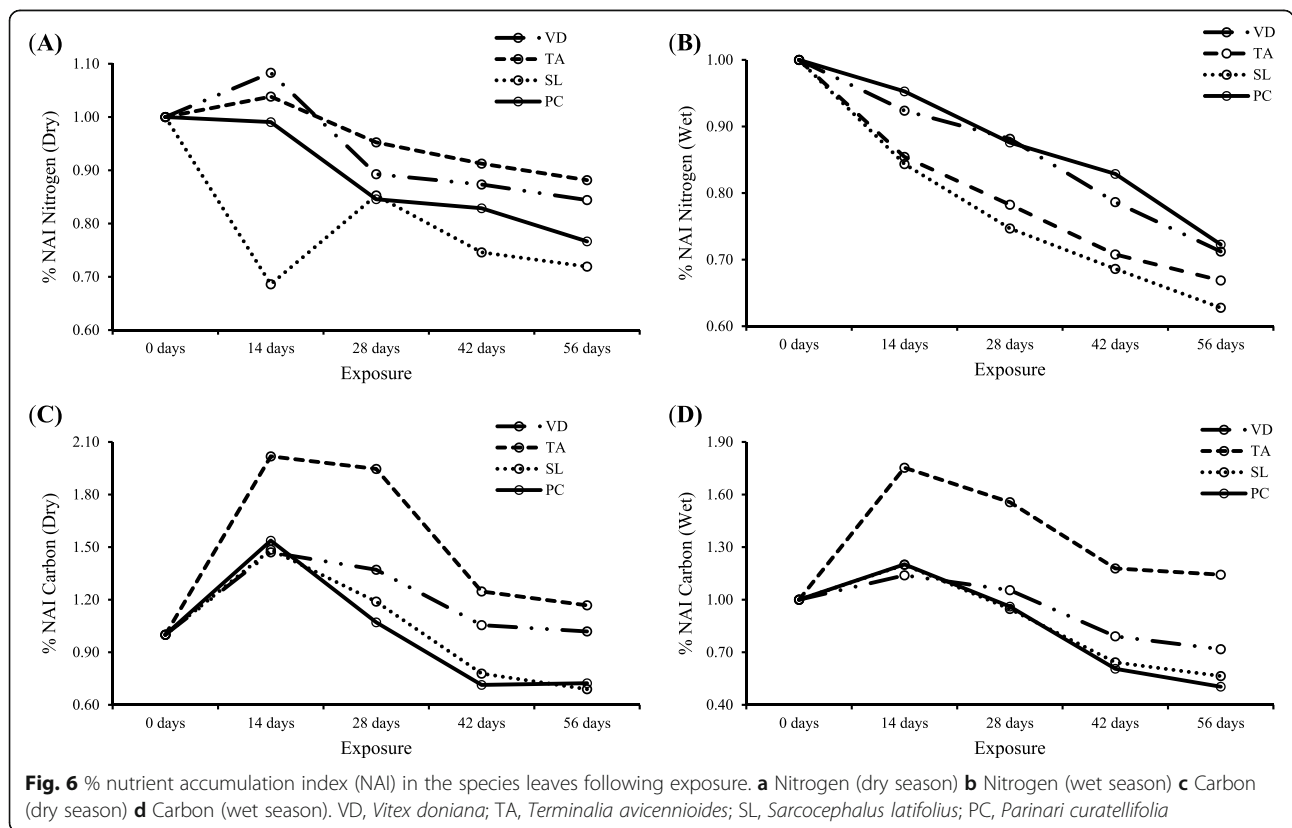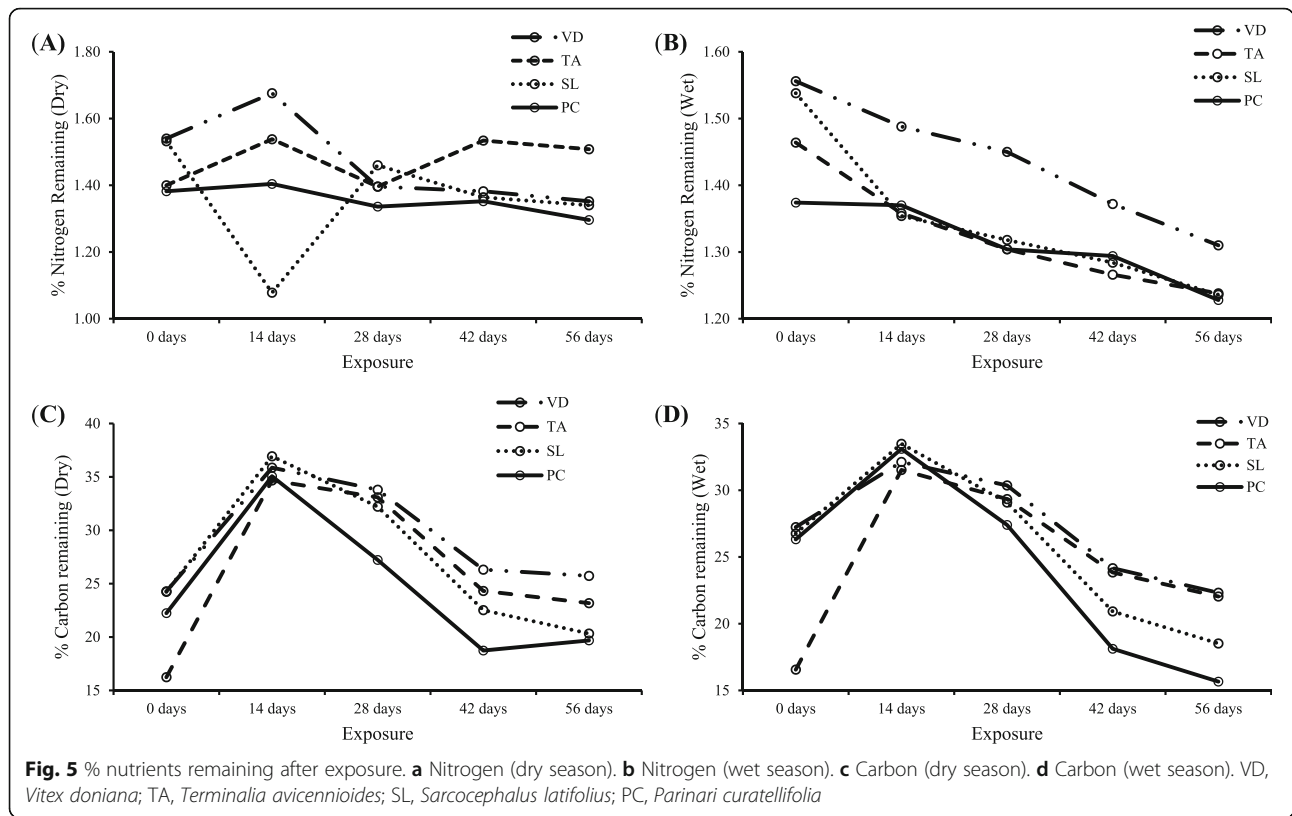
Discussion

The faster rate of decomposition in the wet season suggested the possible interactive effects of climatic conditions that stimulated the activity of soil fauna (Gautam et al. 2016; Xu et al. 2011), microbial activity, and loss of labile carbon through the carbon pool. Furthermore, in the dry season, inadequate moisture might have slowed down the decomposition process. Aponte et al. (2012), Negrete-Yankelevich et al. (2008), stated that, trees provide specific requirements which in turn determine the availability of decomposer communities that drive the decomposition process. Hence, placing the leaves (in litterbags) under tree canopy in this study probably enhanced the rate of decomposition than in naturally decaying leaves. Variation in species mean decay coefficients (K_d) in the study could possibly be due to differences in species litter quality and nutrient type, as suggested by other researchers (Gholz et al. 2000;

Prescott et al. 2000; Cornelissen et al. 2007). Turnover rates indicate loss through decomposition since the decomposing leaves are trapped. The study site is an open Savanna plagued with high farming activities, grazing animals, turbulent wind, bush burning, seasonal surface run-offs, as well as macro-consumers. The species with high decomposition rate will therefore enhance organic matter retention supporting agricultural production in the area.

Negative relationship between mean percentage of nutrients (nitrogen and carbon) and exposure time in both seasons suggests that decomposition was not affected by the length of exposure but based on other factors such as microbial utilization of litter and litter quality that enhanced decomposition rate. 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

Fig. 5 % nutrients remaining after exposure. **a** Nitrogen (dry season). **b** Nitrogen (wet season). **c** Carbon (dry season). **d** Carbon (wet season). VD, *Vitex doniana*; TA, *Terminalia avicennioides*; SL, *Sarcocephalus latifolius*; PC, *Parinari curatellifolia*

Fig. 6 % nutrient accumulation index (NAI) in the species leaves following exposure. **a** Nitrogen (dry season) **b** Nitrogen (wet season) **c** Carbon (dry season) **d** Carbon (wet season). VD, *Vitex doniana*; TA, *Terminalia avicennioides*; SL, *Sarcocephalus latifolius*; PC, *Parinari curatellifolia*

model of litter decomposition which includes initial leaching of nutrients, nutrient immobilization, and nutrient release into the soil.

The significant variations ($p < 0.01$) between nutrient contents in the decomposing leaves and exposure time in both seasons (Table 1; Fig. 5) suggested that different nutrients have different patterns of release in time (Girisha et al. 2003; Aponte et al. 2011; Augusto et al. 2002). This is possibly due to species differences in leaf composition, oxygen availability, soil characteristics, and microbial utilization as suggested by other researchers (Mitchell et al. 2007; Aponte et al., 2011; Austin and Vivanco 2006). Negrete-Yankelevich et al. (2008), The tree canopies (with limited abiotic mineralization driven by solar radiation and mechanical forces) provided a home-field advantage to the decomposing leaves placed under it and supplied specific nutrients that influenced microbial populations, resulting in nutrient enrichment in the decomposing leaves (Vivanco and Austin 2008; Ayres et al. 2009; Arriaga and Maya 2007). Abugre et al. (2011) explained that, nutrient release depends on whether such nutrient is limiting or not to microbial growth. He further explained that when a nutrient is limiting in amount and carbon:element ratio is above critical level, such element will be accumulated resulting in immobilization, whereas, if the carbon:element ratio is below critical level the element will be released.

Nutrient accumulation index (NAI) of nitrogen and carbon (Table 1 and Fig. 6), indicated a release of nitrogen (NAI < 1) from the decomposing leaves into the soil while carbon was immobilized or assimilated (NAI > 1) probably through increased microbial population. The negative relationship between mean percentage nutrient remaining and exposure time in both seasons (Table 1) reflects microbial utilization of litter which enhanced decomposition rate and nutrient release (Gusewell and Gessner 2009).

Conclusion

The high percentage mass of initial litter remaining after exposure indicated slow decomposition which implied nutrient retention and slow release of nutrients back to the ecosystem. Net changes in nutrient (mineralization and immobilization) varied among species and seasons. Nitrogen was mineralized in both seasons, while carbon was immobilized (assimilated), supporting productivity in the system.

The species decomposition showed their ecological importance in building up organic matter for nutrient cycling in the ecosystem. It also suggested that the species litter would remain longer in the ecosystem before decomposing; hence, they are suitable for mulching activities in the study area. The species

therefore showed effectiveness in nutrient cycling and enhancing productivity. Nutrient dynamics in decomposing litter could indicate whether the ecosystem is in a nutrient conservative stage. This is important particularly for the study area since agriculture is the mainstay of its economy.

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