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Carbon Credits Assessment in Four Woody Species of the Guinea Savanna Ecosystem in Makurdi, Benue State, Nigeria

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Abstract

Carbon credits in *Prosopis africana, Parkia biglobosa, Morinda lucida* and *Daniellia oliveri* were investigated in Makurdi, Benue State, Nigeria over twelve months (November 2015 to October 2016) as losses through litter production. Litterfall rate and composition were measured using litter traps and quadrats on the floor, while carbon was determined as 50% of litter (dry weight). There were significant differences ($p<0.01$) in rates of litter production and composition (in trap and on the floor) across months and species. Mean total litterfall (g m^{-2}) was 36.98, with leaf litter contributing 17.20 (46.51%), wood litter 12.44 (33.64%) and miscellaneous litter 7.33 (19.82%), with bimodal peaks in January (94.89 ± 13.01) and July (43.28 ± 23.92) between *P. africana* (18.81 ± 20.49) and *M. lucida* (57.16). Plant height correlates negatively with litterfall ($r = -0.699$, $R^2= 0.489$, $p=0.001$) and crown diameter ($r =-0.611$; $R^2=0.0373$, $p=0.004$). *P. biglobosa,* and *M. lucida* have the highest litter turnover rates (2.01, 2.71), while residence times were generally ≤ 1 day in both seasons. Carbon stocks in plant litter (tones/ m^{-2} y^{-1}) ranged between *M. lucida* (0.105, 0.062) and *P. africana* (0.035, 0.035). Species with higher litter production loose more carbon, while the fast loss of litter from the floor that less litter is available for biogeochemical sequestration of carbon and reduces productivity in the system.

Keywords: Carbon credits; Litter fall; Litter biomass; Turnover rate; Residence time; *Prosopis africana; Parkia biglobosa; Morinda lucida; Daniellia oliveri*; Makurdi

Introduction

Litter production (the shedding of vegetative plant structures either because of senescence, wilting or environmental factors) in most plants is a phenological behaviour that occurs in specific time of the year [1,2]. Litterfall may also be due to aging of forests, changing stand density, increasing forest growth [3], more frequent disturbances and pathogen attacks [4], or elevated CO_2 concentration and nitrogen deposition [5].

It is also an indirect way for measuring the loss of biomass accumulated during growth period, hence the loss of carbon gained through photosynthesis. Litterfall provides a better input of carbon and nutrients into the forest floor than environmental imputes, by protecting the underlying humus and mineral against drought and acts as a buffer, improving the ecosystem capacity [6,7]. Zhang et al. [8] explained that litterfall is characteristic of tropical ecosystems under climate and studies on litter production have provided useful information on carbon dynamics of plants in different ecosystems [9,10]. Reliable information on the carbon and nutrient input from litterfall, provided by litter traps, is relevant to a wide audience including policy makers and soil scientists [11,12]. Edu and Bothwell [13,14], revealed that rates of litterfall and decomposition are important in understanding the productivity and nutrient budgeting of agro-forestry systems and for evaluating their sources or sink capacity, climate feedbacks, and hence the overall global carbon cycle [15]. Litterfall is a yet, poorly studied process within forest ecosystems globally, including Nigeria. This research is therefore necessary in order to understand the contributions of the species to biogeochemical sequestration, carbon credit assessment and climate change mitigation. *Prosopis africana* (Guill, Perr. & Rich) Taub.; *Parkia biglobosa* (Jacq.) R. Br. ex G. Don. *Morinda lucida* and *Daniellia oliveri* (Rolfe) Hutch. & Dalziel are common Savanna plants among others well distributed in Makurdi, Benue State. Intense soil tillage for food production, coupled with over exploitation of wood resources, annual bush burning, and urban expansion have resulted in great loss of plant resources in most developing nations, including Nigeria. This study therefore aims at evaluating carbon credits through litter production and specifically investigating temporal variations in litterfall and composition, litter turnover rate, the length of time taken for the litter to disappear from the floor and to estimate the quantity of carbon in the litter produced by the selected species. The results could help in understanding the carbon storage capacities of the species in the study area and form the basis for their use in carbon credit trading.

Materials and Methods

Study area

The research was carried out in Makurdi, Benue State. The area falls within the Southern Guinea Savanna agro ecological zone of Nigeria and lies within latitudes 70 38' and 70 50' North of the Equator and longitude 80 24' and 80 38' East of the Greenwich Meridian. The region is a tropical area with alternating wet and dry seasons, annual average precipitation of 1240 mm to 1440 mm and generally high temperature between 37°C and 16°C [16,17]. The vegetation of the area consists of tall grasses with trees representing a mixture of natural and human managed mosaics of different shape, size and structure [18,19].

Species assessment

A two hundred square meter (200 m^2) area was mapped out along a three hundred (300 m^2) line transect at the Agan open forest in Makurdi, Benue State. Five replicates of each of the four species within the plot were selected for study. Litter was collected monthly, using litter traps (1 m^2). Each litter trap consisted of four-sided wooden frames staked on four wooden stands (1 m each) with 1 mm nylon mesh [20]. The nylon mesh was fitted into the frame and allowed to sag downwards forming a receptacle that prevented other vegetative structures from bouncing off. A total of 20 litter traps were used (one trap per plant).

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Seasonal rates of litterfall for all species were investigated for a period of 12 months (covering dry and wet seasons; from November 2015 to October 2016). The trap contents were harvested at monthly intervals, to minimize leaching or decomposition of leaves within the traps. Litter collected were emptied into clean, labelled polyethylene bags, taken to the laboratory and sorted into 3 categories (leaf, wood and miscellaneous-flowers, fruits). The leaves were dried to constant weight at 80°C for 12 hours in a Gallenkamp (England) drying oven to the nearest 0.1 g.

Litter biomass (standing crop) for each of the species was measured by placing a 1 m^2 quadrat on the floor of each species. The litter collected within the quadrat were harvested monthly and processed as described above for litterfall.

Data Analyses

Litterfall and litter biomass

Two-way multivariate analysis of variance (MANOVA) was used to evaluate total litterfall and litter biomass and composition in all the species, with species and months as the main factors. The rates of litterfall and litter biomass were computed for all species and presented as graphs with litterfall (g m^{-2}) plotted against time (months). The Tukey honest significant difference (HSD) was used to test the level of significant differences between the means (means that were not statistically different were ranked with similar letters).

Relationships between plant parameters (plant height, diameter at breast height and crown diameter), litterfall and litter biomass were evaluated using correlation and regression analyses.

Sequestered carbon in plant litter was determined as 50% of total litterfall and litter biomass (dry weight), based on the general assumption that carbon content in plants is 50% of dry plant material [21,22]. Sequestered carbon dioxide equivalent (SCO_2E) was determined by multiplying carbon in plant biomass by a carbon correction factor of 3.67, which is the ratio of molecular weight of carbon dioxide to carbon [23]. The effects of species and time (months) on total sequestered carbon in total litterfall and total litter biomass were evaluated using a two-way MANOVA, with species and months as the main factors.

Litter turnover rate based on relative measures of litterfall and litter biomass in all the species were evaluated using Equation by Nye PH [24].

$K_t = L/X$

Where L = Litterfall

X = Steady state of litter on the floor.

K_t = Litter turnover

The residence time of litter on the floor and time taken for half of the litter to disappear from the floor were evaluated as $1/K_t$ and $\ln(^2/K_t)$ respectfully.

Results

Litterfall

Mean total litterfall as well as litter composition (leaf, wood and miscellaneous) in all the species are presented in Figure 1. A two-way MANOVA revealed highly significant differences (P<0.01) in rates of

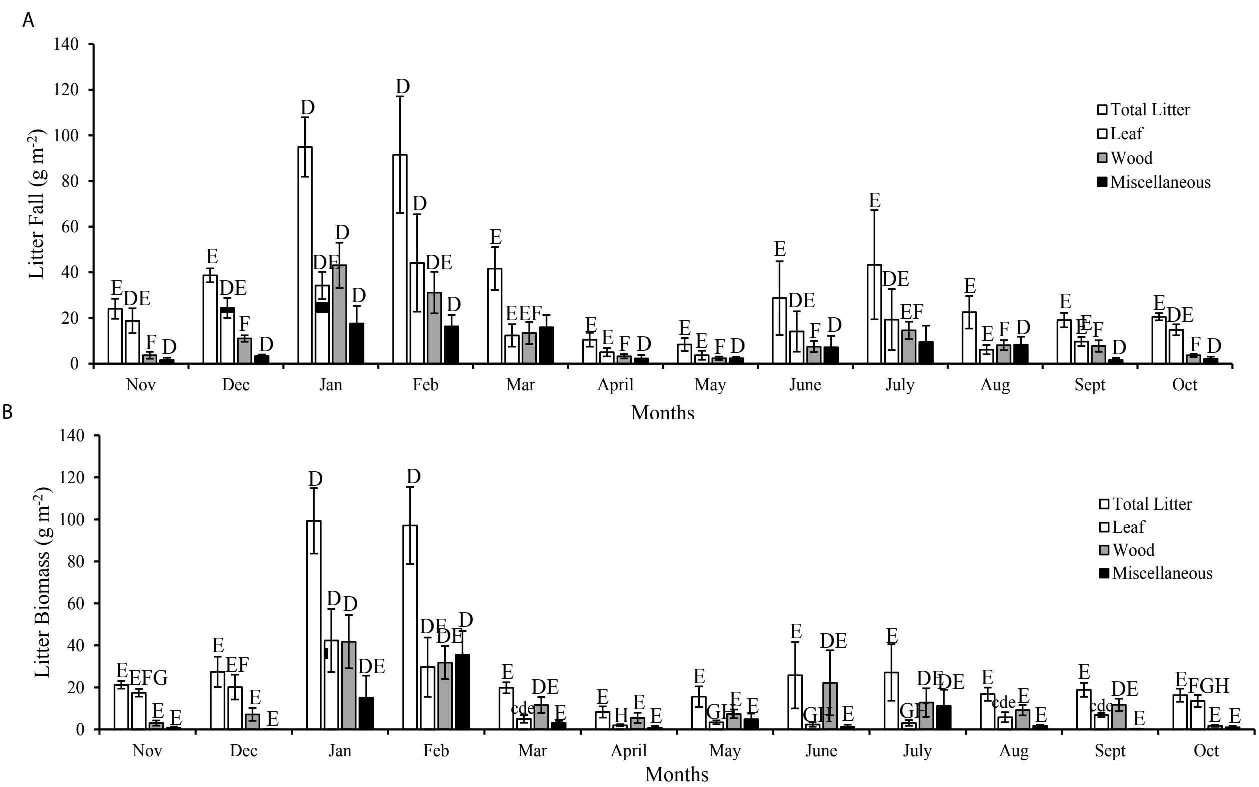

Figure 1: Mean monthly litter production across four species. (A) Litter fall (B) Litter biomass. Vertical bars represent means. Means with the same alphabet are not statistically different from each other P>0.05. Dry season (November to March), Wet season (April to October).

litterfall and composition across months and species. Litterfall generally exhibits seasonality, with greater fall rate in the dry season than the wet season (Figure 1). The average total litterfall for the period was 36.98 g m^{-2} with leaf litter accounting for 46.51% (17.20 g m^{-2}), wood litter 33.64% (12.44 g m^{-2}) and miscellaneous litter 19.82 % (7.33 g m^{-2}). Mean monthly total litterfall varied between January (94.89 ± 13.01) and May (8.38 ± 2.81); while species total litterfall varied between *M. lucida* (57.16 ± 11.95) and *P. africana* (18.81 ± 5.2).

Litter biomass

Mean total litter biomass on the floor within the study period was 32.80 g m^{-2}, with leaf litter contributing 12.64(38.54%), wood litter 13.82(42.13%) and miscellaneous litter 6.35 (19.36%) respectively (Figure 2). MANOVA revealed significant differences ($p<0.01$) in litter composition and quantity of biomass, between species and months. There was also seasonality in mean monthly total litter biomass with January (99.31 ± 13.57) and April (8.29 ± 2.66) having the highest and lowest quantities of litter biomass respectively.

There were moderate negative relationships between plant height and litterfall, between crown diameter and litterfall and weak negative relationships between plant height and litter biomass, crown diameter and litter biomass (Table 1). Litter fall correlates negatively ($p< 0.001$) with height and crown diameter.

Litter turnover rate

Species mean litter turnover rate (g d^{-1}) ranged between 2.01 (*P. biglobosa*) and 1.05 (*P. africana*), 2.71 (*M. lucida*) and 0.94 (*P. africana*) in dry and wet seasons respectively. The residence time of litter on the floor however was generally less than a day in both seasons except, *P. africana* in the wet season.

Carbon loss in plant litter

The sequestered carbon in plant litter (tones/ $m^{-2}y^{-1}$) significantly varied ($p<0.01$) with species litterfall and litter biomass. *M. lucida* had the highest sequestered carbon in litterfall and litter biomass (0.607; 1.107 tones m^{-2} y^{-1}), while *P. africana* had the lowest (0.113; 0.116 tones m^{-2} y^{-1}, Figures 3 and 4), implying that carbon accumulation in litter is species specific. *M. lucida* lost more carbon while *P. africana* retains more of its carbon than every other species studied.

Discussion

Litter production

Litterfall composition within the study period with leaves accounting for 46.51%, wood (33.64%) and miscellaneous litter (19.82%) of the total litterfall is comparable to litter composition in other tropical systems as reported by other researchers [11,25] Odiwe and Muoghalu and suggests that leaf litter is the major constituent of litter production in the species studied. Litterfall exhibited seasonality with the dry season peak in January (94.89 ± 13.0 g m^{-2}) and the wet season peak in July (43.28 ± 23.92 g m^{-2}). This seasonality is the general pattern of litterfall in the tropics [11,26,27] and may be attributable to influences of environmental variables (rainfall, temperature and wind speed) in the study site. The area is located in a humid Savanna ecosystem with two marked seasons; a windy, hot and dry season and the humid wet season.

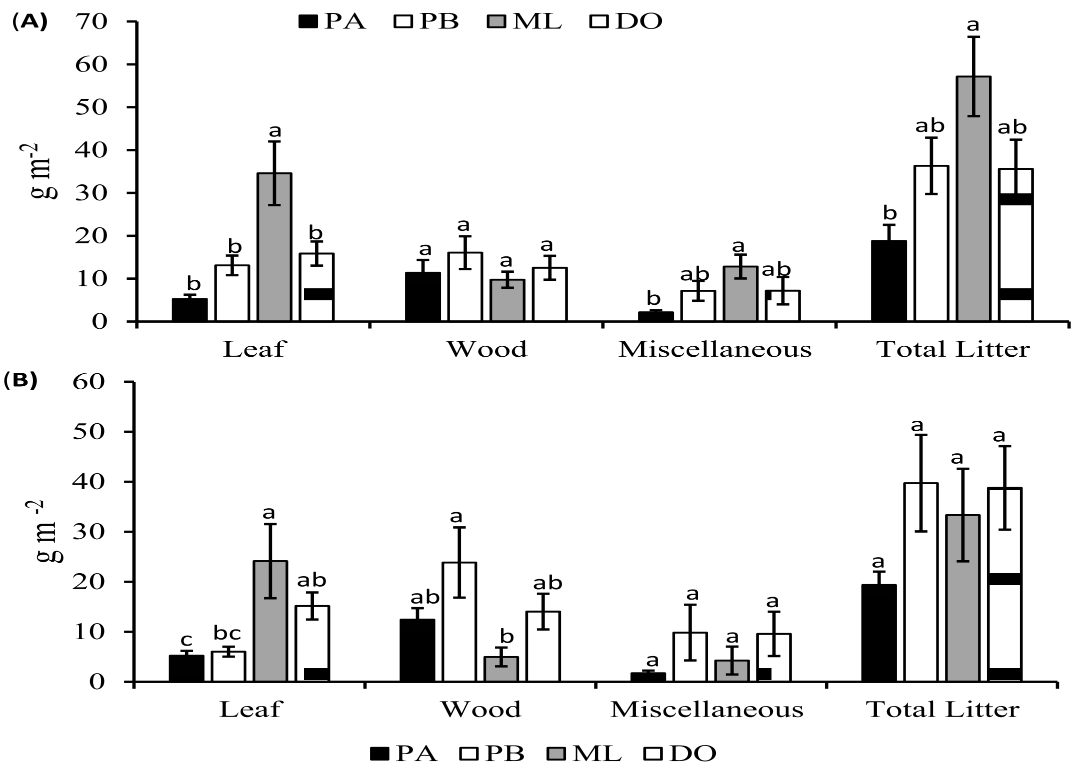

Figure 2: Litter composition in four woody species in Makurdi, Benue State, Nigeria. (A) Litterfall (B) Litter biomass. PA: *Prosopis africana,* PB: *Parkia biglobosa*, ML: *Morinda lucida*, DO: *Daniella oliveri*. Vertical bars represent means. Means with the same alphabets are not statistically different from each other P>0.05.

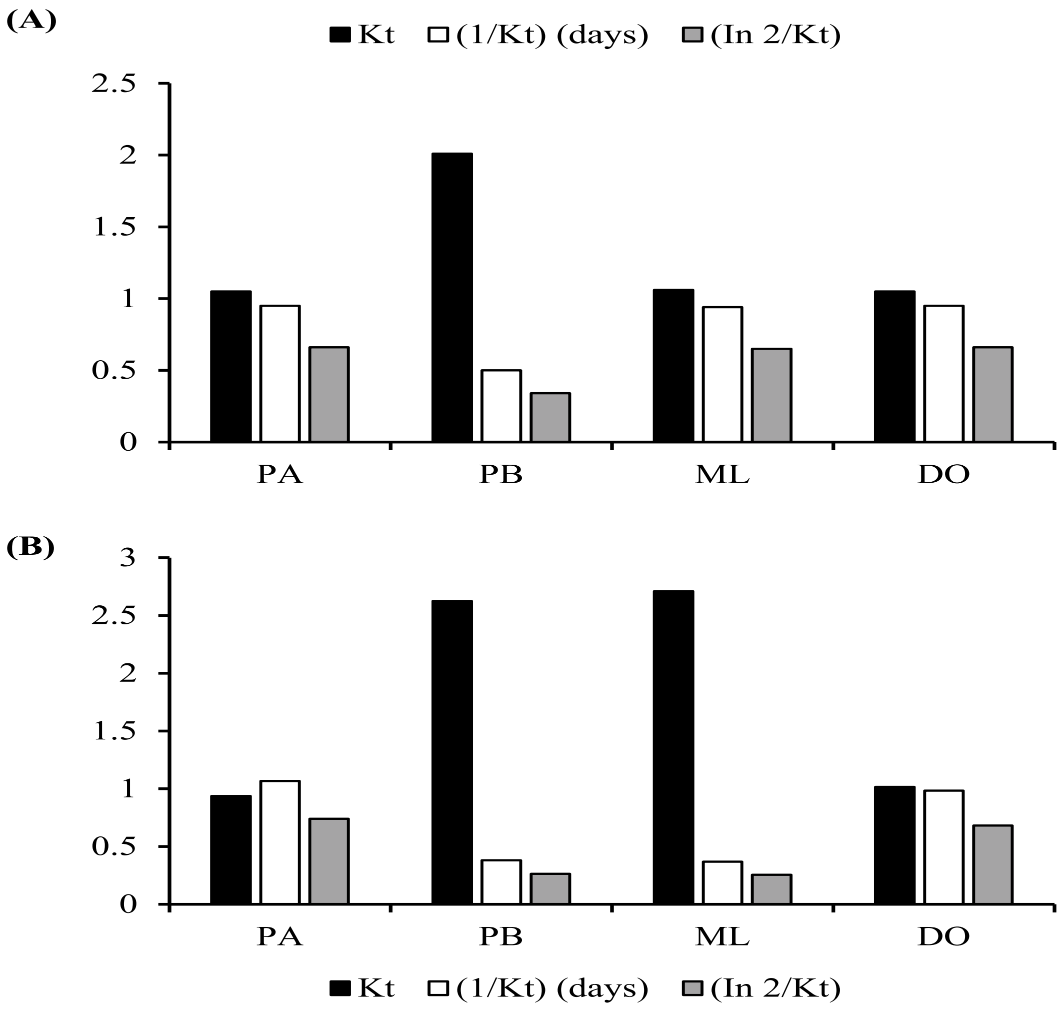

Figure 3: Litter turnover rate and residence time of litter on the floor (A) dry season (B) wet season. PA: *Prosopis africana*, PB: *Parkia biglobosa*, ML: *Morinda lucida*, DO: *Daniella oliveri*.

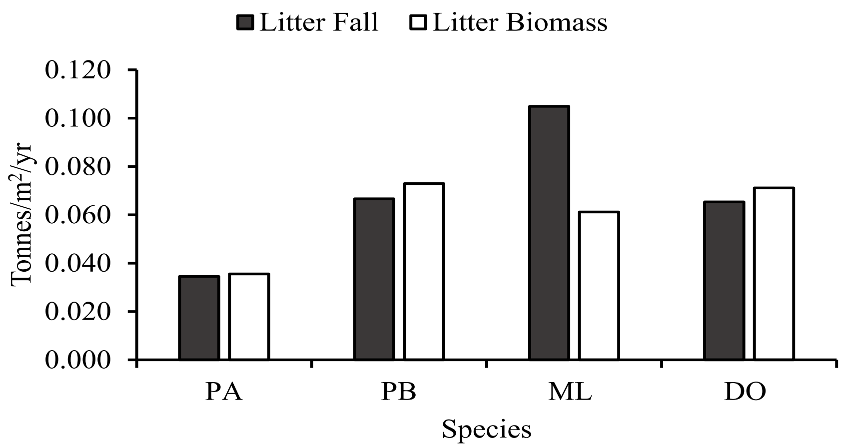

Figure 4: SCO2E in plant litter (Litter fall and litter biomass) in the four species. PA: *Prosopis africana*, PB: *Parkia biglobosa*, ML: *Morinda lucida*, DO: *Daniella oliveri*.

Comparison	Pearson Correlation r	R^2	Strength of Correlation	p-value	Equation
Height vs. Litter Fall	-0.699	0.489	Moderate negative	0.001**	y = 20.13+-0.2 × x
Height vs. Litter Biomass	-0.243	0.059	Weak negative	0.303	y = 15.3+-0.07 × x
Crown Diameter vs. Litter Fall	-0.611	0.373	Moderate negative	0.004**	y = 15.24+-0.12 × x
Crown Diameter vs. Litter Biomass	-0.063	0.004	Weak negative	0.791	y = 11.19+-0.01 × x
**P<0.001					

Table 1: Correlation and regression coefficients and equations showing relationship between litter production and plant parameters.

Average monthly rate of litterfall of 36.98 g m^{-2} (≈1.23 g m^{-2} d^{-1}) for the study period was comparable to other litterfall studies in the tropics. Variation in species mean monthly rates of litterfall with highest rate in *M. lucida* (57.16 g m^{-2}) and lowest rate in *P. africana* (18.81 g m^{-2}) suggests that litterfall was influenced by plant size, species leaf architecture and ornamentation as well as chemical composition (lignin content).

Liu et al., and Cattanio et al. [1,2] suggested that leaf fall is a phenological behaviour in woody species especially in the dry season in response to environmental stress (drought) and physiological senescence. Isaac and Nair [27] further explained that high evapotranspiration in the dry season exceeds rainfall leading to water stress or reduced moisture, excessive dryness and salt stress. Dawoe et al. [28] further explained that reduced humidity and lower night temperatures in the dry season may stimulate production of abscisic acid in the plant leaves which stimulated leaf fall. Röderstein et al. [29] also stated that senescence due to photo-inhibition and stomata closure contributes to leaf shedding in the dry season. De Weirdt et al. [30] stated that leaf fall is an adaptive mechanism by trees to utilize their photosynthetic capacity which enhances their competitive ability in a crowded forest. The plants therefore attempt to reduce the cost of maintaining less productive (photosynthetic) aged leaves through senescence, hence the high litterfall peak in the period. The wet season peaks in litterfall recorded in this study (Figure 1) is probably due to the absorption of water by dead plant parts on the trees during the rainy season which increased their weight and their subsequent abscission or removal from trees and the force of the strong winds which accompany rains during the rainy season [28,31]. Another explanation to wet season litterfall according to De Weirdt et al. [30] is that, when a new leaf is produced, less efficient leaf will shed to enhance canopy photosynthesis.

Average monthly litter biomass of 32.80 g m^{-2} (Figure 2) on the floor was less than the mean monthly litterfall of 36.98 g m^{-2} suggesting less litter retention on the floor. A falling litter is likely influenced by gravity, wind speed and direction as well as density of shrubs such that, not every litter produced was captured by the litter trap hence, the variation between litterfall and litter biomass. Accordingly, annual litter estimates based on litter trap and litter biomass on the floor varies with species canopy cover and the litter amount collected at a specific site on the floor of a plant may not be representative of the whole plant litter biomass. The seasonality exhibited in the average rate of litter biomass accumulation on the floor (111.28 g m^{-2} in January) and (129.68 g m^{-2} in July) indicates higher litterfall in the rainy season than in the wet season and the absence of other mechanisms of litter export (surface run-off, macro and micro consumers) from the floor during the period. The highest monthly total litter biomass for the study period recorded in July (129.68 g m^{-2}) constituted mainly miscellaneous litter (flowers and fruits) produced from increased phenological activities such as flowering, fruiting and fruit fall triggered by rainfall and wind speed. Litter accumulation protects the soil from excessive heat during the dry season, maintains nutrient cycling and enhancing carbon sequestration [27]. The negative relationship (Table 1) between litter production, plant height and crown diameter in this study indicates that, litterfall reduces with increasing height and crown diameter. This means that plant height and crown diameter affect litter production and may be used to predict litterfall pattern especially on tree stand basis.

Litter turnover

The litter turnover rate recorded in this study (Figures 3 and 4) implies that litter is lost from the forest floor. This has implication for nutrient cycling and carbon sequestration, as less biomass accumulates on the floor for decomposition and release into the environment [32]. Differences among species turnover rate reflects differences in species litterfall and litter accumulation on the floor and attributable to ecological factors (surface run-off, macro and micro consumers) other than decomposition [33].

Sequestered carbon in plant litter

Carbon stock in litter represents the rate and pattern of annual carbon loss from the plant. The rate of loss gives an insight into the biogeochemical cycling and carbon sequestration as litter return to the soil is the available plant part for decomposition and nutrient release into the ecosystem. Hence the fate of sequestration depends on the relative rate of litter export (loss) from the soil surface. There was also more carbon accumulation in litterfall than in litter biomass, reflecting the variation in litter amounts between the two methods of litter collection and the existence of other ecological factors (macro-consumers, wind and surface run-off) which exports litter from the soil thus affecting carbon storage.

Conclusion

Litter production as revealed in this study provides a general knowledge on biomass (carbon) loss as the pathway of biogeochemical sequestration and indicates the carbon storage capacities of the species and the study area at large. It further suggests that leaf litter is the major constituent of litter production in the species studied. Litter turnover rate and residence time suggest that more litter is loss from the floor than is available for decomposition.

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