



LITTERFALL DYNAMICS, DECOMPOSITION AND NUTRIENT RELEASE PATTERNS IN *Gmelina arborea* ROXB. PLANTATIONS, SOUTHWESTERN, NIGERIA

*Olajire-Ajayi Bolanle Lisa and Ogundana Oluwasola Abiodun

Forestry and Environmental Technology Department. Federal College of Forestry, Ibadan, Oyo State, Nigeria.

*Corresponding authors' email: jiirebolanle@gmail.com

ABSTRACT

This study quantified litter-fall production, decomposition dynamics, and nutrient release patterns in an 11-year-old *Gmelina arborea* plantation in the Forestry Research Institute of Nigeria, Southwestern Nigeria. Monthly litterfall was collected over six months using litter traps, while decomposition was assessed using a litterbag experiment over 180 days. Organic carbon (OC), nitrogen (N), phosphorus (P), and potassium (K) dynamics were analyzed. Litter-fall exhibited seasonal variation, peaking toward the late dry season. Decomposition followed a negative exponential model with a high decay constant ($k = 2.946 \text{ yr}^{-1}$; $R^2 = 0.976$), resulting in 76.66% mass loss within 180 days. Nutrient release was element-specific, with rapid depletion of K and P, declining to 0.01% and 0.88%, respectively, while N and OC decreased more gradually, with evidence of temporary nitrogen immobilization. The sequence of nutrient loss ($K > P > N > OC$) highlights the dual role of litter as a rapid source of mobile nutrients and a slower contributor to soil carbon and nitrogen pools. The rapid decomposition rate suggests efficient nutrient cycling but limited long-term carbon stabilization. These findings indicate that while *Gmelina arborea* supports short-term soil fertility, its contribution to stable soil carbon pools is constrained. Integrating slower-decomposing species is recommended to enhance carbon sequestration and ecosystem sustainability in plantation systems.

Keywords: *Gmelina arborea*, Litterfall dynamics, Decomposition, Nutrient release, Southwestern

INTRODUCTION

The expansion of monoculture tree plantations is a global response to the increasing demand for wood products and ecosystem restoration (Paudel *et al.*, 2021). *Gmelina arborea* Roxb., commonly known as Gamhar or White Teak, is a prominent species in tropical silviculture due to its exceptionally fast growth rate and good wood properties (Onojah *et al.*, 2022). While its above-ground productivity is well-documented, the below-ground ecological processes, particularly litter dynamics, are less understood but are fundamental to the long-term sustainability of these plantations.

Litterfall represents the primary pathway for the return of organic matter and nutrients to the forest floor, forming the foundation of nutrient cycling (Sena *et al.*, 2022; Dachung *et al.*, 2023). The decomposition of this litter, a process mediated by soil fauna and microbes, regulates the release of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K) back into the soil, thereby influencing soil fertility and subsequent plant growth (Pasha *et al.*, 2020). In monoculture systems, the quality and quantity of litter can significantly alter soil biogeochemical cycles, potentially leading to nutrient depletion or sequestration over time (Rahman and Kabir, 2021).

Recent research has emphasized the role of litter quality (C:N ratio, lignin content) as a critical controller of decomposition rates (Pasha *et al.*, 2020; Sena *et al.*, 2022). Fast-growing species like *Gmelina arborea* often produce litter with lower C:N ratios, which typically decomposes faster than litter from native, slow-growing species (Onojah *et al.*, 2022). However, the specific patterns of nutrient release; mineralization versus immobilization during decomposition are crucial for determining the nutrient supply capacity of the system.

Although *Gmelina arborea* is widely recognized for its commercial value, the interconnected processes of litterfall production, decomposition, and nutrient release in mature plantations remain poorly understood. Consequently, the study quantifies litterfall production, determine leaf litter

decomposition rate constant (k), and examine the dynamic patterns of organic carbon (OC), nitrogen (N), phosphorus (P), and potassium (K) release during decomposition. Understanding these processes is essential for promoting sustainable environmental management in *G. arborea* plantations. Thus, the findings from the study will contribute to strategies that conserve soil nutrients and sustain long-term plantation productivity while safeguarding ecosystem health.

MATERIALS AND METHODS

Study Area

The study was conducted in an 11-year-old even-aged *Gmelina arborea* plantation located in the Forestry Research Institute of Nigeria, Southwestern Nigeria. The area is situated between Longitude $3^{\circ}51'20''$ and $3^{\circ}51'45''$ E, and latitudes $7^{\circ}23'18''$ and $7^{\circ}55'43''$ N (Nurudeen *et al.*, 2014). This region experiences a bimodal rainfall pattern, with peaks in June and July, September and October, averaging approximately 1548.20mm annually (Salami *et al.*, 2020). Located within Nigeria's tropical rainforest zone, the area features mean maximum and minimum temperatures ranging from 39°C to 24.9°C . Relative humidity averages around 82% from June to September and about 60% from December to February (Ugwu and Ojo, 2015). The topography is undulating, underlain by ferruginous sandy loamy soil on the crystalline rock of undifferentiated Pre-Cambrian basement complex (Salami *et al.*, 2020).

Litterfall Collection and Measurement

Eighteen litter traps with area of 1 m^2 and a 1 mm nylon mesh netting were randomly placed within the plantation in accordance with Chapman (1976) and as adopted by Kumar *et al.*, (2022). Litter was collected from three litter traps monthly for six consecutive months (November, 2024 – May, 2025). The collected litter was oven-dried at 65°C to constant weight and weighed. The monthly litterfall production per hectare was estimated using:

$$\text{Litter input (kg ha}^{-1} \text{ month}^{-1}) = \frac{\text{Mean litter fall weight}}{\text{Area of litter trap (m}^2)} \times 10000 \quad (1)$$

Litter Decomposition

The litter bag technique was used to study rate of leaf litter decomposition as used by Wang *et al* (2008) and adopted by Olajuyigbe and Adebo (2022). Fresh leaf litter was collected from the lower branches of the standing trees in the *Gmelina arborea* plantation. 50 g of the freshly collected leaves were placed in a litter bags of 1 mm mesh size of 20 cm by 20 cm and scattered on the soil in the plantation. In total, 25 litter bags were pinned down with pegs to prevent displacement and ensure contact with soil. Five litter bags were randomly retrieved from the plantation at monthly intervals.

The bags were carefully cleaned to remove debris such as soil particles and fine roots. The content was then oven dried at 60 °C and weighed to determine the remaining mass. The initial weight remaining (WR) for leaf litter at each retrieval point was determined using;

$$WR (\%) = \frac{X_1}{X_0} \times 100 \quad (2)$$

Where:

WR (%) = % of leaf litter weight remaining;

X_1 = Weight of leaf litter (g) at time retrieval (0,30,60,90,120,150 days);

X_0 =Initial weight (weight of leaf litter the experiment started with) of leaf litter (g)

Nutrient Analysis

The dried litter from each retrieval period was ground using a laboratory mill and passed through sieved a 0.5 mm mesh. The chemical composition of the leaf litter samples before and after retrieval were analyzed for organic carbon (OC) content of the leaf litter using Walkley Black Wet Oxidation Method. 0.1 g of milled leaf litter will be digested in 10 ml $K_2Cr_2O_7$ solution, before 20 ml of concentrated H_2SO_4 was added, rapidly. The solution was allowed to stay for 10 minutes after which 100 ml of distilled water was added and allowed to cool. The cooled solution was titrated with 0.5 N Ferrous Ammonium Sulphate solution. Percentage organic carbon was then calculated using titre value (TV) as given;

$$\% \text{ Organic Carbon} = \frac{TV \times 0.5 \times 0.003 \times 1.33}{0.1g} \times 100 \quad (3)$$

The total nitrogen (N) content in leaf litter was analyzed using the Kjeldahl digestion method. Approximately 0.5 g of finely ground sample was digested with concentrated sulfuric acid (H_2SO_4) in the presence of a catalyst mixture, typically containing selenium or copper sulfate combined with potassium sulfate. After digestion, the sample was distilled with sodium hydroxide (NaOH), and the resulting ammonia was collected in a boric acid solution. The trapped ammonia was then quantified by titration using standardized hydrochloric acid (HCl), following the procedure outlined by Bremner (1965).

To extract total phosphorus (P), and potassium (K), a wet acid digestion technique was employed. A 0.5 g portion of the ground sample was weighed into a digestion tube and treated with 10 mL of a nitric-perchloric acid mixture in a 2:1 ratio (HNO_3 : $HClO_4$). The mixture was allowed to stand for 30 to 60 minutes to pre-digest, after which it was gently heated on a digestion block at 150–200 °C until a clear solution was obtained. Once cooled, the digest was filtered and diluted to a known volume using deionized water. Phosphorus was

measured using the molybdenum blue colorimetric method as described by Murphy and Riley (1962). Absorbance readings were taken at 880 nm using a UV visible spectrophotometer. Potassium was determined with a flame photometer. Potassium concentration was determined with a flame photometer.

Data Analysis

The exponential decay model of Olson (1963) was used to calculate the decomposition rate constant:

$$\left(\frac{X_t}{X_0}\right) = e^{-kt} \dots \quad (4)$$

Where:

X_t = is the mass remaining at time t (0,30, 60,90, 120 150 days)

X_0 = is the initial mass that the experiment started with

k = is the decomposition constant (yr^{-1})

t = is time in years.

The time for 50% decomposition (t_{50}), also known as the half-life, represents the time required for 50% of the original leaf litter mass to decompose. It is an important indicator of decomposition rate and nutrient cycling efficiency within an ecosystem. A lower (t_{50}) value indicates faster decomposition and nutrient release, whereas a higher (t_{50}) value suggests slower litter breakdown. It was calculated using;

$$t_{50} = \frac{0.693}{k} \quad (5)$$

The nutrient release was calculated using the formula:

$$\text{Nutrient remaining (\%)} = \frac{N_t}{N_0} \times 100$$

Where:

N_t = amount (or concentration) of the same nutrient remaining at time (t)

N_0 = initial amount (or concentration) of the nutrient in the fresh leaf litter

Differences in litterfall across months and nutrient remaining across time were analyzed using analysis of variance (ANOVA) followed by Tukey's HSD test ($p < 0.05$).

RESULTS AND DISCUSSION

Monthly Litter-fall from *G. arborea* Plantation (kg/ha)

Figure 1 shows monthly leaf litterfall collected from litter trap (Nov–May). Litterfall gradually increases from December to May, reaching its peak at 24.5 kg/ha. This pattern reflects the natural cycle of leaf shedding influenced by seasonal changes in climate.

The pattern of leaf litterfall observed in this study (Figure 1) aligns with trends commonly reported across tropical forest ecosystems. Litter production was not constant but strongly influenced by seasonal climatic shifts. Tonin *et al.* (2021) found that leaf shedding peaks during transitional periods between wet and dry seasons as trees prepare for new growth. This is supported by Asigbaase *et al.* (2021), who demonstrated that litterfall is predominantly governed with rainfall, with the largest inputs often occurring at the beginning of the rainy season. These findings suggest that the accumulation is a characteristic feature of tropical systems, shaped by climatic patterns that regulate nutrient cycling and carbon fluxes.

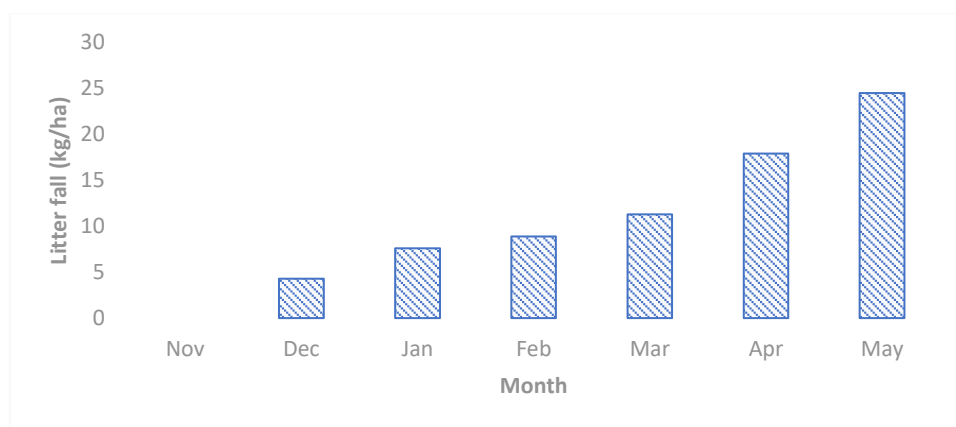


Figure 1: Dynamic of Leaf litter-fall (kg/ha)

Litter Mass Dynamics and Remaining Mass of Litter Over Time

Table 1 shows litter breakdown over 180 days, including how much mass was lost (in grams), how much was left at each stage, and the percentage of the original litter that had decomposed.

Litter decomposition followed rapid exponential decay, >75% mass lost in six months, typical of warm/moist tropics favoring microbes (Seibold *et al.*, 2021; Akinsola *et al.*, 2024). *Gmelina arborea* mass declined to 23.34% over 180

days, indicating a cumulative mass loss of 76.66% (Table 1), reflecting negative exponential patterns (Giweta, 2020; Zhang *et al.*, 2008). Rapid 31.46% loss by 60 days indicates leaching/microbial breakdown of labiles, slowing post-120 days due to lignin (Prescott, 2019; Berg and McLaugherty, 2020). This pattern confirms that *Gmelina arborea* litter undergoes rapid initial decomposition followed by a gradual decline, supporting efficient nutrient cycling under tropical conditions (Giweta, 2020).

Table 1: Litter Mass Dynamics Over Time in the *Gmelina arborea* Plantation

Decomposition time	Initial Weight (g)	Mean Weight (g)	Weight Mass Loss (g)	Mass (%)	Remaining Mass (%)	Loss
0 day	50	50	100	100	0.00	
30 days	50	42.94	7.06	85.88	14.12	
60 days	50	34.27	15.73	68.54	31.46	
90 days	50	29.84	20.16	59.68	40.32	
120 days	50	21.49	28.51	42.98	57.02	
150 days	50	19.89	30.11	39.78	60.22	
180 days	50	11.67	38.33	23.34	76.66	

Litter Mass Loss and Decomposition Dynamics

Table 2 shows the progressive mass loss and decomposition pattern of litter in the *Gmelina arborea* plantation over 180 days. The mass remaining fraction ($\frac{X_t}{X_0}$) steadily decreased from 0.8588 at 30 days to 0.2334 at 180 days, indicating continuous decomposition of the litter material over time.

Similarly, the natural logarithm values $\ln(\frac{X_t}{X_0})$ became increasingly negative, reflecting an increasing rate of litter breakdown as decomposition processes (Giweta, 2020; Sharga *et al.*, 2020). This confirms efficient nutrient cycling and rapid litter breakdown under favorable tropical climatic conditions supported by active microbial communities.

Table 2: Mass Loss and Decomposition Rate *Gmelina arborea* Plantation

Decomposition Time (days)	Time (t) in Years	Mass Remaining Fraction ($\frac{X_t}{X_0}$)	$\ln[(\frac{X_t}{X_0})]$
30	0.0821	0.8588	-0.1522
60	0.1643	0.6854	-0.378
90	0.2464	0.5968	-0.5162
120	0.3285	0.4298	-0.8466
150	0.4107	0.3978	-0.9218
180	0.4928	0.2334	-1.4551

Table 3 presents the linear regression analysis used to estimate the litter decomposition rate constant. The negative slope value (-2.946) indicates a continuous reduction in litter mass with time, while the decomposition constant ($k = 2.946$) suggests a relatively rapid decomposition process consistent with tropical litter systems (Okoh *et al.*, 2019; Akinsola *et al.*, 2024). The y-intercept (-0.016), being close to zero, indicates minimal initial deviation in the model. The high coefficient of

determination ($R^2 = 0.9763$) demonstrates that 97.63% of the variation in litter decomposition was explained by the regression model, showing a very strong fit between time and mass loss. Furthermore, the low standard error of estimate (0.1862) indicates high predictive accuracy of the model, while the highly significant p-value ($p < 0.001$) confirms that the observed decomposition pattern was statistically significant.

Table 3: Linear Regression Analysis for the Decomposition Rate Constant

Statistics/ Parameter	Value
Slope (m = -k)	-2.946
Decomposition constant (k)	2.946
Y – intercept	-0.016
Coefficient of determination (R ²)	0.9763
Standard Error of Estimate	0.1862
P value	< 0.001

The linear regression analysis showed that litter decomposition occurred at a constant rate ($k = 2.946$). The model fit the data very well ($R^2 = 0.9763$), with only a small margin of error ($SE = 0.1862$) and strong statistical significance ($p < 0.001$).

Dynamic of Mass and Nutrient Loss

Table 4 shows the percentage of mass and nutrient content remaining over a 180-day decomposition period. This shows a rapid decline of essential nutrients, particularly P and K,

which exhibit near-complete depletion by day 180. The statistically significant p-values (< 0.001) across all variables demonstrate clear and consistent patterns of decomposition and nutrient release over time.

Table 4: Dynamics of Mass and Nutrient Loss during Leaf Litter Decomposition

Decomposition Time	Mass Remaining (%)	OC Remaining (%)	N Remaining (%)	P Remaining (%)	K Remaining (%)
0	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
30	85.88 ± 0.22	47.06 ± 0.32	36.48 ± 0.51	3.61 ± 0.11	0.93 ± 0.04
60	68.54 ± 0.12	48.91 ± 0.23	30.33 ± 0.33	3.00 ± 0.25	0.79 ± 0.21
90	59.68 ± 0.01	44.62 ± 0.54	27.98 ± 0.15	1.68 ± 0.34	0.75 ± 0.08
120	42.98 ± 0.04	30.67 ± 0.31	21.68 ± 0.67	1.51 ± 0.01	0.43 ± 0.10
150	39.78 ± 0.03	29.53 ± 0.06	22.88 ± 0.45	1.86 ± 0.03	0.26 ± 0.02
180	23.34 ± 0.01	20.87 ± 0.13	8.88 ± 0.04	0.88 ± 0.05	0.01 ± 0.19
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Nutrient dynamics revealed distinct temporal variations (Table 4). Potassium and phosphorus declined rapidly, reflecting their solubility and high susceptibility to leaching, whereas nitrogen and carbon exhibited slower turnover rates. A temporary stabilization of nitrogen between 90–150 days suggests microbial immobilization, a mechanism whereby decomposers retain nutrients to meet metabolic needs before subsequent mineralization (Manzoni *et al.*, 2021). In contrast, carbon was continuously lost throughout decomposition, largely through microbial respiration. These findings show how litter provides both short-term nutrient inputs through rapid leaching of mobile elements and longer-term soil fertility regulation through gradual carbon and nitrogen release.

The sequential nutrient loss ($K > P > N > OC$) demonstrate the importance of litter decomposition in sustaining nutrient availability. The immediate release of base cations such as K can enhance plant growth, while the delayed mineralization of nitrogen provides a sustained nutrient supply (Cotrufo *et al.*, 2023). From a management perspective, these patterns suggest that aligning litterfall dynamics with crop nutrient demand in agroecosystems could enhance natural fertilization and reduce reliance on external inputs. Nevertheless, the rapid decomposition rate also indicates a relatively short carbon residence time, which may limit the potential of such systems for long-term soil organic carbon sequestration (Lehmann and Kleber, 2015).

CONCLUSION

The study concludes that *Gmelina arborea* litter decomposes rapidly, with more than three-quarters of the mass lost within six months. The high decomposition rate ($k = 2.946 \text{ yr}^{-1}$) confirms the easily degradable nature of the litter, which enhances short-term soil fertility through quick release of K and P, while N mineralization occurs more slowly which supports productivity and makes *Gmelina arborea* suitable for short-rotation forestry and agroforestry, the fast turnover

however may limit long-term carbon stabilization and reduces its climate mitigation potential. For greater climate benefits, the study recommends complementing with slower-decomposing or native species that enhance stable carbon pools.

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