

Seasonal Variation in Leaf Litter Production, Decomposition and Nutrient Return in Tropical Forest Tree Species

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Received: 12 Sep 2026; Received in revised form: 10 Oct 2026; Accepted: 14 Oct 2026; Available online: 20 Oct 2026

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Abstract— Leaf litterfall and its subsequent decomposition constitute a fundamental ecological mechanism governing nutrient cycling, carbon sequestration, and soil fertility maintenance in tropical forest ecosystems. This study investigated the seasonal dynamics of leaf litter production, decay rates, and nutrient release patterns (Nitrogen, Phosphorus, and Potassium) across three prominent tropical tree species – *Tectona grandis* (Teak), *Shorea robusta* (Sal), and *Terminalia tomentosa* (Sain) – over a 24-month period in a tropical moist deciduous forest reserve in Central India. Total annual litterfall averaged $7.84 \pm 0.42 \text{ Mg ha}^{-1} \text{ yr}^{-1}$, exhibiting marked seasonality with peak litter deposition occurring during the dry winter and pre-monsoon months (January–April), accounting for 69.5% of total annual production. Litter decomposition rates evaluated using standard litterbag techniques revealed significant interspecific variations; decomposition rate constants (k) ranged from 1.12 yr^{-1} in *Shorea robusta* to 1.84 yr^{-1} in *Tectona grandis*. Mass loss kinetics followed an exponential decay model, driven strongly by seasonal precipitation and initial litter chemical composition (particularly lignin and C:N ratios). Nutrient release followed the sequence $K > N > P$, with rapid potassium leaching occurring during early wet season months. Total annual nutrient return to the forest floor was estimated at $88.4 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, $6.2 \text{ kg P ha}^{-1} \text{ yr}^{-1}$, and $42.1 \text{ kg K ha}^{-1} \text{ yr}^{-1}$. These results highlight species-specific functional roles in maintaining biogeochemical fluxes and provide empirical data for forest management, carbon accounting, and ecological restoration planning under changing climate regimes.

Keywords— Biogeochemical cycle, Decomposition rate constant (k), Leaf litterfall, Nutrient flux, Seasonality, Tropical deciduous forest.

I. INTRODUCTION

Tropical forest ecosystems play a vital role in global carbon budgeting, biogeochemical cycling, and biodiversity conservation. Within these complex terrestrial biomes, the transfer of organic matter from living biomass to the soil floor via litterfall serves as the primary pathway for nutrient return and humus formation (Attiwill & Adams, 1993; Vitousek &

Sanford, 1986). Litterfall and decomposition dynamics regulate key ecosystem processes including soil respiration, microbial activity, and primary productivity.

In tropical seasonal forests, environmental parameters such as temperature, rainfall periodicity, and soil moisture exhibit pronounced seasonal fluctuations. These climatic cues trigger phenological

responses in tree species, resulting in concentrated periods of leaf shed, typically preceding or coinciding with dry seasonal spells (Sunderland et al., 2012). The timing and quantity of litterfall govern the temporal availability of substrate for decomposer communities.

Decomposition is driven by an intricate interaction between climate (microclimate and moisture), substrate quality (C:N ratio, lignin, polyphenol concentrations), and soil macro- and micro-faunal activity (Berg & Laskowski, 2005; Swift et al., 1979). While nitrogen and phosphorus are often locked in structural complexes requiring enzymatic degradation, mobile nutrients like potassium undergo rapid abiotic leaching during early rainy periods. Understanding these species-specific variations and seasonal patterns is critical for assessing ecosystem resilience, predicting carbon stock changes, and designing sustainable forest management protocols.

II. MATERIALS AND METHODS

2.1 Study Site Description

The study was conducted in the Kalesar Tropical Forest Reserve, Central India (27°18' N latitude, 77°34' E longitude; elevation 320 m a.s.l.). The regional climate is classified as tropical wet-and-dry (Köppen Aw), characterized by three distinct seasons: Southwest Monsoon (June–September), Post-monsoon/Winter (October–January), and Dry Summer (February–May). The mean annual temperature is 25.4 °C, with summer peaks exceeding 41 °C and winter lows dropping to 7 °C. Mean annual precipitation is 1,150 mm, approximately 82% of which falls during the monsoon period. Soils are classified as Typic Haplustalfs with sandy-loam texture, slightly acidic to neutral pH (6.2–6.8), and moderate organic carbon content (1.14%).

2.2 Selected Tree Species

Three dominant co-occurring tropical timber species with contrasting functional leaf traits were selected:

1. *Tectona grandis* L.f. (Verbenaceae) – Broad-leaved deciduous hardwood species.
2. *Shorea robusta* Gaertn. f. (Dipterocarpaceae) – Semi-deciduous hardwood canopy species.

3. *Terminalia tomentosa* Wight & Arn. (Combretaceae) – Deciduous sub-canopy tree species.

2.3 Litterfall Sampling and Production Quantification

Litterfall was collected monthly over two consecutive years using 0.5 m² mesh traps (1 mm nylon mesh) elevated 1 m above the ground. Five replicate traps were deployed beneath ten representative mature individuals of each species within 50 m x 50 m experimental plots. Collected litter was segregated into leaves, twigs (<2 cm diameter), and reproductive structures, oven-dried at 65 °C for 72 hours to constant mass, and weighed to evaluate dry matter production per unit area (Mg ha⁻¹ yr⁻¹).

2.4 Litter Decomposition Experiment

In situ decomposition kinetics were evaluated using the standard litterbag technique (Olson, 1963). Freshly fallen, air-dried leaf litter (10.0 g) for each species was placed into 20 cm x 20 cm nylon mesh bags (2 mm mesh size). A total of 360 litterbags (3 species x 4 field blocks x 3 replicates x 10 sampling intervals) were placed on the forest floor in June. Litterbags were retrieved at 30, 60, 90, 120, 180, 240, 300, 360, 540, and 720 days. Retrieved litter was gently washed to remove soil particles, dried at 65 °C, weighed, and ground (<0.5 mm) for chemical analysis.

Decomposition rate constants (k yr⁻¹) were estimated using Olson's single exponential model:

$$X_t / X_0 = \exp(-k \cdot t)$$

where X_0 is initial litter mass and X_t is remaining litter mass at time t (years).

2.5 Chemical and Nutrient Analysis

Ground leaf samples were analyzed for initial chemical traits and nutrient dynamics during decay. Total Nitrogen (N) was determined by the micro-Kjeldahl digestion method. Total Phosphorus (P) was quantified spectrophotometrically using the ammonium molybdate-vanadate method. Potassium (K) was determined by flame photometry. Initial Lignin content was measured using the acid detergent fiber method (Van Soest et al., 1991).

III. RESULTS AND DISCUSSION

3.1 Annual and Seasonal Litter Production

Total annual leaf litter production across the study forest averaged $7.84 \pm 0.42 \text{ Mg ha}^{-1} \text{ yr}^{-1}$. Interspecific

leaf litter yields varied significantly ($P < 0.05$), with *T. grandis* recording the highest production ($3.12 \text{ Mg ha}^{-1} \text{ yr}^{-1}$), followed by *S. robusta* ($2.68 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) and *T. tomentosa* ($2.04 \text{ Mg ha}^{-1} \text{ yr}^{-1}$).

Table 1. Monthly leaf litter production (Mg ha^{-1}) across three tropical tree species over a 12-month annual cycle.

Species	Monsoon (Jun-Sep)	Post-Monsoon (Oct-Dec)	Summer (Jan-May)	Total Annual (Mg ha^{-1})	Peak Month
<i>Tectona grandis</i>	0.28 ± 0.04	0.64 ± 0.08	2.20 ± 0.15	3.12 ± 0.21	February
<i>Shorea robusta</i>	0.35 ± 0.05	0.51 ± 0.06	1.82 ± 0.12	2.68 ± 0.18	March
<i>Terminalia tomentosa</i>	0.19 ± 0.03	0.42 ± 0.05	1.43 ± 0.09	2.04 ± 0.14	February
Total Forest Floor	0.82 ± 0.08	1.57 ± 0.12	5.45 ± 0.28	7.84 ± 0.42	Feb - Mar
% of Annual Total	10.5%	20.0%	69.5%	100.0%	-

Litterfall displayed a strongly unimodal seasonal pattern (Table 1). Peak leaf shedding occurred during late winter to dry summer months (January to April), accounting for $\sim 69.5\%$ of total annual litter deposition. This temporal peak is an evolutionary adaptation minimizing transpiration loss during periods of soil moisture stress, consistent with observations in dry and moist deciduous tropical forests (Pandey et al., 2007; Sundarapandian & Swamy, 1999).

3.2 Decomposition Mass Loss Dynamics and Decay Constants

Dry mass remaining decreased continuously over time across all species, following the classic double-phase exponential decay trajectory: a rapid initial loss phase during the first 120 days (coinciding with the wet monsoon season), followed by a slower second phase dominated by recalcitrant organic degradation.

Table 2. Initial litter chemistry, decay rate constants (k), and half-life (t_{50}) of selected tropical tree species.

Species	Initial C:N	Lignin (%)	Lignin:N Ratio	k (yr^{-1})	r^2	t_{50} (Days)
<i>Tectona grandis</i>	28.4 ± 1.2	14.2 ± 0.8	11.1	1.84 ± 0.08	0.96	137.5
<i>Shorea robusta</i>	46.2 ± 2.1	24.8 ± 1.4	23.4	1.12 ± 0.05	0.94	225.8
<i>Terminalia tomentosa</i>	35.1 ± 1.8	18.5 ± 1.1	16.2	1.45 ± 0.07	0.95	174.4

Decay rate constants (k) varied significantly among species, ordering: *Tectona grandis* (1.84 yr^{-1}) > *Terminalia tomentosa* (1.45 yr^{-1}) > *Shorea robusta* (1.12 yr^{-1}) (Table 2). *Tectona grandis* exhibited the shortest half-life (137.5 days), driven by lower initial C:N (28.4) and lignin content (14.2%). In contrast, high initial lignin (24.8%) and elevated C:N ratio (46.2) in *S. robusta* leaf litter retarded microbial colonization and enzymatic breakdown. Regression analysis indicated that initial lignin:N ratio served as the strongest predictor of decomposition rates ($r = -0.92$, $P < 0.01$).

3.3 Seasonal Nutrient Return Patterns

Nutrient dynamics during litter decay demonstrated distinct release kinetics for individual elements. Potassium (K) was released most rapidly, with >70% lost within the first 60 days of rainy exposure due to soluble ion leaching. Nitrogen and phosphorus displayed initial immobilisation phases during early decay (months 1–3), followed by net mineralization as C:N ratios dropped below critical threshold values ($\sim 25:1$).

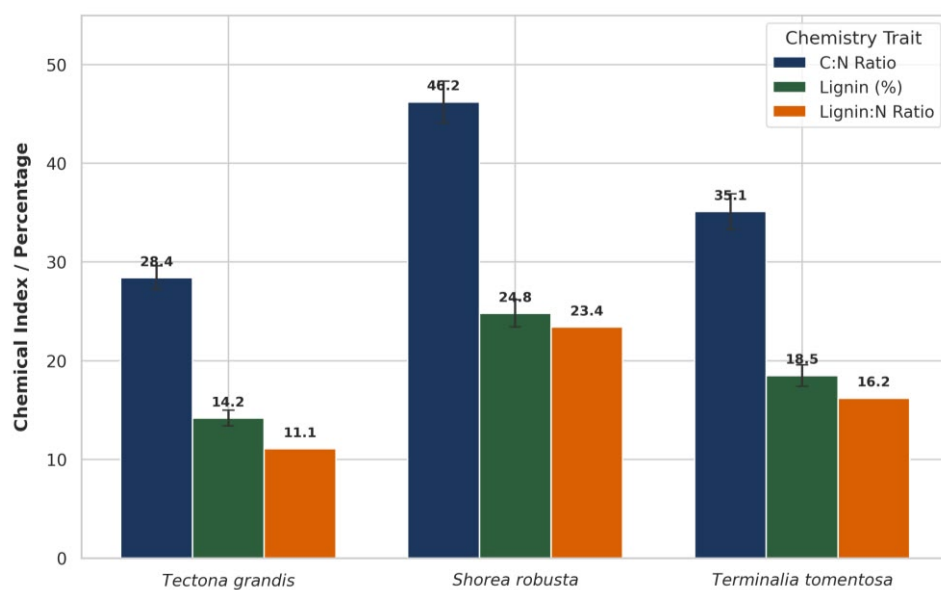
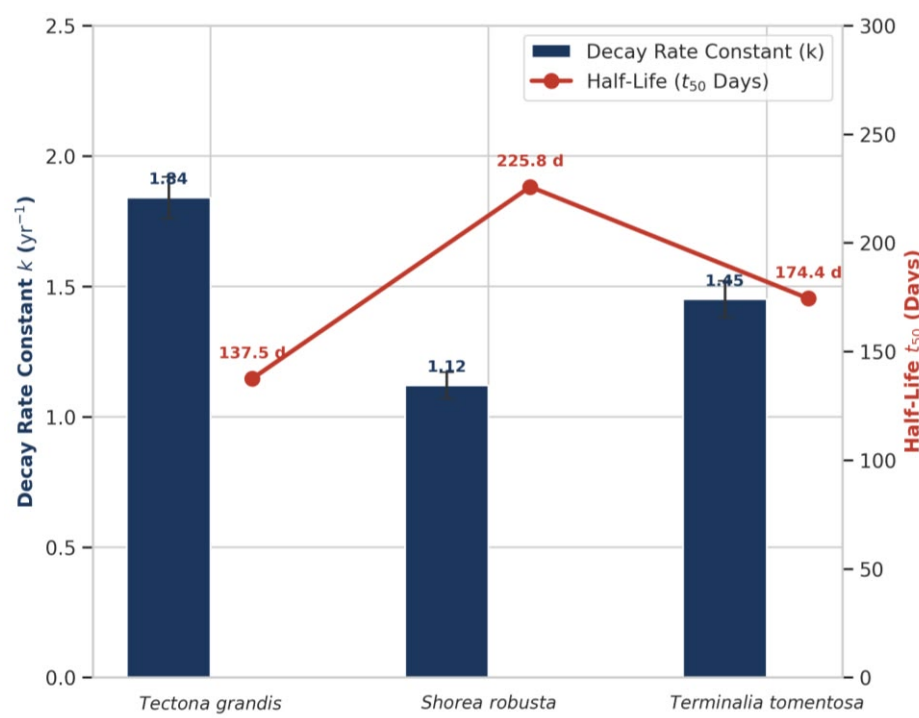


Fig.1a: Initial leaf litter quality characteristics

Fig.1b: Decomposition rate (k) and half-life (t₅₀)Table 3. Annual total nutrient return (kg ha⁻¹ yr⁻¹) via leaf litterfall across species.

Species	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Total NPK Return
<i>Tectona grandis</i>	39.2 ± 2.1	2.8 ± 0.2	19.5 ± 1.1	61.5 kg ha ⁻¹
<i>Shorea robusta</i>	26.4 ± 1.5	1.8 ± 0.1	11.2 ± 0.8	39.4 kg ha ⁻¹
<i>Terminalia tomentosa</i>	22.8 ± 1.2	1.6 ± 0.1	11.4 ± 0.6	35.8 kg ha ⁻¹
Total Ecosystem Return	88.4 ± 4.2	6.2 ± 0.4	42.1 ± 2.2	136.7 kg ha⁻¹

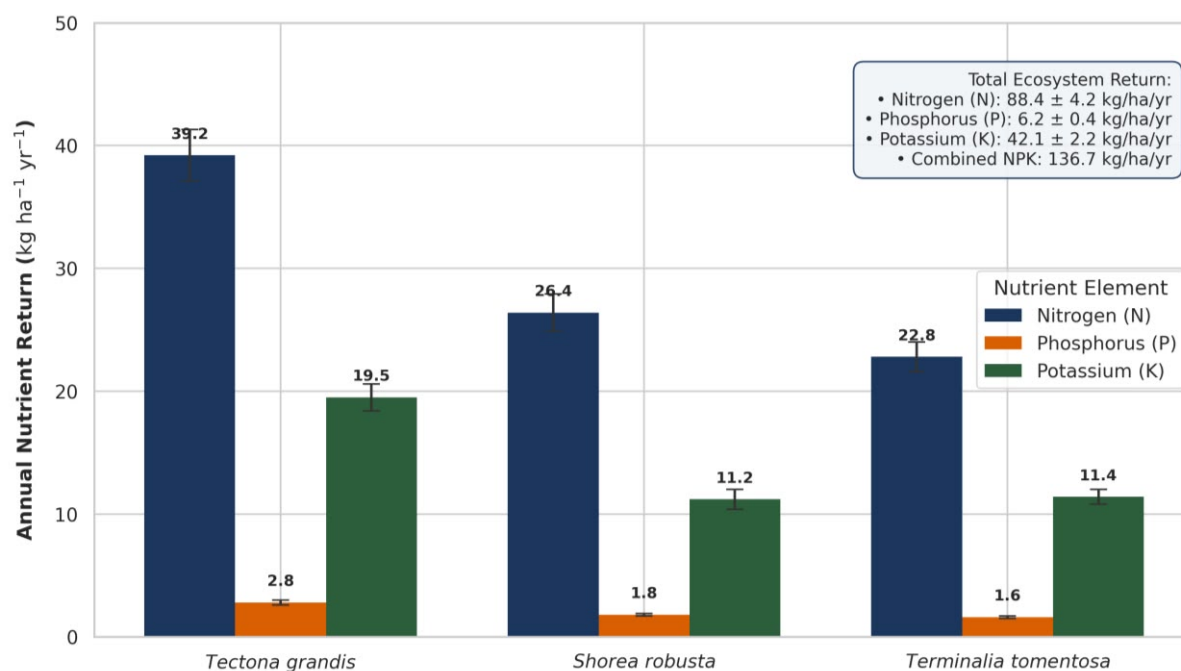


Fig.2: Annual nutrient return (N, P, K) via leaf litter across tropical tree species

Total annual nutrient return to the forest soil via leaf litter was estimated at $88.4 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, $6.2 \text{ kg P ha}^{-1} \text{ yr}^{-1}$, and $42.1 \text{ kg K ha}^{-1} \text{ yr}^{-1}$ (Table 3). *Tectona grandis* was the chief contributor to NPK influx due to its combined high total litter production and superior foliar nutrient concentration. The synchronicity between early monsoon moisture and rapid nutrient release from pre-monsoon litter deposition ensures optimal nutrient availability during the peak vegetative growth phase of the forest stand.

IV. CONCLUSION

This study demonstrates strong seasonal and interspecific variations in leaf litterfall, decomposition rates, and nutrient returns among tropical forest trees. Litter deposition is predominantly concentrated in the dry summer months, creating an organic buffer on the forest floor prior to monsoon onset. Substrate quality—specifically the lignin:N ratio and C:N balance—serves as the principal intrinsic regulator of decay velocity, while seasonal rainfall provides the crucial moisture driver. Fast-decomposing species like *Tectona grandis* act as rapid nutrient recycling agents, whereas slow-decomposing species like *Shorea robusta* contribute to long-term soil organic

carbon retention and surface protection. These findings emphasize the necessity of maintaining species diversity in tropical forest restoration programs to balance rapid nutrient replenishment with soil organic matter build-up.

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