

Litterfall Patterns and Decomposition of Selected indigenous Tree Species Litter in Farmed Parklands of Bawku West District of Ghana

Joshua Amodabila Adombire

joshua_adombire@wvi.org

University of Technology and Applied Sciences

Abdul- Wahab Mbelayin Imoro

University of Technology and Applied sciences

Douti Nang Biyogue

University of Technology and Applied Sciences

Eunice Essel

University of Technology and Applied Sciences

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Abstract

Indigenous trees in parkland agroecosystems in West Africa play significant roles in soil fertility through the production of litter, nutrient cycling, and accumulation of organic matter. In Ghana, however, there is still a limited amount of information available on litterfall dynamics and decomposition rates of indigenous tree species in the northern part of the country. The study involved farmed parklands in the Bawku West District, Upper East Region of Ghana, to compare litterfall production and decomposition rates of three tree species: *Piliostigma thonningii*, *Lannea microcarpa* and *Diospyros mespiliformis*. Litter was collected monthly for 1 year (August 2023 through July 2024) beneath mature trees using litter traps. The degradation of litter was measured by burying nylon litter bags filled with dried leaf litter for 120 days, with monthly measurements of litter mass and decomposition rate. Litter production differed significantly ($p \leq 0.05$) among species when compared the annual production. *Lannea microcarpa* produced the highest litter quantity ($6,938.5 \text{ g m}^{-2} \text{ yr}^{-1}$), followed by *P. thonningii* ($5,864.7 \text{ g m}^{-2} \text{ yr}^{-1}$) and *D. mespiliformis* ($2,153.7 \text{ g m}^{-2} \text{ yr}^{-1}$). The leaf litter was the predominant component of litterfall for all species. Litterfall was significantly increased during the dry season and was negatively related to rainfall and temperature ($r = -0.61$). The order of decomposition rate was *L. microcarpa* > *D. mespiliformis* > *P. thonningii*, with *L. microcarpa* having the highest decomposition rate ($k = 0.0069$; half-life = 101 days) and *P. thonningii* having the lowest decomposition rate ($k = 0.0047$; half-life = 148 days). Litter production and decomposition rates vary widely among indigenous tree species in the parkland, which also contribute varying amounts to natural nutrient cycles and soil fertility. They are therefore recommended for conservation and incorporation into agroforestry systems for climate-smart Agriculture and Sustainable Land Management in northern Ghana.

Introduction

Soil degradation and soil fertility loss have become significant limitations to sustainable agricultural production in sub-Saharan Africa (Tefera et al., 2024) due to the growing challenges faced by crop productivity and the livelihoods of farmers from nutrient depletion, decline in soil organic matter content, soil erosion, continuous cultivation, and climate variability (Stewart et al., 2020; Mogale et al., 2026). Integrated solutions that incorporate sources of mineral and organic nutrients and management practices that can enhance soil organic carbon, nutrient availability and long-term soil health are particularly important for soil fertility restoration and maintenance (Gram et al., 2020; Stewart et al., 2020). This growing focus on sustainable agricultural intensification has consequently boosted the uptake of agroforestry as a land-management practice to support agricultural production, ecosystem functionality and livelihood resilience (Kuyah et al., 2019; Muthee et al., 2022).

Agroforestry is the conscious conservation or incorporation of trees into agricultural systems and can enhance soil fertility through complementary use of resources, nutrient cycling, biomass production, sequestration of carbon and alteration of soil microclimatic conditions (Kuyah et al., 2019; Mogale et al., 2026). Available data from sub-Saharan Africa show that agroforestry enhances soil organic carbon, total N, available P, soil moisture and crop productivity compared to non-forestry systems, but the

magnitude of these benefits is dependent upon the tree species, soil environment and agroforestry management (Kuyah et al., 2019; Muthee et al., 2022). Therefore, it is especially pertinent in savannah habitats where the presence of indigenous trees on farmed land can offer various ecosystem services and add organic matter to nutrient-poor soils (Muthee et al., 2022; Mogale et al., 2026).

Litterfall also provides an avenue for carbon and mineral nutrient transfer from aboveground biomass to agricultural soils and plays an important role in linking vegetation productivity with soil nutrient cycling (Giweta, 2020; Asigbaase et al., 2021). The amount and seasonality of nutrients returned to the soil depend on the quantity, seasonal variation and chemical quality of the litter, and subsequent decomposition controls the rate at which nutrients become available for plant uptake (Giweta, 2020; Asigbaase et al., 2021). The quality of litter, species characteristics, environmental conditions, litter moisture, temperature, and microbial activity all affect litter decomposition, and therefore different species can contribute significantly in different ways to soil fertility even under similar conditions (Giweta, 2020; Siegwart et al., 2022). Therefore, understanding the litterfall and decomposition rates for each species is essential for understanding the nutrient cycling roles that the indigenous tree species play in agricultural lands (Asigbaase et al., 2021; Akpalu et al., 2020).

Multipurpose trees like *Piliostigma thonningii*, *Diospyros mespiliformis* and *Lannea microcarpa* are important trees in the landscapes of West Africa because of their ecological and livelihood benefits, including soil amendment, fodder, food, fuel wood, medicine, and others (Hailemariam et al., 2021; Atchadé et al., 2021; Tinguéri et al., 2022). For instance, *P. thonningii* is known as an agroforestry species of indigenous origin that can contribute to soil fertility and agricultural production in arid and semi-arid regions (Hailemariam et al., 2021). Likewise, *D. mespiliformis* and *L. microcarpa* are significant West African indigenous savannah trees that play an ecological and socio-economic role to ensure the sustainability of farm landscapes in West Africa (Atchadé et al., 2021; Tinguéri et al., 2022).

The significance of indigenous trees and litter-mediated nutrient cycling is acknowledged, but there is limited evidence regarding the comparative litter production, decomposition rate and nutrient supply of the three species in cultivated parkland systems of northern Ghana (Giweta, 2020; Muthee et al., 2022). Although the role of tree litter in nutrient return and soil fertility in agroforestry systems has been established in existing Ghanaian research, comparatively little attention has been paid to species-specific tree litter dynamics of less studied indigenous species of trees found in parkland (Akpalu et al., 2020; Asigbaase et al., 2021). It is thus important to have such information to guide sustainable agroforestry management and to guide species selection, conservation and research in the Sudan savannah.

Thus, the current study evaluated and compared the pattern of litterfall, decomposition rate, and macronutrient (N, P, and K) contribution of *Piliostigma thonningii*, *Diospyros mespiliformis*, and *Lannea microcarpa* in the cultivated parklands of Bawku West District of Ghana. In particular, the study examined the annual litter production and the decomposition rates of litterfall in relation to rainfall and temperature, and the contribution of litter decomposition to soil fertility in terms of nitrogen, phosphorus

and potassium for the three tree species studied. Interspecific differences in litter production, decomposition rates and nutrient contributions were hypothesised due to differences in litter quality, species characteristics and nutrient allocation strategies.

Materials and Methods

Study Area

The study was conducted in the Tilli and Widnaba communities of Bawku West District in the Upper East Region of Ghana in the Northeastern part of Ghana. The district was established in the 1990s with the enactment of the LI 1442 (Ghana Statistical Service, 2010). The district has an area of 1,070 Sq km, representing 12% of the land area of the Upper East Region (8,842 Sq km). The district is also home to 94,023 residents, representing 9% of the population of the region. This study district has geographical coordinates of 0°20'East of Greenwich and 10° 30'North of the equator; and 0°35'East of Greenwich and 11° 10'North of the equator, respectively (Ghana Statistical Service, 2021).

The rainfall is unimodal (May–October) with a long dry season (November–April). The annual rainfall is between 900 and 1,150 mm while the mean annual temperature is about 28.5°C (Ghana Statistical Service, 2021). The vegetation type is open savannah woodland with scattered indigenous trees that are interspersed in cultivated areas and in traditional parkland systems (Amoako and Gambiza, 2021). Rain-fed agriculture is the primary livelihood activity, with the major crops grown by farmers being maize, millet, sorghum and legumes (Ghana Statistical Service, 2021; Amoako and Gambiza, 2021).

The justification for the selection of the communities was that they practiced agroforestry and were easily accessible, particularly during the rainy seasons, and that they were receptive to learning because a good rapport had been established while working with them as a social worker.

Tree Selection

Maize farms in the study communities were used to select mature trees of *Piliostigma thonningii*, *Diospyros mespiliformis* and *Lannea microcarpa* between 20 and 25 cm diameter at breast height (DBH). The following parameters were used to determine selection: healthy appearance of foliage, mature canopy development, upright stems, lack of disease symptoms, and within cultivated fields. Six trees of each species were selected in each of the two study communities for a total of 18 trees.

Litterfall Measurement

Litter Trap Installation

Litterfall production was determined by litter traps using standard ecological practices of measuring litter fall in agroforestry systems (Verma et al., 2022; Rodríguez et al., 2023). The litter traps were 1 m × 1

m in size and were comprised of nylon mesh framed with wooden supports at 1 m above the soil surface.

Four litter traps were placed under each tree at the 4 cardinal points (north, south, east, and west) and 2 m away from the tree stem. This was designed to ensure maximum coverage of the canopy, and greater accuracy in the estimation of litterfall. There were 72 litter traps under 18 trees.

Litter Collection and Processing

Litter samples were taken every 2 weeks from August 2023 until July 2024 to span the annual phenological cycle of the species. The collected litter was sorted into six categories (Leaves, Flowers and floral parts, Fruits, Bark, Twigs and Miscellaneous materials) in the laboratory.

All litter fractions were dried to constant weight in an oven at 80°C for 48 hours. The dry weights were then measured by a precision electronic balance and expressed as grams per square meter per year ($\text{g m}^{-2} \text{yr}^{-1}$). Litter production was calculated as annual litterfall by adding all the litter accumulation during the sampling periods.

Climatic Data Collection

The data for rainfall and temperature which spanned the study period were obtained from the office of the Ghana Meteorological Agency (GMet), Bolgatanga. Average monthly rainfall and temperature were computed and relationships among climatic variables and litterfall production patterns assessed.

Pearson correlation analysis was used to evaluate relationships between litterfall amount and rainfall and temperature. In tropical and savannah ecosystems, similar methods have been applied to determine climatic influences on dynamics of litter (Giweta, 2020; Saj et al., 2021).

Leaf Litter Decomposition Experiment

Litter Collection

Under mature trees of each species, the freshly senesced leaf litter was collected. To remove extraneous samples, litter samples were cleaned by hand and then oven-dried at 80°C for 48 hours before the decomposition experiment.

Preparation of Litterbags

The litterbag technique was used to measure the rate of decomposition as described by Xie (2020), Devendar et al. (2022) and Zemskov and Bogatyrev (2025). The experiment was conducted using nylon mesh litter bags of size 15 cm x 10 cm and with a 1 mm mesh size.

The oven-dried leaf litter was placed in each litter bag 50g of leaf litter was bagged. A total of 90 litter bags were buried comprising:

- 30 litter bags with *P. thonningii* litter.
- *D. mespiliformis* litter (30 litter bags)
- 30 litter bags with *L. microcarpa* litter

Litter was evenly distributed in each bag to ensure contact with the surrounding soil environment and microbial colonisation.

Litterbag Incubation and Retrieval

Litter bags were buried 20 cm under each tree species in the study area. The burial depth was chosen to simulate the local tillage practices and maximise interaction between litter and decomposer organisms.

Three litterbags per species were randomly retrieved at 30, 60, 90, and 120 days of incubation. Samples of litter were retrieved and then cleansed of soil and other non-litter debris; the litter was oven-dried for 48 hours at 80°C and then weighed to find the residual dry mass.

Determination of Decomposition Rates

Mass Loss Calculation

Litter mass loss was calculated as:

$$MassLoss = InitialMass - ResidualMass$$

where:

- Initial Mass = 50 g
- Residual Mass = dry mass remaining after retrieval

The mass losses were similarly calculated to facilitate comparisons among species.

Decomposition Constant (k)

Decomposition dynamics were modelled using the single exponential decay equation proposed by Olson (1963):

$$\frac{X}{X_0} = e^{-kt} \text{ where:}$$

- X = remaining litter mass at time t
- X_0 = initial litter mass
- k = decomposition constant
- t = time (days)

Rearrangement of the equation enabled computation of the decomposition constant:

$$k = -\frac{\ln(X/X_0)}{t}$$

The projected litter half-life (time required for 50% mass loss) was estimated as:

$$t_{50} = \frac{\ln(2)}{k}$$

Higher k values indicate faster decomposition rates and more rapid nutrient release to the soil (Berg and McClaugherty, 2020; Xie, 2020; Devendar et al., 2022).

Chemical Characterisation of Leaf Litter

The macronutrient composition and physicochemical properties such as Total Nitrogen (N), Available Phosphorus (P), Available Potassium (K), pH, Electrical Conductivity (EC) and Organic Matter Content were determined with fresh leaf litter samples collected from each species. Ten subsamples of each species were pooled together to make a composite sample before laboratory analysis.

Determination of Total Nitrogen

Kjeldahl digestion method (Bremner 1960) was used to determine the total nitrogen content of litter samples. About 0.5 gm – 1.0 gm of oven-dried litter was digested in concentrated sulphuric acid and catalyst tablets.

The digest was then distilled with sodium hydroxide, and the ammonia released was trapped in boric acid, after which it was titrated with standardised hydrochloric acid. Nitrogen concentration was determined based on the amount of acid used in titration.

Determination of Available Phosphorus

The concentration of phosphorus was measured by the molybdenum blue spectrophotometric method (Lin et al., 2021; Zhai, 2023). Digested samples were then treated with ammonium molybdate under acidic conditions and produced a phosphomolybdate complex, which was reduced to a blue-coloured compound. The absorbance was determined at 840 nm by UV-Visible spectrophotometer, and the concentration of phosphorus was determined by the calibration curve constructed from the standard solutions.

Determination of Available Potassium

Neutral ammonium acetate was used for extraction, and potassium concentration was measured by flame photometry (Chavan et al., 2024). The flame photometer was calibrated with standard potassium solution, and potassium concentration in litter extracts was measured by plotting on the calibration curve.

Statistical Analysis

Analysis of Variance (ANOVA) was used to compare differences in species litterfall production, litter components, decomposition rates, residual mass, and decomposition constants. In cases of significant differences, the treatment means were separated by the Least Significant Difference (LSD) post hoc test at a 5% significance level.

Pearson correlation analysis was done to check the correlation between litterfall, rainfall and temperature. A p-value < 0.05 was considered statistically significant. Data were analysed using the common statistical methods used in ecological and agroforestry studies (Steel and Torrie, 1980; Gomez and Gomez, 1984).

Results

Annual Litter Production and Composition of Indigenous Tree Species

The annual litter production was significantly different ($p < 0.05$) among the three indigenous tree species (Table 1). The litter production of *Lannea microcarpa* was the highest (6,938.5 g m⁻² year⁻¹) and represented about 46.4% of the total litter production in the study period. The subsequent species was *Piliostigma thonningii* (5,864.7 g m⁻² yr⁻¹) and *Diospyros mespiliformis* registered the least amount (2,153.7 g m⁻² yr⁻¹).

Table 1
Mean annual litter production of the three indigenous tree species in Bawku West District

Litter components	Litter production (g m ⁻² yr ⁻¹)		
	<i>P. thonningii</i> ,	<i>D. mespiliformis</i>	<i>L. microcarpa</i>
Leaves	3872.9 ± 2960.6 ^a	1484.0 ± 578.0 ^b	5799.1 ± 9699.6 ^c
Floral parts	907.7 ± 1032.2 ^c	304.8 ± 466.9 ^b	398.8 ± 862.0 ^b
Mature fruits	914.4 ± 938.7 [⌘]	22.4 ± 30.6 [⌘]	237.3 ± 522.7 [⌘]
Bark	0.43 ± 0.62 ^a	0.86 ± 0.98 ^a	0.22 ± 0.40 ^a
Twigs	162.7 ± 191.3 [⌘]	168.4 ± 302.3 [⌘]	476.7 ± 445.6 [⌘]
Miscellaneous	6.5 ± 12.0 [⌘]	173.2 ± 235.3 [⌘]	26.4 ± 54.8 [⌘]
Total litter	5864.7 [⌘]	2153.7 [⌘]	6938.5 [⌘]

Values within rows with the same superscript letter did not differ significantly (P < 0.05)

The leaf litter was the most abundant by amount of litter for all species and accounted for over 2/3 of annual litter input. There were significant ($P < 0.05$) differences observed in the leaf litter production among the species. The mean annual leaf litter production was highest in *L. microcarpa* ($5,799.1 \pm 969.9 \text{ g m}^{-2} \text{ yr}^{-1}$), followed by *P. thonningii* ($3,872.9 \pm 2,960.6 \text{ g m}^{-2} \text{ yr}^{-1}$) and *D. mespiliformis* ($1,484.0 \pm 578.0 \text{ g m}^{-2} \text{ yr}^{-1}$).

There were significant differences ($p < 0.05$) in fruit litter production between species. *Piliostigma thonningii* produced the highest quantity of fruit litter ($914.4 \pm 938.7 \text{ g m}^{-2} \text{ yr}^{-1}$), exceeding values recorded for *L. microcarpa* ($237.3 \pm 522.7 \text{ g m}^{-2} \text{ yr}^{-1}$) and *D. mespiliformis* ($22.4 \pm 30.6 \text{ g m}^{-2} \text{ yr}^{-1}$). In the same way, the production of twig litter was significantly higher for *L. microcarpa* ($476.7 \pm 445.6 \text{ g m}^{-2} \text{ yr}^{-1}$) than for the other species.

The amount of bark litterfall was the lowest and not significantly different ($p > 0.05$) among the species. There was significant (> 0.05) variation in the miscellaneous litter components, with the highest amount being produced by *D. mespiliformis* ($173.2 \pm 235.3 \text{ g m}^{-2} \text{ yr}^{-1}$).

Seasonal Patterns of Litterfall

The monthly litter production varied significantly among the species. The litterfall tended to be higher during the dry season and lower during the rainy season, in general. The amount of litterfall of *Lannea microcarpa* also rose significantly after the dry period and peaked at $2,829.71 \text{ g m}^{-2}$ in November 2023 (Fig. 3). The litterfall then slowly declined, followed by a rise in April.

The litter production of *Piliostigma thonningii* increased with the advancement of the dry season from November to February and reached its maximum in February 2024 (938.45 g m^{-2}), Fig. 4. Another rise was noted for May and June, followed by a drop towards the end of the rainy season.

The litterfall of *Diospyros mespiliformis*, however, remained fairly uniform throughout the year with only slight variations. The litterfall was highest in April 2024 (208.30 g m^{-2}) when ambient temperature was high, at the end of the dry season (Fig. 5). In general, the peak time for litterfall was when rainfall was lowest and temperatures highest, indicating a high degree of seasonal control of leaf shed by environmental conditions in the dry season.

Relationship Between Litterfall and Climatic Variables

The Pearson correlation analysis revealed generally modest connections between litterfall and meteorological factors (see Table 2). The litter production in *P. thonningii* was not connected with rainfall ($r = -0.30$) and very modest with temperature ($r = 0.22$). *Lannea microcarpa* exhibited a low negative association with rainfall ($r = -0.33$) and a low positive association with temperature ($r = 0.26$). For *D. mespiliformis*, there was practically no relationship between litterfall and rainfall ($r = 0.02$) and a weak positive correlation between litterfall and temperature ($r = 0.16$). The results showed that climatic variables explained little of the variation in litter production. The species-specific phenological characteristics accounted for a greater control over litterfall dynamics than climatic variables.

Table 2
Pearson Correlation coefficient between litterfall,
rainfall and temperature

Species	Rainfall(r)	Temperature(r)
<i>P. thonningii</i>	-0.30	0.22
<i>L. microcarpa</i>	-0.33	0.26
<i>D. mespiliformis</i>	0.02	0.16

Mass Loss During Litter Decomposition

The leaf litter decomposition differed significantly ($p < 0.05$) among the three species in the 120-day incubation period (Table 3; $F = 81.40$, $p < 0.05$). For all the species, there was a progressive increase in mass loss as incubation time increased. At 30 days after burial, *L. microcarpa* exhibited the greatest mass loss (18.87 ± 5.72 g), compared with *D. mespiliformis* (10.99 ± 2.63 g) and *P. thonningii* (5.90 ± 3.83 g). This trend continued throughout the experiment.

Table 3
Mean mass loss of litter of the three different indigenous tree species in the Bawku West District.

Tree Species Litter	Number of Days of Incubation of Litter/Mass Loss (g)				
	0	30	60	90	120
<i>P. thonningii</i>	50 ± 0	5.90 ± 3.83^b	14.94 ± 2.74^b	16.1 ± 1.91^c	21.79 ± 2.40^b
<i>D. mespiliformis</i>	50 ± 0	10.99 ± 2.63^{ab}	14.08 ± 3.31^b	19.99 ± 1.70^b	22.16 ± 2.92^b
<i>L. microcarpa</i>	50 ± 0	18.87 ± 5.72^a	22.68 ± 0.64^a	26.3 ± 1.55^a	28.53 ± 1.39^a

Means within the same column followed by different superscripts are significantly different at $p < 0.05$ using the Least Significant Difference (LSD) test.

After 120 days, the mass losses were: 28.53 ± 1.39 g for *L. microcarpa*; 22.16 ± 2.92 g for *D. mespiliformis* and 21.79 ± 2.40 g for *P. thonningii*. The results showed that there was a significant ($p < 0.05$) difference in decomposition rate of *L. microcarpa* litter compared to the other species.

Residual Litter Mass During Decomposition

The litter mass remaining after 6 weeks of incubation was found to be reducing, which was significant ($p < 0.05$) for all species as their incubation period increased. The residual litter mass for *L. microcarpa* and *P. thonningii* was 31 ± 6 g and 44 ± 4 g, respectively at 30 days. The result indicated that the residual mass of the litter at the end of the experiment was lowest for *L. microcarpa* (21.5 ± 1.0 g), which means that it had the fastest rate of decomposition (Table 4). The other species, however, had a higher residual mass, which is considered to be an indication of their poorer decomposing ability than *L. microcarpa*.

Table 4
Mean Residual Mass of Leaf litter over time

Days of incubation	Mass(g) <i>P. thonningii</i>	Mass(g) <i>D. mespiliformis</i>	Mass(g) <i>L. microcarpa</i>
0	50 ^a	50 ^a	50 ^a
30	44 ± 4 ^a	39 ± 3 ^a	31 ± 6 ^a
60	35 ± 3 ^a	36 ± 3 ^a	27.5 ± 1 ^a
90	34 ± 2 ^a	30 ± 2 ^a	24 ± 1.5 ^a
120	28 ± 3 ^a	26 ± 3 ^b	21.5 ± 1 ^c

Means within the same row followed by different superscripts are significantly different at $p < 0.05$ using the Least Significant Difference (LSD) test.

Decomposition Constants and Half-Life Projections

The difference among the species in the decomposition constants calculated by Olson's exponential decay model was significant ($p < 0.05$) (Table 5). *Lannea microcarpa* had the highest decomposition constant (k) (0.0069), *D. mespiliformis* had the closest value (0.0068), and the lowest value was for *P. thonningii* (0.0047).

Table 5
Decomposition constant k and the decomposition equations of the litter of three indigenous tree species.

Tree Species	Projected 50% mass loss time (Days)	Constant K	Exponential decay equation	Rate of decomposition (g/day)
<i>P. thonningii</i>	148	0.0047 ^a	$y = 50e^{-0.0047x}$	0.1816
<i>D. mespiliformis</i>	102	0.0068 ^b	$y = 50e^{-0.0068x}$	0.1847
<i>L. microcarpa</i>	101	0.0069 ^c	$y = 50e^{-0.0069x}$	0.2378

y = amount remaining at time, x = time. Values in the third column, accompanied by different superscripts, differ significantly.

The estimates of the half-life of the species indicated similar differences among species. The amount of time needed for litter mass loss of 50% for *L. microcarpa*, *D. mespiliformis* and *P. thonningii* was respectively 101, 102 and 148 days (Table 5).

Discussion

Annual Litter Production and Litterfall Patterns of Indigenous Tree Species

A significant ($p < 0.05$) difference in annual litter production was found among *Piliostigma thonningii*, *Diospyros mespiliformis* and *Lannea microcarpa*, which indicated that litterfall dynamics in parklands of Sudan savannah are species dependent. *Lannea microcarpa* had the greatest annual litterfall, and *D. mespiliformis* the least. These findings corroborate earlier studies conducted in tropical and savannah forests, where species identity, canopy architecture, growth strategy and phenological characteristics were found to be important factors that influence litter production (Giweta, 2020; Bayliss et al., 2026). The significantly ($p < 0.05$) high litter production of *L. microcarpa* is due to its deciduous growth habit, wide canopy and complete shedding of leaves which results in a high amount of litter deposition when there was water stress.

This dominance of leaf litter is similar to that reported from tropical dry forests and African savannah ecosystems where leaves tend to be the most prevalent component of annual litterfall (Costa et al., 2020; Tonin et al., 2021). The leaf litter is ecologically valuable as it is the major route for the return of nutrients to the soil. The leaf breakdown is often the most important source of nutrients, microbial activity, and soil fertility restoration, as leaf tissues are likely to have a higher nutrient content than woody parts (Lanuza et al., 2019; Nair et al., 2022). These high amounts of leaf litter from *L. microcarpa* and *P. thonningii* suggest that there is significant potential for the accumulation of organic matter and nutrient replenishment in parkland farming systems.

There was also a large interspecific difference in the floral and fruit litter. The quantity of fruit litter was much higher for *Piliostigma thonningii*. This much reproductive litter production has been reported in some Fabaceae species and could be due to flower/fruit abortion during stressful environmental conditions (Saj et al., 2021). Nitrogen, phosphorus and other nutrients are relatively high in reproductive litter components and lead to rapid decomposition and localised nutrient enrichment under the canopy (Shah et al., 2024). The fruit and floral litter, which accounted for only a small percentage of litterfall in the stand, can still be a significant portion of the litter contributing to nutrient cycling and soil fertility.

Twig production is significantly higher for *L. microcarpa*, so there is an increased likelihood of branch senescence and tree shedding, which may be due to wind damage, canopy restructuring or livestock disturbance. Other studies have demonstrated that woody litter is more resistant to decomposition and has more lignin (He et al., 2019; Berg and McClaugherty, 2020) and thus can help store C in the soil over longer time scales. Thus, *L. microcarpa* can potentially play a dual role both as a species that has high rates of recycling nutrients through leaf litter and as a species that accumulates carbon through woody litter deposition.

In general, the findings showed that there was a significant variation in the contribution of organic matter to agricultural lands between the indigenous trees. These variations highlight the need for species

selection when planning agroforestry activities to support degraded soils and boost farm productivity in northern Ghana.

Seasonal Variation in Litterfall Production

The amount of litterfall showed a good correlation with the climate of the Sudan savannah environment. In general, litterfall rose in the dry season and fell in the rainy season when rains were active. Many tropical deciduous species have a pattern of leaf abscission as an adaptive response to drought and high evaporative demand (Yang et al., 2021; Lenza et al., 2025).

L. microcarpa has a much more synchronised deciduous strategy than the other species, with a distinct litterfall peak at the beginning of the dry season. By dropping in the dry season, trees help to limit water loss by transpiration, thereby maintaining internal water resources (Peguero-Pina et al., 2020; Koala and Takenaka, 2024). During the dry season, the high amount of litter that has accumulated is then available for decomposition and nutrient release when rains resume.

In contrast, the relative amounts of litterfall were fairly constant for *D. mespiliformis* year-round. This is also validation of its semi-evergreen nature and drought tolerance. Semi-evergreen species usually have a high dry season canopy fraction and have a slow leaf turnover instead of a synchronised turnover (Macías-Pro et al., 2025). The net effect is that litter deposition rates are reduced but more uniform. This approach can offer long-term nutrient additions to soil instead of big pulses in certain seasons.

This seasonality is accentuated by the progressive rise in litterfall that occurred during the dry season in *P. thonningii*. These patterns have also been observed in savannah ecosystems of West Africa where leaf senescence and abscission occur gradually over an extended drought period (Ibrahim et al., 2021). The deposition of dry-season litter is also advantageous from an agroecological viewpoint, as the deposited organic carbon is ready to be decomposed at the arrival of the rainy season when the crops are new and in demand for nutrients.

The results indicated that seasonal litter production can affect the seasonality of nutrient availability in agroforestry systems. The species, which are prolific producers of litter prior to the rainy season, could help facilitate nutrient release during crop development, which could help improve agricultural production.

Relationships Between Litterfall and Climatic Variables

The litterfall usually rose with decreasing rainfall and increasing temperature, but these relationships between litter production and climatic factors were not particularly strong. For *P. thonningii* and *L. microcarpa*, there were weak negative rainfall-litterfall relationships, and weak positive litterfall-temperature relationships for all three species.

The inverse association with rainfall is consistent with findings from other tropical ecosystems that drought-induced canopy loss is related to water availability (Janssen et al., 2020; Lian et al., 2024). The

trees have an active photosynthetic canopy during the rainy season, which leads to less deposition of litter. On the contrary, under moisture deficits in the dry season, leaf drop and senescence are induced.

The positive, but weak, litterfall-temperature correlations are probably due to the fact that temperatures are an indirect measure of drought stress, and not necessarily of leaf shedding. Warming temperatures can cause more evapotranspiration and greater water stress of plants, which can accelerate senescence under moisture stress conditions (Wu et al., 2022; Qiu et al., 2025). The low correlation coefficients, however, suggest that the influence of the climatic variables on litterfall dynamics is not complete.

The low correlations found indicate that inter-specific differences in phenology, canopy structure, rooting depth, drought and nutrient conservation strategies, etc., may have a greater influence on litter production than short-term weather variability. The patterns of litterfall in savannah environments are often heavily influenced by internal biological controls more so than climatic factors (Giweta, 2020; Saj et al., 2021). So, it is important to know and predict litter production and nutrient cycling processes in agroforestry systems by recognising species-specific ecological strategies.

Litter Decomposition and Mass Loss Dynamics

The decomposition results showed significant ($p < 0.05$) differences among the three indigenous tree species. *Lannea microcarpa* always recorded the highest mass loss during the incubation period, and *P. thonningii* was the slowest decomposing species. These findings are consistent with the ecological theory that decomposition is mainly affected by the quality of the litter and the nutrient composition, lignin content, and carbon-to-nitrogen ratios (Berg and McClaugherty, 2020; Wu et al., 2023). *Lannea microcarpa* litter apparently decomposes quickly because it contains greater amounts of labile organic materials that are easily broken down by decomposer organisms. A high decomposition rate of litter increases nutrient mineralisation and helps to release nutrients to the soil more quickly, leading to better nutrient availability for crops (Fanin et al., 2020; Martínez-García et al., 2021). Therefore, *L. microcarpa* might have a special role in short-term fertility enhancement in low-input farming systems. The lesser mass loss observed for *P. thonningii* suggests the presence of higher amounts of inhibitors such as lignin and phenols that slow down the degradation process by microorganisms. Nutrient release is slower from such litter, but litter residues persist for a longer time, which results in the long-term increase in soil organic matter and soil structure (Liebmann et al., 2020; Bourget et al., 2023). *Diospyros mespiliformis* exhibited intermediate decomposition, indicating intermediate nutrient release and organic matter persistence. This intermediate behaviour might be a result of good intermediate quality of litter and a good ratio of labile carbon to resistant carbon fractions. A progressive decrease in mass with time was recorded for all the species, which agrees with the classic two-phase decomposition model (Zane et al., 2024; Li et al., 2026), a first rapid phase of mass loss due to leaching and microbial utilisation of soluble compounds, followed by slower loss of mass from structurally resistant materials. The pattern here indicates that decomposition in the Sudan savannah follows a litter decomposition pattern typical of other tropical ecosystems.

Decomposition Constants and Implications for Nutrient Cycling

The decomposition constants calculated in this study also revealed significant inter-species variation in their contribution to nutrient cycling. The highest decomposition constant ($k = 0.0069$) was observed for *Lannea microcarpa*, followed by *D. mespiliformis* with $k = 0.0068$, while *P. thonningii* recorded the lowest decomposition constant ($k = 0.0047$).

The higher the decomposition constant, the more rapid the decomposition, and the faster the nutrients are released (He et al., 2019). The short projection of the half-life for *L. microcarpa* (101 days) indicates that nutrients in *L. microcarpa* litter are made available relatively soon after deposition. This fast turnover of nutrients is especially useful in annual cropping systems in which nutrient availability, crop growth, and nutrient requirement are linked.

On the other hand, *P. thonningii* has a longer half-life (148 days), which suggests it persists in the litter for a longer period and releases nutrients slowly. Slow nutrient release can minimise nutrient losses from leaching and facilitate nutrient supply over the growing season. In addition, the persistence of litter residues leads to carbon sequestration, soil aggregation, and better moisture-holding capacity (Rawat et al., 2019; Oyebiyi et al., 2026).

These different decomposition methods show the complementary ecological roles of the species studied. Fast-decomposing species are important for providing immediate nutrient availability, and slow-decomposing species are important in maintaining soil organic matter. So maybe, a mix of native trees in the parkland system can improve short-term productivity and long-term soil sustainability.

Implications for Agroforestry and Sustainable Land Management

Overall, the litter production and decomposition suggest that there is an important contribution from both indigenous tree species and Exotic Tree Species(ETS) to ecosystem functioning in Sudan savannah parklands. *Lannea microcarpa* produces substantial amounts of fast-decomposing litter for rapid nutrient cycling, and *P. thonningii* produces large amounts of litter that result in slow decomposition and long-term soil organic matter accumulation and soil structural improvement. *D. mespiliformis* is in a transitional ecological niche, characterised by moderate litter production and a relatively fast litter decomposition rate.

The complementary functions are in line with the principles of integrated soil fertility management and agroforestry diversification. Agroforestry practices in northern Ghana should not focus on promoting one species, but rather a range of native tree species that can provide a variety of ecological services (Asigbaase et al., 2019; Sanchez, 2019).

The results also indicate that some of the practices such as farmer-managed natural regeneration (FMNR), enrichment planting, and conservation of indigenous parkland trees may provide additional benefits to nutrient cycling, inorganic fertiliser dependency, soil health, and climate resilience within farming landscapes. In northern Ghana, with growing worries of degradation and loss of soil fertility, Indigenous Tree- Based Agroforestry systems (ITAS) can be a pragmatic approach to sustainable intensification of agriculture over the long term.

Conclusion

The results of this study show and highlight the significant contribution of indigenous trees in the parkland of northern Ghana for the maintenance of soil fertility and nutrient cycling in the Sudanic Savanna agroecosystems of northern Ghana. The litter production, seasonal litterfall, decomposition and nutrient-release potential differed significantly among *Piliostigma thonningii*, *Diospyros mespiliformis* and *Lannea microcarpa*. The litterfall and decomposition rate were highest for *L. microcarpa* and intermediate for *P. thonningii*, suggesting that this species has strong potential for rapid nutrient recycling and low potential for long-term organic matter accumulation and carbon storage, while *L. microcarpa* has a high potential for both. *Diospyros mespiliformis* had intermediate properties. The litterfall tended to be higher in the dry season, presumably due to seasonal leaf senescence and water stress, but with species-specific phenology more important than climatic variation. In general, the conservation and inclusion of these indigenous trees in parkland systems can enhance nutrient cycling, soil fertility, ecosystem resilience, climate-smart agriculture and sustainable agricultural productivity in the northern region of Ghana.

Recommendations

The study suggests that indigenous agroforestry systems that use trees, particularly *Lannea microcarpa*, *Piliostigma thonningii* and *Diospyros mespiliformis*, should be promoted in northern Ghana by encouraging farmers to keep and sustainably manage these trees in their farms to enhance soil fertility, organic matter inputs, nutrient cycling and ecosystem services. Integrated soil fertility management should also be promoted by making farmers use leaf litter in the fields, add tree biomass to the soil, and avoid burning it. *Lannea microcarpa* litter may be utilised for community-level composting due to its relatively short rot time and nutrient-releasing capacity. Conservation activities such as Farmer Managed Natural Regeneration, Assisted Natural Regeneration, community nurseries, and sustainable harvesting should be encouraged to ensure the maintenance of indigenous trees. Government agencies, extension and development partners should incorporate indigenous-tree management into climate-smart agriculture, land-restoration and farmer-training programmes and offer species-specific management recommendations.

Future Research

Long-term decomposition, carbon stabilisation, microbial communities and soil biological processes involved in decomposition of litter should be examined in future studies. Further studies are needed to assess nutrient availability under conditions of crop production such as with mixed species, and to test other native species of trees found in parkland. The need for multi-location studies under different savanna agroecological zones to increase the regional applicability of the results and the robustness of evidence for sustainable agricultural development through agroforestry is recommended.

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Declarations

Author Contribution

Joshua Amodabila Adombire(J.A.A) wrote the manuscript including the tables and figures and the review work was done by the other three authors i.e Eunice Essel, Biyogue Douti Nang and Abdul-Wahab Mbelayin Imoro reviewed the manuscript.

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Figures

Figure 2

Mean monthly rainfall (mm) and temperature (°C)

Source: Ghana Meteorological Service (2023 and 2024)

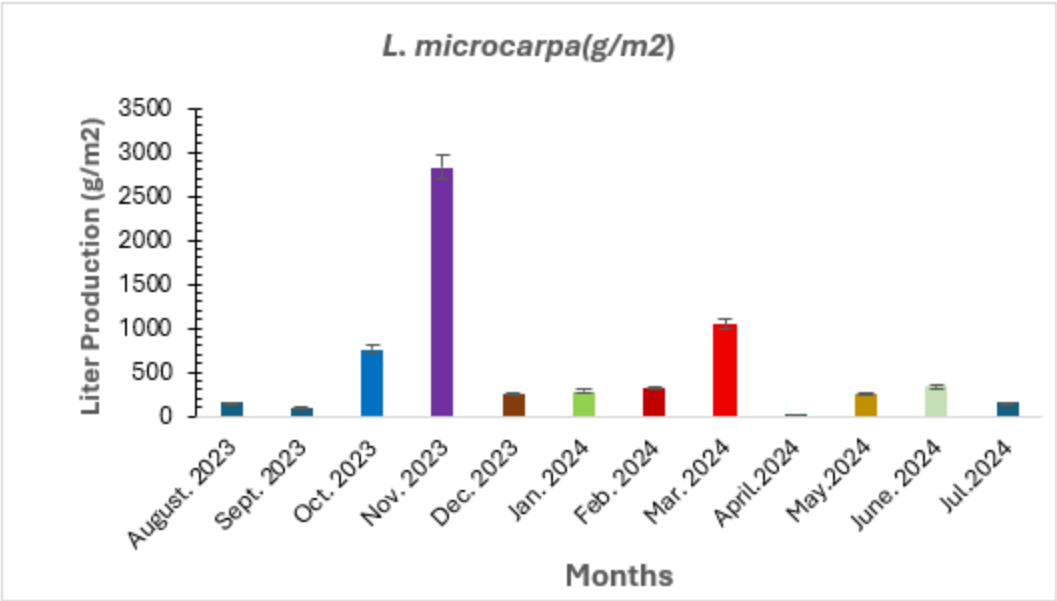


Figure 3

Mean monthly *L. microcarpa* litter production (g/m²)

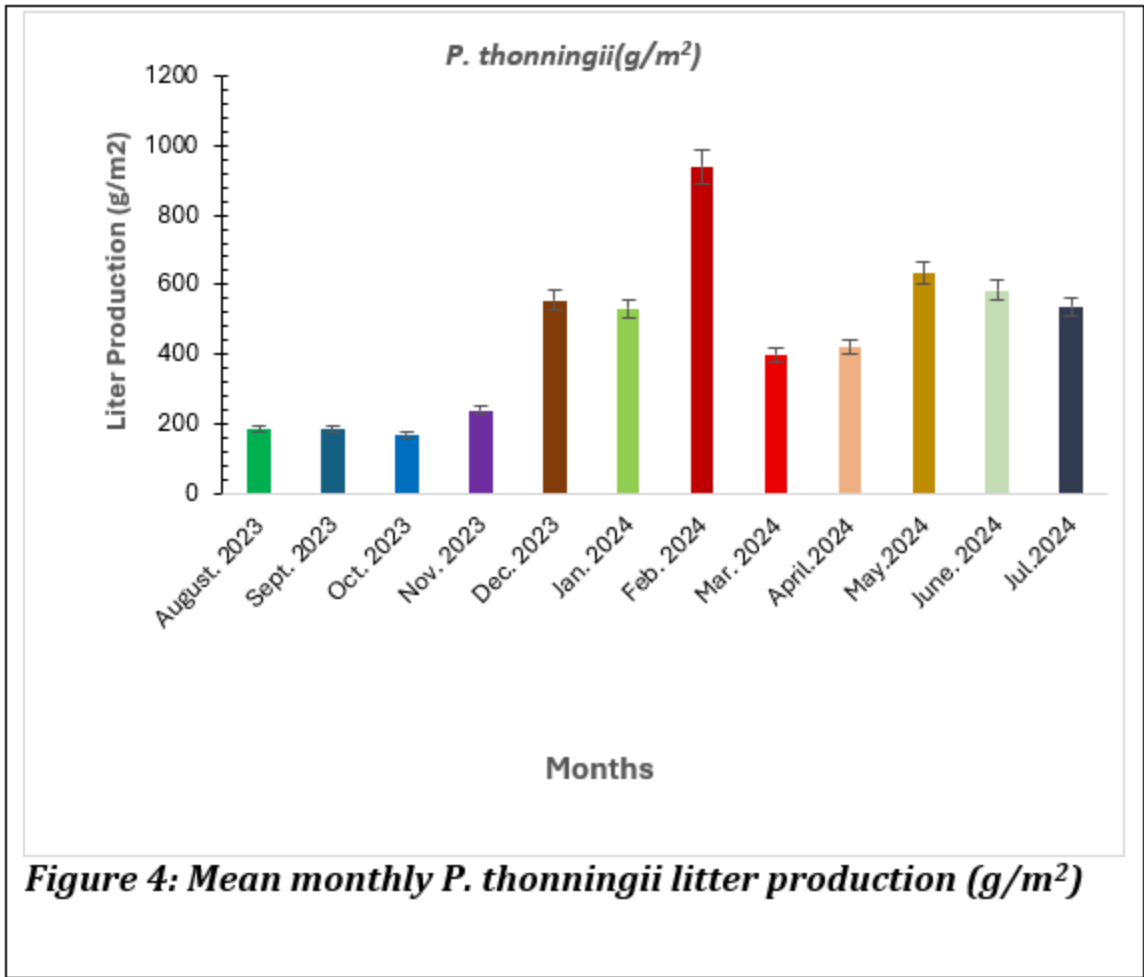


Figure 4: Mean monthly *P. thonningii* litter production (g/m²)

Figure 4

See image above for figure legend.

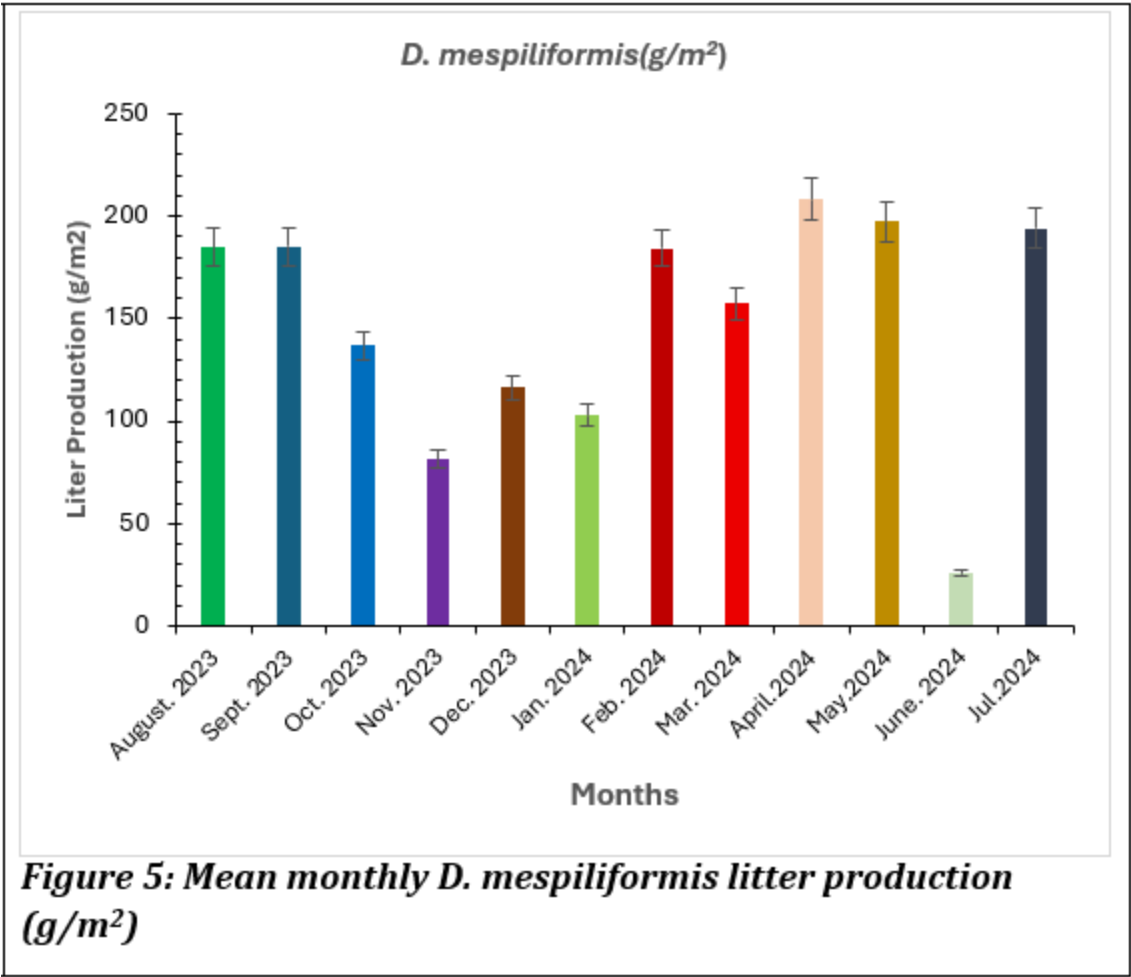


Figure 5

See image above for figure legend.