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Assessment of Annual Litterfall of Woody Plant Community in Southern Thorn Forest, Tirunelveli, Peninsular India

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Abstract

The biological phenomenon, litterfall acts as a connection between tree canopy and substratum of the habitats, influencing the concentration of vital soil nutrients thereby contributing to the tree growth and forest productivity. Information on litter generation of tropical forests including tropical thorn forest is lacking. Therefore, the current study was conducted to find annual litterfall of tree community existing within a Reserve Forest in Tirunelveli, India. A field ecological study was carried out to find annual litter production of woody plant community. Litter traps were kept randomly across the forest to assess the litter production. The litter fallen in each trap was collected separately on monthly basis for one calendar year. The collected litter was separated in to four different classes *viz*., leaf, wood, amorphous and reproductive organs. The relationship of climatic variables with litterfall was estimated by Pearson's simple correlation test. The annual litter generation of the study area was estimated at 8.058 tons ha^{-1} y^{-1}. The amount of total fallen and four classes litter per month varied significantly. In addition, litterfall did not show any significant relationship with the mean monthly temperature ($p = 0.128$; $r^2 = 0.216$) and monthly rainfall ($p = 0.817$; $r^2 = 0.0056$). The deciduous species accounted for 95% (3.449 tons ha^{-1}) of total annual leaf litterfall. Among four litter classes, the leaf litter accounted for 45.05%. The quantity of annual litterfall recorded from present study area is comparable with other tropical dry forests. The present study concentrated on limited forest areas, further studies with larger study area are needed to quantify the actual annual litter generation of southern thorn forests flourishing in various districts of Tamil Nadu.

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Leaf Litterfall;
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Introduction

The litterfall is one of the important events in forest ecosystem, it facilitates the return of vital nutrients and add significant amount of carbon (C) into the soil.[1-4] Information on forest litterfall is important to understand the patterns and factors which influence

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litterfall across forest types.[5] In addition, the litterfall offers energy and nutrients to detritivores, adds organic matter content to soil and provides essential growth nutrients to plants.[3,6,7] The total litterfall consists leaf litter and non-leaf litter including reproductive organs, barks, twigs and amorphous or inseparable litter.[8]

The rate of degradation depends on an array of factors including chemical composition of leaves,[9] C/N ratio,[10] physiognomy[11] and functional traits.[12] It is well known that environmental factors including rainfall, temperature and length of the growing season, and characteristics of vegetation including community composition, density, basal area, and age influence litter production.[13-16] Comparative studies on the total litter production showed that litter production of dry forests is lower than in wet tropical forests.[14,17] The global terrestrial litter production has been estimated as 39 to 54 Gigaton (Gt) yr^{-1},[18,19] in which global forest litter production was 29 Gt yr^{-1}.[20] Notably, 13% of the world's annual litterfall is constituted by tropical forests.[21] In general, the amount of litterfall vary across forests, the litterfall in temperate, tropical rain and sub-tropical rain forests recorded as 3-5, 12 and 16 tons ha^{-1} yr^{-1}, respectively.[22] The mean annual litterfall of Indian tropical forests was estimated as 9.3 tons ha^{-1}.[23]

Indian researchers concentrated on many aspects of litterfall including pattern of litterfall;[24] nutrient addition by litterfall to soil;[25] influences of environmental factors on litterfall;[26-27] litterfall nutrient dynamics,[28] litter decomposition,[29] impact of precipitation on litterfall,[30] and, long-term changes in litterfall production.[31] Quantitative ecological studies on litterfall largely concentrated on forests of the Himalayas,[32] Western Ghats,[33] Eastern Ghats,[34] and, dry forests.[35] However, information on litterfall production of Indian dry forests, especially Southern Thorn Forest (STF) has been very limited, thus, the current study was planned to estimate annual litterfall in a legally protected STF ecosystem, namely, Uthumalai Reserve Forest located in Tirunelveli district, Tamil Nadu. The objectives of the current field ecological study were (i) to record litter generation of woody plant community, (ii) to assess the relationships among environmental factors and monthly litter generation, and, (iii) to quantify the litter generation of deciduous and evergreen woody plants.

Materials and Methods

Study Area

The current field ecological study was carried out during January to December 2019 in Uthumalai Reserve Forest (URF; 8°59'49.1 "N latitude and 77°35'11.4" E longitude) located in Tirunelveli, Tamil Nadu (Fig. 1). The vegetation of the forest has been classified as southern thorn forest (Sub-group 6A/Type 6A/C1).[36] The forest cover of URF is 1300 ha, located 150 to 320 m amsl. The normal annual precipitation is 643.3 mm, in which 64% falls from September to December. Notably, the forest experiences 5-6 dry months in a year, the month December has the low mean temperature (24.5 °C) while the highest was recorded during May (30 °C), (Fig. 2). Red laterite and red loamy are common soil types.[37] *Acacia planifrons* Wright & Arn. (Umbrella thorn), *Dalbergia spinosa* Roxb. (Prickly Dalbergia), *Commiphora berryi* (Arn.) Engl. (Indian Balm of Gilead), *Grewia flavescens Juss*. (Donkey berry), *Anogeissus pendula* Edgew. (Button tree), and *Dichrostachys cinerea* (L.) Wright & Arn. (Sickle bush) were found as dominants. Tree density, species richness and basal area was recorded as 4135 trees ha^{-1}, 26 species and 15.238 m^2 ha^{-1}.[37] The relationships of climatic variables with components of litter were estimated by Pearson's simple correlation test (https://datatab.net/statistics-calculator/correlation).

Litter Sampling and Collection

Litterfall of woody plant vegetation was recorded monthly for one calendar year (January to December 2019). A total of 11 litter traps made of fine nylon mesh (pore size 2mm) with 50cm×50cm×100cm (width, length, height) were kept randomly across the forest site.[38,39] The fallen litter from each trap was collected and kept in polythene bags, and brought to the laboratory. Litter collected from the forest were separated into leaf, wood (small bark and branch), reproductive parts, and amorphous (inseparable in to organs and degraded). Further, the litter samples kept in forced-air circulating oven at 60 °C for 72 h and dry matter determined. The mean litter generation data obtained from a m^2 was extrapolated in to ton ha^{-1} to facilitate the comparison of the present study with published litterfall studies nationally and globally.

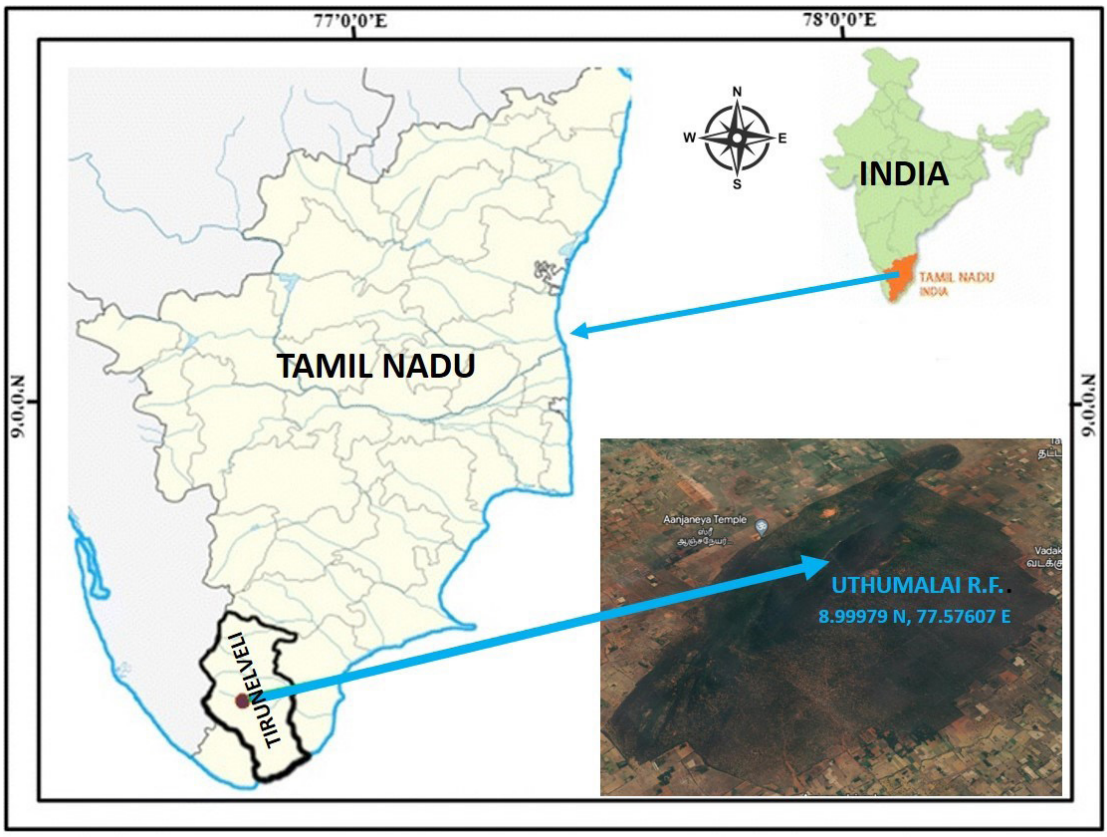

Fig. 1: Map of study area in which information on litter generation of woody plant community was recorded (the base map has been retrieved from Mohan et al. 2018).[58]

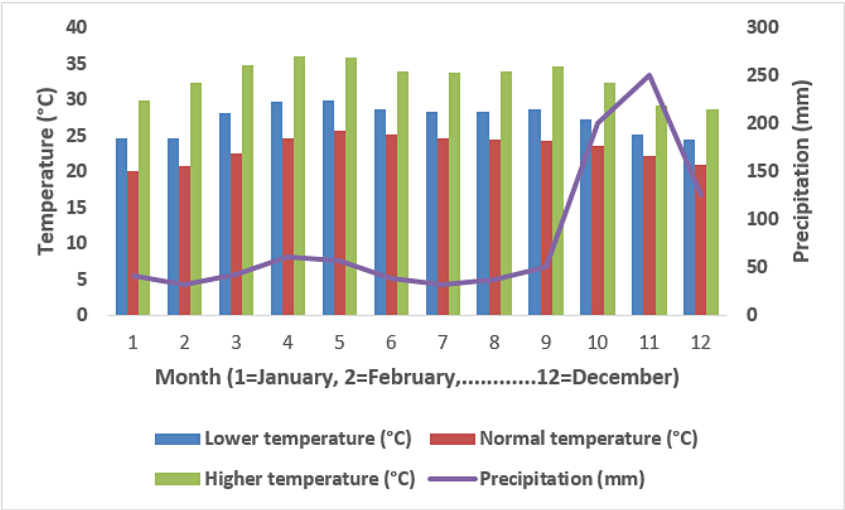

Fig. 2: The maximum, minimum and normal monthly temperatures (°C) and cumulative monthly precipitation (mm) of study area.

Results

Annual Litterfall

The annual litter generation of the study area estimated as 8.058 tons ha^{-1}. The amount of litter falls in a month varied significantly across the litter sampling traps (Fig.3). In addition, the monthly litter fall also differed notably in study area. Litterfall peaked during the month of March (1.2189-ton ha^{-1}, 15.13%) followed by February (1.1925-ton ha^{-1}; 14.80%) and April (1.1523-ton ha^{-1}; 14.01%), whilst the month of September recorded the lowest value (0.1582-ton ha^{-1}; 1.96%) (Fig. 4). The percentage contribution of litter classes varied significantly. The leaf constituted the highest proportion of annual litterfall (45.05%, 3.631-ton ha^{-1}) followed by amorphous (27.08%, 2.182-ton ha^{-1}), wood (24.68%, 1.988-ton ha^{-1}), and reproductive organ (3.21%, 0.259-ton ha^{-1}).

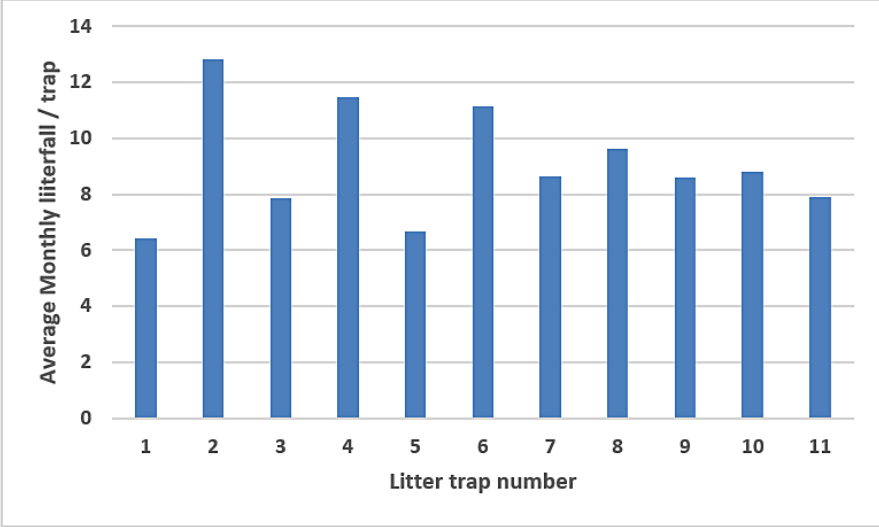

Fig. 3: Mean monthly litterfall recorded using litter traps in study area.

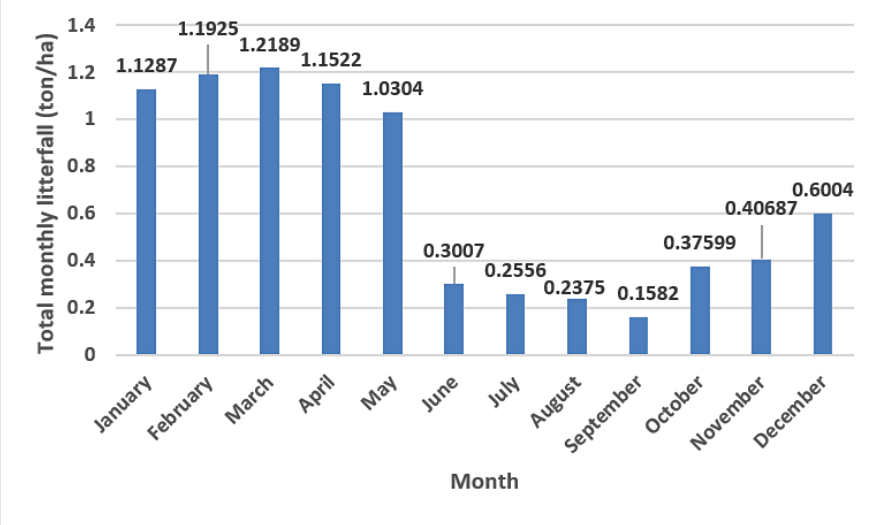

Fig. 4: Amount of total monthly litterfall (ton ha^{-1}) recorded from study area

The amount of four classes of fallen litter differed across the months. The fall of leaf, amorphous, wood and reproductive organs peaked on February (0.971-ton ha^{-1}), March (0.329-ton ha^{-1}), March (0.394-ton ha^{-1}) and September (0.091-ton ha^{-1}), correspondingly. Whereas, the lowest amount of litter classes recorded on October (0.033-ton ha^{-1}), February (0.026-ton ha^{-1}), October (0.069-ton ha^{-1}) and July (0.004-ton ha^{-1}), correspondingly (Fig. 5).

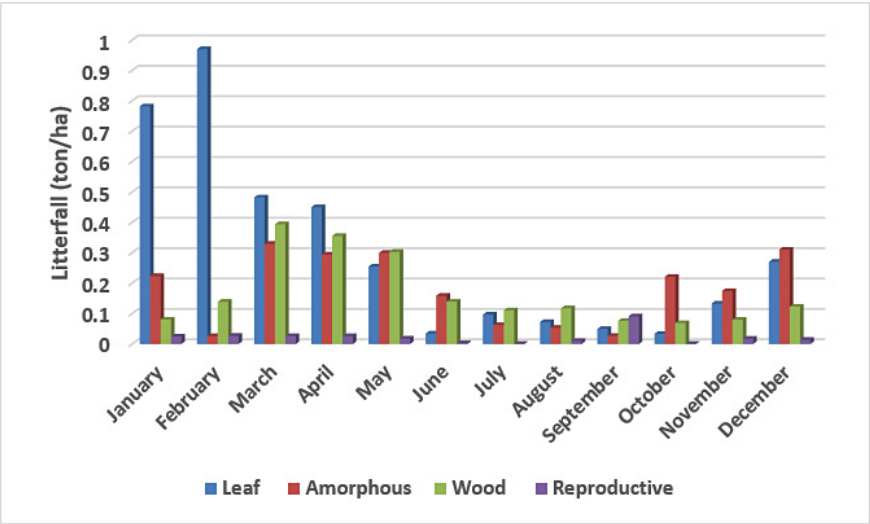

Fig. 5: Contribution of four litter components to total annual litterfall

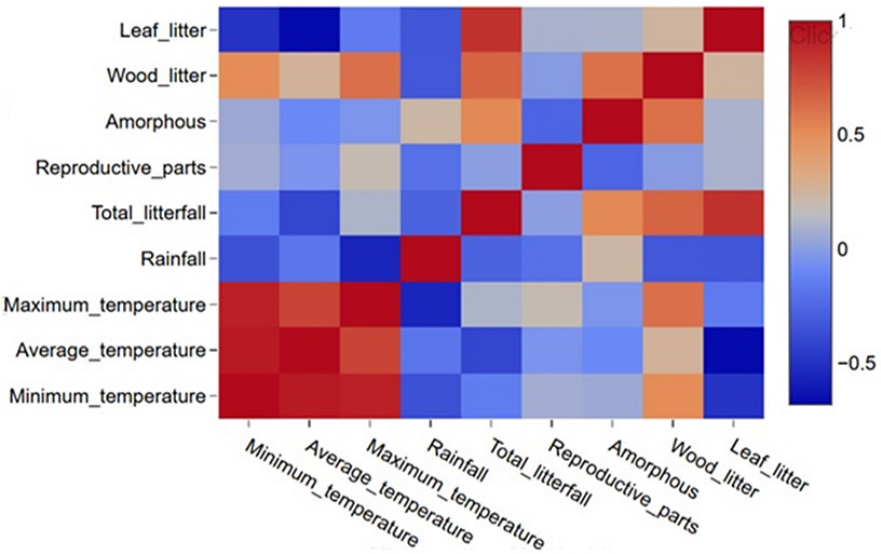

Fig. 6: Correlation heatmap showing relationships of climatic factors on total litterfall and components of litterfall.

Relationship with Monthly Litterfall and Climate Variables

The total litterfall did not show any significant correlation with the mean monthly temperature (*p* value is 0.128; r^2= 0.216) and total monthly rainfall (*p* = 0.817, r^2 = 0.0056). However, mean monthly leaf fall correlated with mean monthly temperature (*p* = 0.014; p <0.05 r^2 = 0.469). The mean monthly wood fall had

a relationship with mean minimum monthly temperature ($p = 0.032$, $p < 0.05$; $r2 = 0.382$) (Fig. 6).

Contribution of Woody Species to Leaf Litterfall

A sum of 23 woody plant species belonged to 20 genera and 17 families contributed to leaf litterfall. The Mimosaceae and Tiliaceae are the most speciose families (3 species each), followed by Burseraceae and Capparidaceae (2 species each), while 13 families had a single species each. *Grewia serrulata*, *Commiphora berryi* and *Anogeissus pendula* constituted 41.71% (1.514-ton ha^{-1}), 18.71% (0.679-ton ha^{-1}) and 8.67% (0.315-ton ha^{-1}) of leaf litter, respectively. These three species constituted 69.1% of annual leaf litterfall (Table 1).

Table 1. Plant name, family, physiognomy and leaf litterfall of trees recorded from study area. *D – Deciduous; EG – Evergreen

	Plant name	Family	Physiognomic group*	Leaf litterfall (ton ha^{-1} y^{-1})
1	*Grewia serrulata* DC.	Tiliaceae	D	1.514
2	*Commiphora berryi* (Arn.) Engl.	Burseraceae	D	0.679
3	*Anogeissus pendula* Edgew.	Combretaceae	D	0.315
4	*Dalbergia spinosa* Roxb.	Papilionaceae	D	0.214
5	*Gyrocarpus americanus* Jacq.	Hernandiaceae	D	0.187
6	*Commiphora caudata* (Wright &Arn.) Engl.	Burseraceae	D	0.159
7	*Crateva religiosa* G.Forst.	Capparidaceae	D	0.151
8	*Ziziphus xylopyrus* (Retz.) Willd.	Rhamnaceae	EG	0.109
9	*Mundulea sericea* (Wild.) A.Chev.	Papilionaceae	D	0.088
10	*Chloroxylon swietenia* DC.	Rutaceae	D	0.045
11	*Grewia rotundifolia* Juss.	Tiliaceae	D	0.033
12	*Ehretia laevis* Roxb.	Boraginaceae	EG	0.029
13	*Holoptelea integrifolia* Planch.	Ulmaceae	D	0.018
14	*Acacia planifrons* Wright &Arn	Mimosaceae	D	0.015
15	*Erythroxylum monogynum* Roxb.	Erythroxylaceae	EG	0.015
16	*Grewia flavescens* Juss.	Tiliaceae	D	0.013
17	*Capparis sepiaria* L.	Capparidaceae	EG	0.012
18	*Carissa spinarum* L.	Apocynaceae	EG	0.011
19	*Ochna serrulata* Walp.	Ochnaceae	D	0.009
20	*Albizia amara* (Roxb.) B.Boivin	Mimosaceae	D	0.007
21	*Reissantia indica* (Wiild.) N.Halle	Celastraceae	EG	0.005
22	*Dichrostachys cinerea* (L.) Wright &Arn.	Mimosaceae	D	0.002
23	*Borassus flabelifer* L.	Arecaceae	EG	0.001

Physiognomy and Leaf Litterfall

Of the two physiognomic groups, the deciduous species accounted for 95% (3.449-ton ha^{-1} y^{-1}) of total annual leaf litterfall, while the evergreen species constituted just 5% (0.181-ton ha^{-1} y^{-1}). Further, the present study area is dominated by deciduous species both in terms of density and species richness (17 species), while only six are evergreens, represented by a smaller number of individuals. Among families, Tiliaceae contributed the highest amount of annual leaf litterfall 52% (1.560-ton ha^{-1} y^{-1}), (Table 1).

Amorphous Litterfall

Overall, the amorphous class constituted 27.07% (2.182-ton ha^{-1} y^{-1}) annual total litterfall. The monthly amorphous litter generation ranged from a low of 0.026-ton ha^{-1} to a high of 0.329-ton ha^{-1}. The amor-

phous litterfall peaked during the month of March (0.329-ton ha^{-1}; 15.1%) and lowest during the month February (0.026-ton ha^{-1} y^{-1};1.2%), (Fig. 4).

Wood Litterfall

A total of 1.989-ton ha^{-1} y^{-1} (24.68%) wood litterfall recorded from the study area. The range of monthly wood litterfall differed between 0.069 and 0.394-ton ha^{-1} y^{-1}. The wood litterfall peaked in March (0.394-ton ha^{-1} y^{-1}; 19.81%), whilst, lowest quantity was recorded in October (0.069-ton ha^{-1} y^{-1}; 3.47%), (Fig. 4).

Litterfall of Reproductive Organs

Among four litter classes, reproductive parts (flower, fruit and seed) contributed the lowest amount to the total litterfall. The fall of reproductive organs was highest in September (0.091-ton ha^{-1} y^{-1}), while, the lowest amount was recorded during the month of July (0.004-ton ha^{-1} y^{-1}), (Fig. 4).

Discussion

Total annual litter production of the present study area (8.058-ton ha^{-1} y^{-1}) is comparable to other tropical dry forests, globally and nationally. One of the global reviews on dry forest biome by Murphy and Lugo (1986)[40] found annual litterfall of global dry forests as 3.00 to 10.00-ton ha^{-1} y^{-1}.

The total litter production of southern thorn forest is higher than that of tropical dry forest of southeastern Brazil (4.00 to 4.50-ton ha^{-1} y^{-1}, [41]) tropical forests of Costa Rica (5.30-ton ha^{-1} y^{-1},[42] 6.70 -ton ha^{-1} y^{-1}, [43]), and *Acacia albida* woodland of Zimbabwe (1.50-ton ha^{-1} y^{-1},[44]). While, the annual litterfall found in STF is lower than in Columbia's dry deciduous forest (8.50-11.00-ton ha^{-1} y^{-1}).[45]

Furthermore, the annual litter generation of the present study area is higher than in Northern dry tropical forest, India (4.88 to 6.71-ton ha^{-1} y^{-1},[17]), dry tropical forests of the Borromeo Wildlife Sanctuary, Chhattisgarh (4.75 to 7.56-ton ha^{-1} y^{-1},[46]); dry tropical forest of Barnowpara Sanctuary, Raipur Forest Division, Chhattisgarh (1.84 to 3.51-ton ha^{-1} y^{-1},[39]); tropical dry thorn forests of Rajasthan (6.00-ton ha^{-1} y^{-1},[47]); dry tropical deciduous forest in Vindhyan highland (4.76-ton ha^{-1} y^{-1},[48]), whereas the annual litterfall of STF is lower than in tropical dry evergreen forest of Villupuram in Tamil Nadu (13.27 and 13.51-ton ha^{-1} y^{-1}).[3]

Leaf Litterfall

In general, among different organs, the leaf constitutes the highest proportion of litterfall in forest ecosystems. In southern thorn forest the leaf litterfall recorded as 45.05%. Earlier, a huge number of studies including King and Campbell (1993)[49] from miombo ecosystem (70% leaf litter), Chun-jiang *et al.,* (2003)[5] from European dry forest (70-79%) and European continental forest (64-87%), Pragasan and Parthasarathy (2005)[3] from Indian tropical dry evergreen forests (67.9-71.4%); Bisht *et al.,* (2014)[8] from Northwest Himalayan subalpine forest (62-78%), Darro and Swamy (2020)[50] from Indian tropical dry forest (52.1-91.7%), and, Castellanos-Barliza *et al.,* (2022)[51] from Colombian tropical dry forest (>70%) found a higher proportion of leaf litterfall. Environmental factors, rainfall, temperature, elevation, altitude and latitude play major roles in litterfall production. In general, plants in STF tends to have smaller leaves with lesser leaf lifespan.

Relationship Among Litterfall and Climatic Variables

The relationship was statistically insignificant between total monthly litterfall and rainfall, and total monthly litterfall and mean monthly temperature. There are reports where no correlation was recorded among annual litterfall, rainfall and temperature in forests around the world. For instance, researchers did not find any relationship between litterfall with climatic factors in montane forest of Costa Rica,[52] Atlantic forest,[53] and, open restinga vegetation, Southern Brazil.[54] Additionally, in a mangrove forest of Malaysia, Hoque *et al.,* (2015)[55] found no relationship among litterfall, rainfall and temperature. Recently, Kassa *et al.,* (2022)[56] also did not find any link between litterfall and temperature (r^2 = 0.046, p = 0.145), and litterfall and rainfall (r^2= 0.010, p = 0.501) from Ethiopia. It has been found that leaves are not shed or flushed only in response to variation in rainfall.[57]

Conclusions

The annual litterfall production recorded in the present study is higher compared to Indian dry forests located across the states. Litterfall peaked during the month of March (beginning of dry season), it is explicit that the present study area followed a unimodal litterfall pattern. Among four litter classes, the leaves constituted a highest quantity followed by amorphous, wood

and reproductive organs. The total monthly litterfall showed no relationship with mean monthly temperature and total monthly rainfall. Further, the deciduous species produced large amount of litter compared to evergreens. *Grewia serrulata*, *Commiphora berryi*, and *Anogeissus pendula* together produced a significant amount of litter. This study focused on litterfall production of URF alone, further studies with large number of similar forest sites are needed to understand the actual annual litterfall production of southern thorn forest ecosystem, as the whole.

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Conflict of Interest
The authors declare no conflict of interest.

Data Availability Statement
The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Authors' Contribution
Muthulingam Udayakumar designed and conceptualized the study. Muthulingam Udayakumar and Johnson Evitex-Izayas conducted field surveys, collection and estimation of litterfall from study area. Johnson Evitex-Izayas prepared the first draft of the manuscript; Muthulingam Udayakumar corrected and revised it.

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