



Litter fall production pattern and leaf litter decomposition rate from three dominant tree species found in a subtropical semi ever green riparian forest of Dikhu river, north east India

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Abstract

Litter fall and leaf decomposition rates from a subtropical semi-evergreen riparian forest of Dikhu river, Nagaland, north east India were studied from three dominant tree species viz., *Melia azedarach* L., *Terminalia chebula* Retz. and *Duabanga grandiflora* (DC.) Walp. Found at upper, middle and lower zone of the river. Total annual litterfall range from 9.55 – 16.99 t ha⁻¹ yr⁻¹. Maximum litterfall occurred during winter season. Percentage contribution of leaf litter fall for *T. Chebula*, *M. azedarach* and *D. grandiflora* were 57.35 %, 25.05 % and 17.4 % respectively. Annual decomposition rate lies within the range 0.92 – 1.51k yr⁻¹. *D. grandiflora* decomposed at faster rate followed by *M. azedarach* and *T. chebula*. Value of the turnover rate (0.923) indicates that the riparian forest floor is characterized by a high replacement rate. There exist a significant relationship between abiotic variables with litterfall production and decomposition of leaf litter.

Keywords: climatic factor, decomposition, litter fall, restoration, riparian forest, secondary forest

Introduction

Litter fall is a critical pathway for nutrient transfer in riparian zones. The amount and quality of litter inputs to coupled terrestrial-aquatic ecosystems drive consumer community structure Tibbets and Molles 2005 and key ecosystem processes, such as decomposition and nutrient cycling Follstad Shah and Dahm 2008. The temporal dynamics of litter inputs (i.e., litterfall phenology) also play an important role in ecosystem functioning because they determine the temporal variation in the supply of organic matter and in light availability to aquatic systems Acuna *et al.* 2007. Tree species composition and the hydrologic regime of rivers are the main factors that contribute to explain litter quantity, quality and phenology in floodplain forests. First, some species produce more litter than other species (Meier *et al.* 2006)^[45], whereas flood type, duration and frequency determine organic matter production Gonzalez *et al.* 2010c. Second, species and functional groups may use and process nutrients differently in terms of uptake, resorption, storage and loss, ultimately affecting litter quality (N₂-fixing vs. non N₂-fixing species, Follstad Shah *et al.* 2010^[23]; ruderal vs. competitive species, Gonzalez *et al.* 2010b)^[28]. Moreover, litter-leaf nutrient concentrations also vary as a function of the flooding regime Gonzalez *et al.* 2010b)^[28]. Third, litterfall quantities display seasonal peaks in deciduous forests, typically in autumn in the temperate zone (Abelho 2001)^[1] but also in summer, in some cases (*Eucalyptus* spp., McIvor 2001^[43]; sclerophyllous vegetation, Stewart and Davies 1990)^[62]. Hydrology may play a role in litterfall timing by triggering the onset of the process under severe drought conditions Rood *et al.* 2000^[57]. Conversely, evergreen trees display an irregular litterfall pattern throughout the year. Unfortunately, both forest composition and hydrology have been altered in most rivers during recent decades. This alteration is not expected to be reverted in the near future but instead is expected to be aggravated by increasing global pressure

on the natural water resources (Tockner and Stanford, 2002)^[66]. The important of litter fall decomposition, as a stage of matter and energy balance in natural and some modified ecosystem, is confirmed by results of many studies. In forest ecosystems, decomposition is a critical process in nutrient cycling, which often determined their bio availability. Chemical composition of initial material, soil properties, including biological activity, species composition of plant communities and climatic conditions (especially temperature and humidity) are the most important factors affecting intensity of the process Preston *et al.* 2009. Quantitative proportions between annual production of litterfall and its decomposition rate in a longer time determine forms and stocks of soil organic matter. Tree species associated with riparian areas (like alder, poplar and willow) produce rich in nutrients, soft, susceptible to decomposition litterfall, which is almost completely decomposed within the first Year (Jaonczak 2009)^[35]. Many studies on litter fall production, decomposition and nutrient released by trees in upland forest have been carried out in different parts of the world. Few works on litter fall, decomposition and nutrient release in riparian forest elsewhere. Chauvet (1997)^[12] reported a case study of the leaf litter decomposition in the river Garonne (France). Bernal *et al.* (2003)^[10] studied leaf litter dynamics in a Mediterranean riparian forest. Ruan *et al.* (2005)^[58] examined the interactions between forest debris and litter decomposition in riparian and upland sites within a tropical wet forest. Gonzalaz (2012)^[26] studied seasonal patterns of litter fall in the floodplain forest of a large Mediterranean river. Jonczak *et al.* (2016)^[36] research on dynamics, structure and chemistry of litterfall in headwater riparian forest in the area of Middle Pomerania. Jonczak *et al.* (2015)^[37] studied decomposition of four tree species leaf litter in Headwater riparian forest in Northern Poland. Londe *et al.* (2016)^[39] examined at Das Velhas river, Southeast Brazil. Tonin *et al.*

(2017) [67] gave a scientific report on plant litter dynamics in the forest- stream interface. Till date no literatures are available about the studies of litterfall pattern and leaf litter decomposition rates of trees from riparian forest found in India. Hence, the present study has been taken up to evaluate the litterfall patterns and leaf litter decomposition rate of three dominant trees species found along the subtropical semi ever green riparian forest of Dikhu river, Nagaland, north east, India.

Materials and Methods

Site Description

The study was conducted in the three unprotected zones of riparian forest along Dikhu River, Nagaland, India. Nagaland has a total geographical area of 16,579 sq. km and extends between 25° 6' N to 27° 4' N Latitude and 93° 20' E to 95° 15' E Longitude. The Dikhu River is one of the most prominent rivers of Nagaland which passes mainly to Zunheboto, Tuensang, Longleng, Mokokchung and Mon districts of the state. The Dikhu River is one of the tributaries of Brahmaputra. It originates from Nuroto Hill area in Zunheboto district, flow further northward and leaves the hill near Naginimora and finally joined with the Brahmaputra River in Assam. The river has a total length of about 160 km. Three zones were selected for the present study and designated as 1. Upper zones (zone I), Lumami (Latitude 26° 12' 57.2" and Longitude 094° 29' 45.5") with an elevation of 960 m above 'm a.s.l.' in Zunheboto district 2. Middle zones (zone II), Chare (Latitude 26° 17' 58.00" and Longitude 094° 35' 26.8") with an elevation of 566 m above 'm a.s.l.' in Tuensang district and 3. Lower zones (zone III), Yachem (Latitude 26° 29' 51.5" and Longitude 094° 41' 40.00") with an elevation of 292.6 m above 'm a.s.l.' in Longleng district. Through observation the level of disturbance is much more in the lower zone compared to rest of other zones. The lower zone being located near the residential area and passing highway, it is much prone to anthropogenic activities like logging, rock quarrying, farming and plantation practices. However, upper and middle zone are not much affected as they are located in the interior portion of the riparian forest but logging is taking place in these zones.

Climatic Conditions of the Study Areas

The state enjoys subtropical to warm temperate monsoonic types of climate with an annual mean rainfall of approximately 2600 mm. Nagaland experiences four season viz., autumn, winter, spring and summer seasons. In zone I, the average mean temperature ranged from 9.6 (January) – 20.1 °C (June) and the average relative humidity from 78.8 (April) – 87.6% (June). Maximum and minimum rainfall recorded were 232.8 mm (June) and 21.2 mm (December). In zone II, the average mean temperature ranged from 13.6 (December) – 20.1 °C (August) and the relative humidity ranged from 73 (February) – 93.2 % (September). Maximum rainfall was recorded during July (207.2 mm) and minimum in January (0.02 mm). In zone III, the average mean temperature ranged from 14.8 (February) – 21.7 °C (August) and the average relative humidity ranged from 65.8 (February) – 86.5% (July). Maximum and minimum rainfall observed were 276.5 mm (April) and 20 mm (December) respectively. The study areas fall under subtropical semi-evergreen forest as classified by Champion and Seth (1968) [11] for the types of forest in Nagaland.

Litter Trapping

100 x 100 m permanent plots were established in each of the three zones. Four 20 x 20 m sub-plots were demarcated inside the 100 x 100 m plot. Five 1 x 1m litter traps were placed randomly in each of the sub plot. Thus, a total of 20 litter traps each having height of 1 m² area and 4 cm depth were used in each zone for the study of litter productions. Measurement was carried out for a period of one year continually from April 2016 to March 2017. The litter traps were fixed with fine mesh nylon sheet to provide for free drainage of water during rainfall. These traps were designed to allow litter to remain in the trap (containers) once trapped and prevents collected litter from mixing with that outside the trap by the action of wind or small animals. The traps were fixed about 15-20 cm above the ground level by pegs at the corners. The litter collected in each traps was removed at monthly intervals. Immediately after recovery, the litter bags were placed individually in the polyethylene bags and transported to the laboratory. Collected litterfall were divided into (a) fresh leaf litter (b) wood litter and (c) miscellaneous litter (Pandey and Singh 1981) [50]. The miscellaneous litter consisted of material other than the leaf, mosses etc. The twigs were included in the woody litter component. After, separation of litter the recovered residual material was carefully washed with water to remove soil particles, then oven dried at 80 °C to constant.

Litter Mass Loss and Decay Rate Co-Efficient

Turnover rate (k) of litter was calculated Olson (1963) [48]:

$$k = \frac{A}{A+F}$$

Where, A is the annual increment of litter (i.e., annual litterfall) and F is the mean monthly litter (annual average across months). The decomposition constant k and half-life T_{1/2} was calculated for each leaf using exponential decomposition method, the equation given by Olson (1963) [48]:

$$X_t = X_0 e^{-kt} \quad (1)$$

$$T_{1/2} = \ln(2)/k = 0.69315/k \quad (2)$$

Where, X_t is the remaining weight of the litter at time t, X₀ the initial weight of the litter placed in the litter bags, k the decomposition constant, and T_{1/2} the half-life time of the decomposition.

The time required for 50% and 95% mass loss was calculated as t₅₀=0.693/k and t₉₅=2.9957/k respectively.

The mean relative decomposition rate (RDR) was calculated by using the formula:

$$RDR (g g^{-1}day^{-1}) = \ln\left(\frac{w_1 - w_0}{t_1 - t_0}\right)$$

Where, w₀ is the mass of litter percent at time t₀, w₁ the mass of litter at time t₁, and t₁-t₀ is the sampling (days).

The mass loss over time was fitted to a simple negative exponential model (Olson 1963) [48]:

$$\ln\left(\frac{x_1}{x_0}\right) = -kt$$

Where, x_0 is the original mass of litter, x_1 the amount of litter remaining after time t , t the time (year) and k is the decomposition rate (yr^{-1}).

The rate of litter material was expressed as the percentage material remaining (% R) after a given time, calculated as:

$$\% R = w(t_x) / w(t_i) \times 100$$

Where, $w(t_x)$ is the dry weight (g) of the leaf material after time (t_x), and $w(t_i)$ is the initial weight of the leaf material (Peterson and Cummins 1974) [51].

Experimental Set Up for Leaf Litter Decomposition Study

Leaves of three dominant tree species viz., *Melia azedarach* L., *Terminalia chebula* Retz. and *Duabanga grandiflora* (DC.) Walp. were collected from Zone I, Zone II and Zone III located at upper, middle and lower stretch of the river. The collected leaves were brought to the laboratory and air dried. Nylon litter bags of 20 x 20 m size with 1 mm mesh were used to quantify decomposition rates. 50 gram of air dried leaf samples of each species were kept separately in each litter bag. A mesh size of 1 mm was sufficient to permit movement of micro arthropods which are the predominant litter feeders (Singh *et al.* 1990). Moisture content of the litter was determined by oven drying three sub-samples for each species at the time the bags were placed in the field. During March, 2016, 120 litter bags of each species were placed separately in the forest in such a manner that they were in contact with soil and care was taken not to disturb the floor vegetation as much as possible. Five litter bags of each species were recovered randomly at monthly interval between April, 2016 and March, 2017. Immediately after recovery, the litter bags were placed individually in the polyethylene bags and transported to the laboratory. The recovered residual material was carefully washed with distilled water to remove soil particles then oven dried at 60 °C to constant weight.

Results and Discussion

Litter Production Pattern

On the *M. azedarach* found at upper zone, the peak leaf litter fall occurred in November. The monthly leaf litter fall ranged from 49 gm^{-2} (July) - 148 gm^{-2} (November). Leaf shedding occurred throughout the year (Figure 1). Monthly woody litter fall ranged from 53 gm^{-2} (July) - 423 gm^{-2} (November) as shown in Figure 2. The monthly miscellaneous litter fall show peak value in November (144 gm^{-2}) minimum in July (24 gm^{-2}) as given in Figure 3.

On the *T. chebula* found at middle zone leaf litterfall showed a peak values in January (144 gm^{-2}) and December (138 gm^{-2}). The monthly leaf fall ranged from (October) 62.0 and 144 gm^{-2} (January). The woody fall among different months ranged from 56 gm^{-2} (August) - 295 gm^{-2} (December). Maximum woody litterfall occurred from November to February. The monthly miscellaneous litter ranged from 21 gm^{-2} (August) - 54 gm^{-2} (December) and the pattern was irregular. On the *D. grandiflora* found in lower zone, peak leaf litterfall occurred in between November to January with highest litterfall in December (141 gm^{-2}).

The peak monthly leaf fall ranged from 65 gm^{-2} (February) - 141 gm^{-2} (December). The peak woody litter fall exhibited in December (329 gm^{-2}). The litterfall of miscellaneous litter ranged from 15-52 gm^{-2} with a peak in January (42 gm^{-2}).

The seasonal patterns of leaf litter fall from three zones were found to be similar (Table 1). The highest values occurred during winter followed by spring, summer and autumn. The maximum seasonal leaf litterfall amongst the three species ranged from 105.66 - 134 gm^{-2} and the lowest from 87.0 - 94.0 gm^{-2} . The recorded value of daily leaf litterfall was obtained highest in winter (1.17 - 1.48 $\text{gm}^{-2} \text{d}^{-1}$) followed by spring (0.98 - 1.28 $\text{gm}^{-2} \text{d}^{-1}$), summer (1.02- 1.09 $\text{gm}^{-2} \text{d}^{-1}$) and autumn (0.96 - 1.07 $\text{gm}^{-2} \text{d}^{-1}$). The annual leaf litterfall was in the order: *M. azedarach* > *T. chebula* > *D. grandiflora*.

The seasonal pattern of woody litterfall was also similar amongst the three zones and followed the order autumn > summer > winter > spring (Table 2). The woody litterfall ranged from 265 - 375 gm^{-2} during (autumn), 86 - 260 gm^{-2} (summer), 62.33 - 182 gm^{-2} (winter) and 45.33 - 156 gm^{-2} (autumn). The woody litterfall on per day basis ranged from 2.51 - 4.16 $\text{gm}^{-2} \text{d}^{-1}$ (autumn), 0.95 - 2.88 $\text{gm}^{-2} \text{d}^{-1}$ (summer), 0.69 - 2.02 $\text{gm}^{-2} \text{d}^{-1}$ (winter) and 0.50 - 1.73 $\text{gm}^{-2} \text{d}^{-1}$ (spring). The seasonal pattern of the fall of miscellaneous litter was not similar in all the three species. In *M. azedarach*, the seasonal pattern of the miscellaneous litter followed the order: winter > spring > summer > autumn. Whereas, *T. chebula* it followed the pattern as: summer > spring > winter > autumn (Table 3).

The total annual litter fall production of the three tree species which lies within the values given by Arunachalam *et al.* (1998) for subtropical forest of Northeast India (10.7 - 19.5 $\text{t ha}^{-1} \text{yr}^{-1}$), Gonzalez (2012) [26] in the floodplain forest of large Mediterranean river (119 - 916 $\text{g m}^{-2} \text{yr}^{-1}$). The total litter fall value was higher than that found in other riparian forests in the Mediterranean and Iberian rivers (mean = 551 $\text{g m}^{-2} \text{yr}^{-1}$, by Gonzalez *et al.* 2010c) but had a low proportion of leaves (57 %) compared with the worldwide average of 70 % in deciduous riparian forests Meentemeyer *et al.* 1982. Total litter fall observed in the present secondary riparian forest (9.55 - 16.99 $\text{t ha}^{-1} \text{yr}^{-1}$) was greater than the rehabilitated forest at Das Velhas River southeast Brazil (8.4 $\text{Mg ha}^{-1} \text{yr}^{-1}$) reported by Londe *et al.* (2016) [39] and also the values for some primary riparian zones of semi-evergreen forests in western Sao Paulo state: 6.4 $\text{kg ha}^{-1} \text{yr}^{-1}$ at Assis farm, 8.8 $\text{kg ha}^{-1} \text{yr}^{-1}$ at Maarilia I station, 9.7 $\text{kg ha}^{-1} \text{yr}^{-1}$ at Taruma farm and 11.1 $\text{kg ha}^{-1} \text{yr}^{-1}$ at Marilia II station (Durigan *et al.* 1996). In addition, litter fall in our study was greater than in Cerrado/savanna (622 $\text{kg ha}^{-1} \text{yr}^{-1}$), cerrado/tall savanna (1046 $\text{kg ha}^{-1} \text{yr}^{-1}$) and transition forest (6566 $\text{kg ha}^{-1} \text{yr}^{-1}$) work out by Silva *et al.* (2007) [59]. Machado *et al.* (2008) [40] reported the value which lies within the range of our observed value in a secondary forest (10.17 $\text{Mg ha}^{-1} \text{yr}^{-1}$) and close to (8.98 $\text{kg ha}^{-1} \text{yr}^{-1}$) in a recovered forest both in the state of Rio de Janeiro, Brazil.

The low relative percentage of leaves in the litter fall at floodplain level might be explained by the ongoing process of canopy dieback (i.e., generalized presence of dead and/or leafless branches in the canopy, Rood *et al.* 2000) [57] that is observed similar in the present study. The canopy dieback is generally attributed to a lack of hydrogeomorphic dynamism, abrupt and long low-water periods during winter and spring (Gonzalez *et al.*, 2010a; 2012) [27,26]. The high amount of litter fall observed in our

study may be an indirect indicator of regular nutrient return to the soil or to the reserve of nutrients. Naiman *et al.* (2005) [47] argued that litter production in riparian zones is greater at early successional stage than in mature forests because the young plant community actively invests in growth. This is evidence from the population study of the present riparian forest which obtained reverse J-shaped gbh-density distribution of trees indicating that the present forest sites are disturbed and trees are in their successional stages of growth (Devlin and Singh 2018) [17]. In the present study, maximum leaf litter fall occurred during the winter season followed by summer and minimum during autumn which may be due to the physiological responds of plants to the dried period. The litter fall pattern shows significant seasonal variations. The seasonal pattern of litter fall may be attributed to difference in climatic factors, such as temperature and moisture and intrinsic genetic factors (Jamaludheen and Kumar, 1999). Several workers (Sundarapandian and Swamy 1999) have reported peaks litter fall mass in spring, summer and autumn in tropical climates. The peak litter fall in summer also may be associated with physiological leaf senescence and this consequence is similar to studies in evergreen broadleaved forests Yang *et al.* 2004 [72]. According to results of Rapp (1984) [54], the early senescence of plant organs, especially the leaf, is triggered by the dry period. Jenson (1974) [34] declared that the occurrence of a dry period increases the fall of litter. Within the genetic views, the phenology of the senescence leaf depends on environmental factors, including humidity and temperature. The great accumulation of litter in the end of the dry season is a response of the tree community to water stress, mainly through leaf fall to reduce water loss by transpiration (Martins and Rodrigues 1999). Moreover, the seasonality in litter fall is also influenced by photoperiod and variations in temperature and relative humidity (Durigan *et al.* 1996). Several researchers also declared that the largest amount of litter fall was in the dry season Devi and Yadava 2010.

Higher litter fall in the driest months has been previously reported for riparian forest of Cerrado Rezende *et al.* 2016, in the Mediterranean climate (Gasith 1999) and for tropical forest worldwide (Zhang *et al.* 2014). Temporal variation in litter fall suggests important repercussions for litter decomposition and nutrient recycling in streams and riparian forests as well as for aquatic and terrestrial food webs. This is due to the fact that leaf litter will not be supplied at the same rates over the year, leading to probable reduction in litter quantity and changes in litter quality (i.e., chemical composition of stored litter in pools or soils due to biological or physical process).

The annual total litter fall ranged from 9.55 to 16.99 t ha⁻¹yr⁻¹ among the three zones (Table 4). Leaf litter fall was recorded highest for the *M. azedarach* (433.3 gm⁻¹yr⁻¹) followed by the *T. chebula* (407.32 gm⁻¹yr⁻¹) and the *D. grandiflora* (386.66 gm⁻¹yr⁻¹). The annual woody litter followed the trend as: *M. azedarach* > *T. chebula* > *D. grandiflora*. The percentage contribution of total leaf litterfall were 25.50%, 57.35% and 17.14% for *M. azedarach*, *T. chebula* and *D. grandiflora* respectively (Table 5). The woody litterfall accounted were 13.08% (*D. grandiflora*), 48.2% (*T. chebula*), 38.70% (*M. azedarach*) and the miscellaneous litter accounted 11.02% (*D. grandiflora*), 48.48% (*T. chebula*) and 40.48% (*M. azedarach*). Percentage composition of litter was composed mainly by *D. grandiflora* and *T. chebula* compared to the other components except in *M. azedarach* the leaf litter percentage contribution was less. Similar trends in leaf litter have been reported in litter fall in the flood plain forest of a large Mediterranean river (Gonzalaz 2012) [26], headwater riparian forest of middle Pomerania (Jonczak *et al.* 2015) [37]. The woody component occupied the second out of the total annual contribution of litter fall with peak production during autumn followed by summer season. This may be due to the occurrence of strong winds that broke tree branches, as also observed by Martins and Rodrigues (1999) [42] in a semi-evergreen forest in Campinas, Sao Paulo.

Table 1: Seasonal patterns of leaf litter fall (gm⁻² ± SE) of three dominant tree species.

Leaf Litter (gm ⁻²)					
Species	Summer	Autumn	Winter	Spring	Annual Total
<i>M. azedarach</i>	92.33±13.33 (1.02)	94±24.66 (1.04)	134±9.07 (1.48)	113±13.01 (1.25)	433.33
<i>T. chebula</i>	98.66±11.14 (1.09)	97±12.12 (1.07)	105.66±22.65 (1.17)	106±19.69 (1.17)	407.32
<i>D. grandiflora</i>	92.33±4.33 (1.02)	87±5.19 (0.96)	118.33±20.59 (1.31)	89±20.59 (0.98)	386.66

*Values in parenthesis indicate g m⁻² d⁻¹

Table 2: Seasonal patterns of woody litterfall (gm⁻² ± SE) of three dominant tree species.

Woody Litter (gm ⁻²)					
Species	Summer	Autumn	Winter	Spring	Total
<i>M. azedarach</i>	260.33±95.76 (2.89)	375±29.26 (4.16)	182±100 (2.02)	156±43.51 (1.73)	973
<i>T. chebula</i>	111±32.34 (1.23)	226±35 (2.51)	62.33±17.32 (0.69)	108±29.14 (1.2)	507.33
<i>D. grandiflora</i>	86±2.88 (0.95)	26± 34.11 (2.94)	66±20.07 (0.73)	45.33±6.17 (0.50)	462.33

*Values in parenthesis indicate gm⁻² d⁻¹

Table 3: Seasonal patterns of miscellaneous litter fall (gm⁻² ± SE) of three dominant tree species.

Miscellaneous (gm ⁻²)					
Species	Summer	Autumn	Winter	Spring	Total
<i>M. azedarach</i>	64.33±17.36 (0.71)	48.33±14.49 (0.53)	112.66±15.70 (1.25)	66±10.96 (0.73)	291.3
<i>T. chebula</i>	40.33±6.64 (0.44)	26±2.51(0.28)	33.66±11.28 (0.37)	37.66±1.66 (0.41)	137.7
<i>D. grandiflora</i>	26±2 (0.28)	23.66±4.17 (0.26)	30.33±5.69 (0.33)	25.33±8.41 (0.28)	105.3

*Values in parenthesis indicate gm⁻² d⁻¹

Table 4: Total annual litterfall of three dominant tree species.

Tree species	Annual litterfall (gm ⁻² yr ⁻¹)	Annual litterfall (kg ha ⁻¹)	Annual litterfall (t ha ⁻¹ yr ⁻¹)
<i>M. azedarach</i>	1699.33	16993.3	16.9933
<i>T. chebula</i>	1052.32	10523.2	10.5232
<i>D. grandiflora</i>	954.96	9549.6	9.549

Table 5: Percentage contribution of leaf litter fall, woody litter and miscellaneous of three dominant tree species

Category	<i>M. azedarach</i>	<i>T. chebula</i>	<i>D. grandiflora</i>
Leaf litter	25.50%	57.35%	17.14%
Woody litter	38.70%	48.27%	13.08%
Miscellaneous	40.48%	48.48%	11.02%

Leaf Litter Weight Loss and Decomposition Pattern

The patterns of weight loss in the litter during decay is presented in Figure 4. Weight loss expressed as percentage of the original dry weight decrease exponential with time are shown in (Figure 5 to 7). The exponential equation for leaf litter in one year cycle for *M. azedarach*, *T. chebula* and *D. grandiflora* may be expressed as $Y = 102.7e^{-0.00x}$, $r^2 = 0.963$; $Y = 94.86e^{-0.00x}$, $r^2 = 0.973$ and $Y = 100.4e^{-0.00x}$, $r^2 = 0.977$ respectively. The progress of weight loss was uniform in all the three tree species. The percentage weight loss in the three species was observed to be peak during end of the decomposition experiment (spring) and minimum during summer (i.e., beginning of the experiment). To ascertain the influence of abiotic factors on weight loss, the monthly weight loss values were regressed against rainfall, temperature and relative humidity of respective periods (Table 6). It was found that the percent weight loss was significantly correlated with the above climatic factors except for *T. chebula* weight loss was found to be insignificant with temperature and for *M. azedarach*, weight loss was found to be insignificant with relative humidity. The litter fall shows negative correlation between temperatures, relative humidity and rainfall in all the three tree species (Table 7). However, *M. azedarach* show positive correlation with relative humidity. The relationship between the litter fall components to mean monthly temperature and humidity in *M. azedarach* was found to be insignificant whereas, it was found to be significant negatively with rainfall. In *T. chebula* litter fall components were found to be significant negatively with temperature, relative humidity and rainfall. In *D. grandiflora*, the litter fall components were found to be insignificant with temperature, relative humidity and rainfall. Whereas, in woody litter it was found to be negatively correlated with rainfall. The negative relationship between litter fall and precipitation for Amazon and Cerrado indicate that precipitation is a limiting factor for litter fall regulation, supporting our results and suggesting that litter fall helps reduce water stress during the driest periods Reich 1995 [55].

The turnover rate of litter indicated that 92% of the forest floor is replaced each year with a turnover time of 1.08 year thus the riparian forest floor is characterized by a high replacement rate. Similar to our observation was reported by Devi and Yadava (2010) [16] in sub-Tropical forest of Northeast India. The higher

turnover rate in the present study may be due to a high temperature, rainfall pattern and lower elevation, favoring microbial activity and decomposition. Garkoti *et al.* (1995) [24] stated a decline in turnover rate of litter with increase in elevation and decline in temperature.

The relationship between percentage of weight remaining of leaf litter and day elapsed show significant negative correlation ($p > 0.01$) for all the species. A high significant negative correlation exists between percentage of weight remaining of leaf litter and day elapsed for the three tree species was also observed by Bargali *et al.* (2015) [8]. Also, there exist a significant positive correlation between percentage weight loss with rainfall, temperature and relative humidity in all the three species except *M. azedarach* showed negative correlation with rainfall. Similar to our observation was also reported by Bargali *et al.* (2015) [8] in four tree species of deciduous forest at Barnawapara wildlife sanctuary in Raipur, Chhatisgarh, India.

The rate of decomposition (% day⁻¹) at monthly intervals of decomposition rate after 365 days were: in *M. azedarach*, it was 0.20 % day⁻¹, 0.23% day⁻¹ in *T. chebula* and 0.27 % day⁻¹ in *D. grandiflora*. The monthly relative decomposition rate (g g⁻¹ d⁻¹) ranged from 0.18 - 0.25, 0.16 - 0.52 and 0.21 - 0.45 for *M. azedarach*, *T. chebula* and *D. grandiflora* respectively. The relative decomposition rate was maximum during summer in and autumn season and minimum during winter and spring. The decay rate (k) was highest in *D. grandiflora* (1.51) followed by *M. azedarach* (1.27) and lowest in *T. chebula* (0.92). These values were lower than the value reported by Jonczak *et al.* (2015) [37] from the decomposition studies of four tree species leaf litter in headwater riparian forest in Northern Poland ($k = 2.77 \text{ yr}^{-1}$), $k = 2.13 \text{ yr}^{-1}$ (Wedderbaur and Carter 1999) [71] and much higher than that reported by Terre *et al.* (2001) [65] where they reported the values of $k = 0.686$ in mixed species and $k = 0.416$ in single species found in Cache river Arkansas and also $k = 0.841$ in mixed species and $k = 0.788$ in single species of Coosa what chie river, South Carolina luel Oak (SC dry). Near to our values of k in *T. chebula* was reported by Pereira *et al.* (1998) where $k = 0.908 \text{ yr}^{-1}$. When compared with upland forest the annual decay rate coefficient (k) of temperate hardwood species ranged from 0.08 to 0.47 (Melillo *et al.* 1982) [46], subtropical forest ranged from 0.66 to 1.09 (Alhamd *et al.* 2004) [3] and Mediterranean ecosystem ranged from 0.30 to 0.75 (Fioretto *et al.* 2005) [21]. Alvarez *et al.* (1992) [4] reported that in the tropical forest, k values were often greater than 1.0, indicating that leaf-litter turnover occurred in a year or less than a year. The varying k value may be due to the nutrient content of leaves (Songwe *et al.* 1995) [61] and season. The enhanced litter decomposition rates during wet season in autumn may be due to a combined effect of higher precipitation and relative humidity (Pandey *et al.* 2007) [49]. The large differences in k value could be attributed to decomposition population dynamics (Kumar and Deepu 1992) [38]. According to Dechaine *et al.* (2004) [13], there was a significant difference between mean annual decay rates in the

riparian and upland forest sites. Upland sites ($k = 1.47, r^2 = 0.92, p < 0.05$) had a significantly higher mean annual decay rate than riparian sites ($k = 0.94, r^2 = 0.95, p < 0.05$). This may be related to the chemical composition of the leaf litters (Swift *et al.* 1979)^[64] and the consequent differences in microbial activities (Vandervalk and Attiwill 1984)^[70]. It has been reported that soil animals, mainly macro invertebrates, are more abundant and diverse in floodplain woodlands than in adjacent uplands and responsible for at least 29 – 32 % loss of original litter weight in the whole season, although low oxygen in the soil reduces subterranean animal activity (Merritt and Lawson 1980). Microbes may also play an important role in breaking down in riparian areas. Decomposition by fungi is quite slow during dry conditions (Holand and Coleman 1987)^[31] but bacteria may burst after wetting (Polunin 1984)^[52] and result in an increased litter decomposition. Malanson (1993)^[41] concluded that the rate of litter decomposition generally decreases from the riparian zone towards the uplands. Since water availability is higher in the riparian than in the upland ecosystems, one could expect that it is a major governing factor for the decomposition process. Litter decomposition is also influenced by physicochemical properties of the plant parts (stem wood, leaves or root) and decomposer organisms present in the soil and environmental factors (Devi and Yadava 2007)^[15]. Greater decomposition during the autumn season is perhaps due to pronounced microbial

activity under favorable temperature and moisture conditions and accentuated leaching due to rainfall (Pandey and Singh 1982). Continuous decomposition of litter after the loss of soluble components is primarily a result of biotic processes. Differences in the rate of decomposition among species of different forest sites have been reported by several authors Bargali *et al.* 1993^[9]. Gupta and Singh (1977)^[30] have shown highest disappearance rate, 36 – 53% during rainy season, while a weight loss of 15 – 26% was recorded in winter season. The enhanced litter decomposition rates during summer and autumn in all the three zones showed a combined effect of higher rainfall, air temperature and relative humidity. In winter, however, decreased soil moisture and low air temperature were responsible for the slow rate of litter decomposition as a result of retarded activity of soil microorganisms (Tripathi and Singh 1992a)^[68, 69]. Consequently the values of half life (t_{50}) were 167, 267 and 274 days, (t_{95}) were 724, 860 and 1188 days for, *D. grandiflora*, *M. azedarach* and *T. chebula* respectively. The decay rate constant of different species indicated the difference in the process of decomposition. The rate of decomposition within 365 days was highest in *D. grandiflora* followed by *M. azedarach* and *T. chebula*. Although the study continued throughout the study period relatively highest weight loss occurred within 167 days for *D. grandiflora*, 267 days for *M. azedarach* and 274 days for *T. chebula*.

Table 6: Relationship between percent weight loss (WL) and rainfall (R, mm), temperature (T, °C) and relative humidity (RH, %).

X vs Y	Tree species	Intercept (a)	Slope (b)	Correlation coefficient (r)
R vs WL	<i>M. azedarach</i>	-61.028	2.486	-0.595*
	<i>T. chebula</i>	-97.856	3.245	0.663*
	<i>D. grandiflora</i>	26.516	0.171	0.842*
T vs WL	<i>M. azedarach</i>	22.52	2.633	0.785*
	<i>T. chebula</i>	6.189	3.173	0.494 ^{NS}
	<i>D. grandiflora</i>	-43.096	5.303	0.588*
RH vs WL	<i>M. azedarach</i>	32.69	0.365	0.441 ^{NS}
	<i>T. chebula</i>	-55.888	1.377	0.627*
	<i>D. grandiflora</i>	-75.238	1.639	0.603*

*Significant at $p < 0.05$, NS = not significant

Table 7: Relationship between litter components with temperature (T, °C), relative humidity (RH, %) and rainfall (R, mm).

Tree species	Litter components	Temperature (°C)			Relative humidity (%)			Rainfall (mm)		
		Intercept (a)	Slope (b)	Correlation coefficient (r)	Intercept (a)	Slope (b)	Correlation coefficient (r)	Intercept (a)	Slope (b)	Correlation coefficient (r)
<i>M. azedarach</i>	Leaf	130.572	-1.521	-0.311 ^{NS}	102.973	0.069	0.057 ^{NS}	128.41	-0.222	-0.634*
	Woody	270.007	-1.802	-0.078 ^{NS}	167.419	0.993	0.172 ^{NS}	314.19	-0.778	-0.470 ^{NS}
	Miscellaneous	89.721	-1.155	-0.211 ^{NS}	63.673	0.118	0.087 ^{NS}	91.261	-0.203	-0.521*
<i>T. chebula</i>	Leaf	221.557	-6.848	-0.608*	192.391	-1.060	-0.275 ^{NS}	118.12	-0.159	-0.445 ^{NS}
	Woody	661.599	-30.58	-0.907*	718.227	-6.923	-0.601*	203.55	-0.749	-0.698*
	Miscellaneous	101.707	-3.849	-0.767*	125.833	-1.070	-0.624*	40.533	-0.060	-0.375 ^{NS}
<i>D. grandiflora</i>	Leaf	151.324	-3.053	-0.286 ^{NS}	159.076	-0.805	-0.250 ^{NS}	111.13	-0.098	-0.406 ^{NS}
	Woody	396.732	-15.7	-0.393 ^{NS}	471.845	-4.592	-0.381 ^{NS}	187.75	-0.487	-0.540*
	Miscellaneous	45.364	-1.063	-0.297 ^{NS}	46.698	-0.263	-0.243 ^{NS}	29.706	-0.023	-0.282 ^{NS}

* Significant at $p < 0.05$, NS = not significant

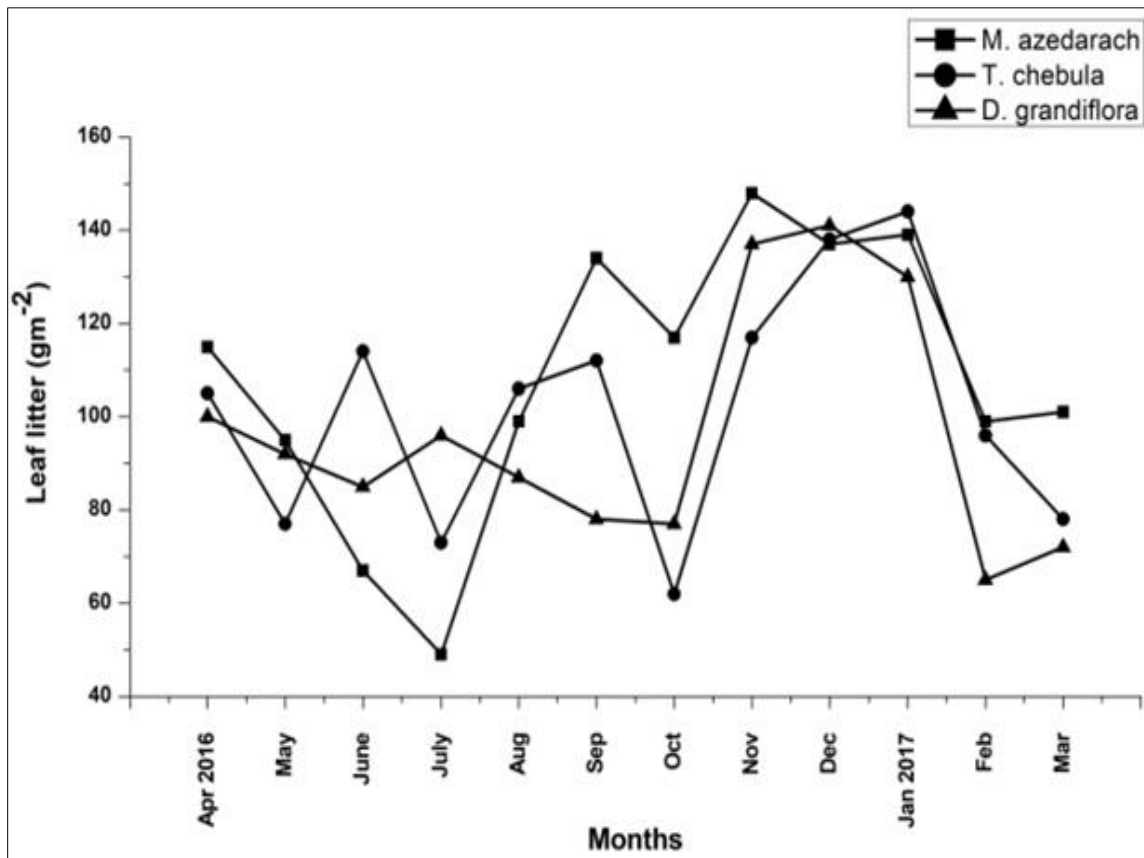


Fig 1: Monthly leaf litter fall (g m⁻²) of three dominant tree species.

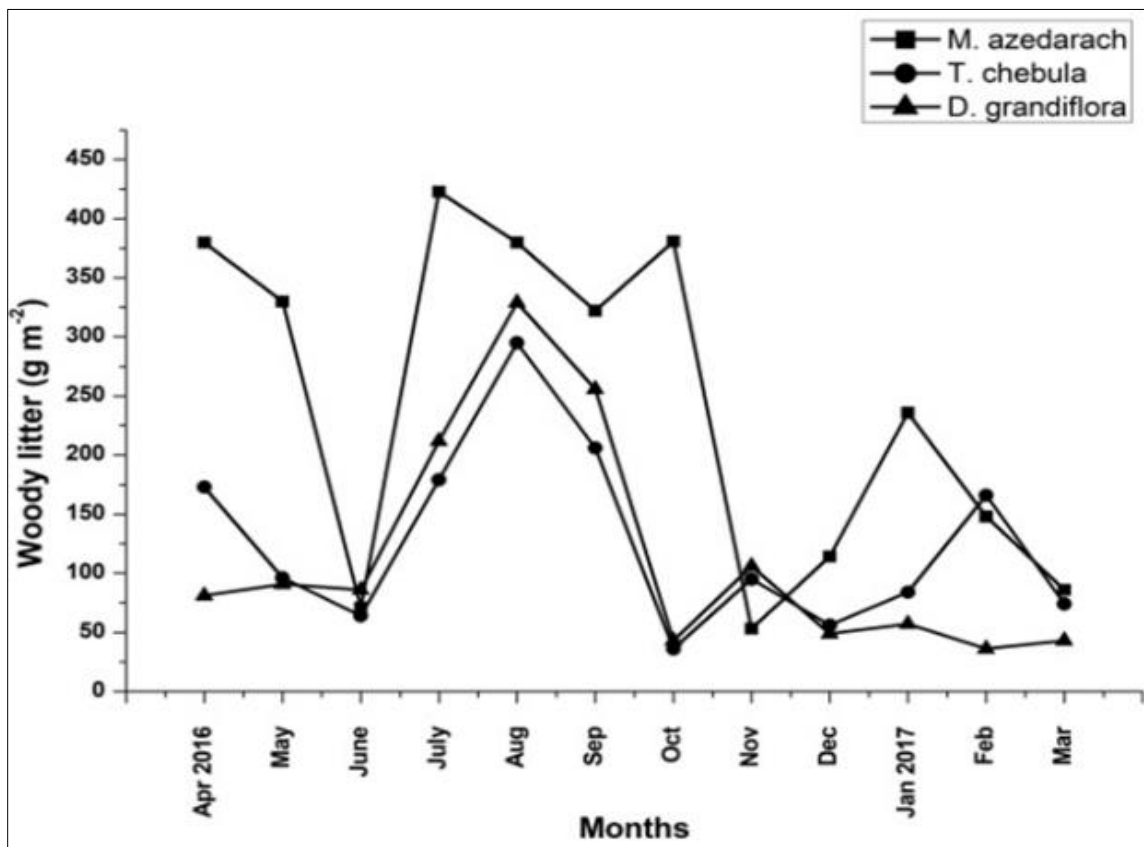


Fig 2: Monthly woody litter fall (gm⁻²) of three dominant tree species.

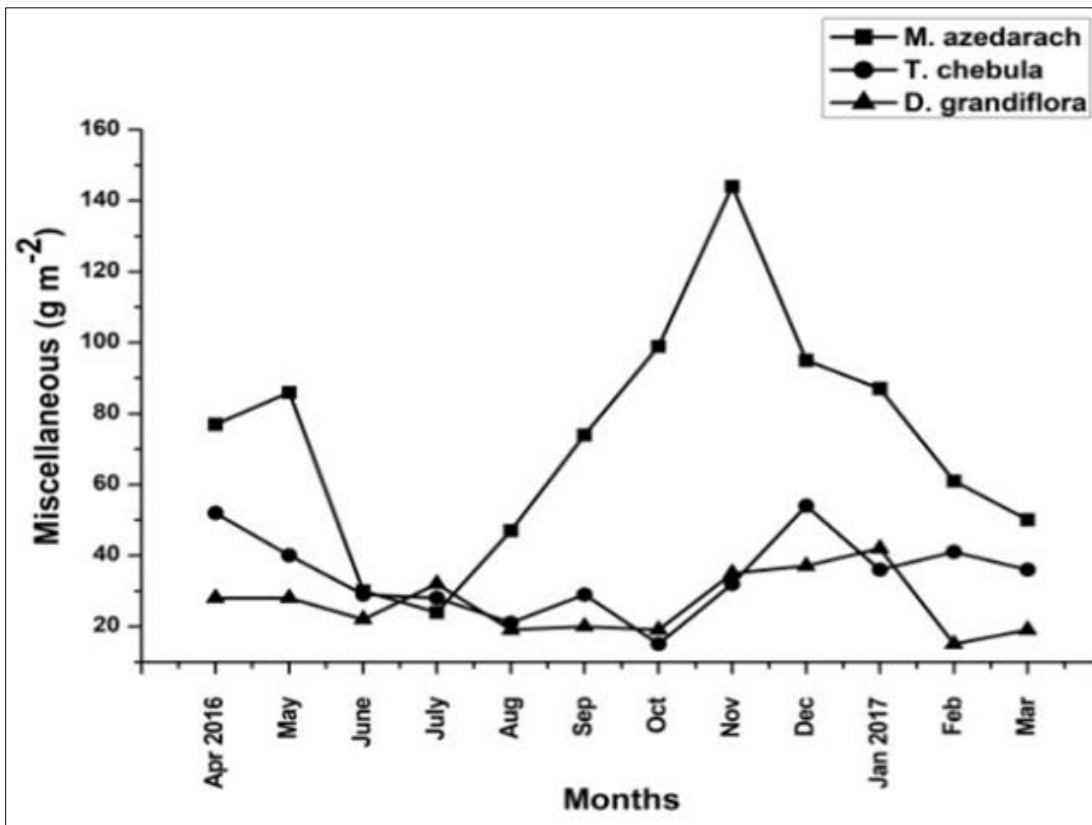


Fig 3: Monthly miscellaneous litter fall (g m^{-2}) of three dominant tree species.

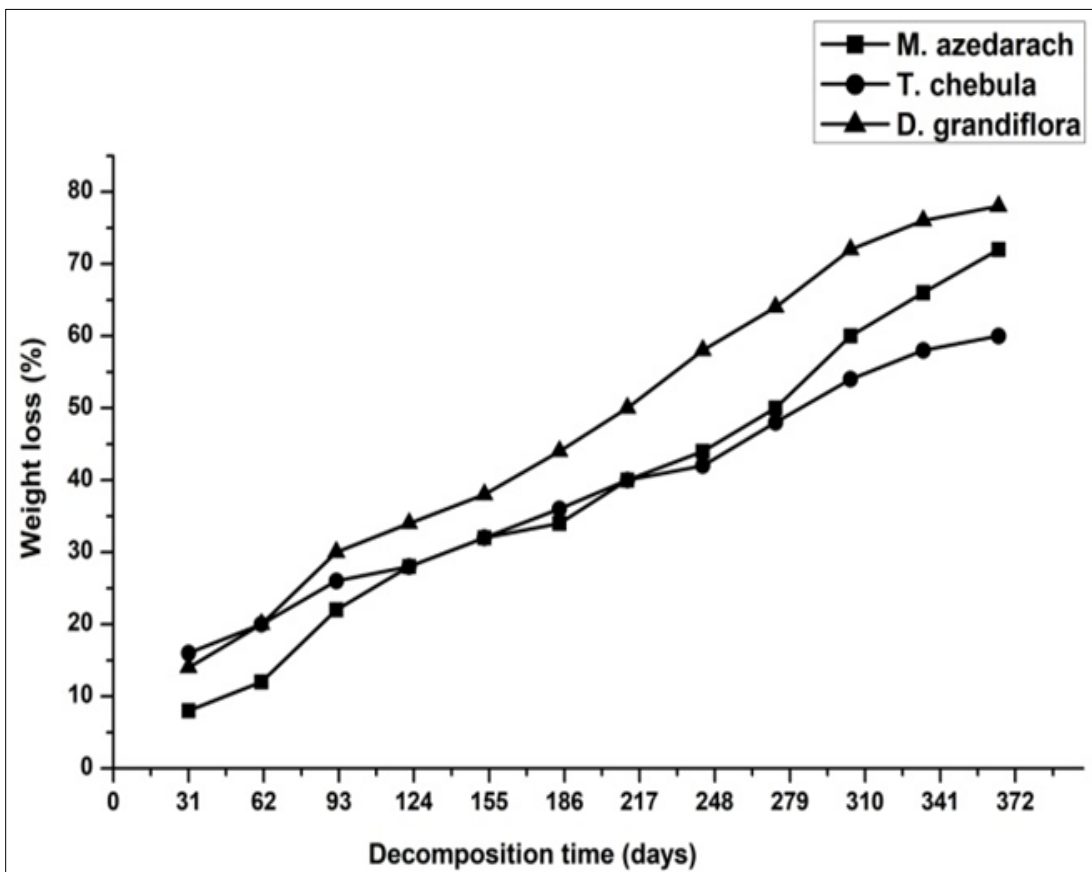


Fig 4: Weight loss (%) of three dominant tree species.

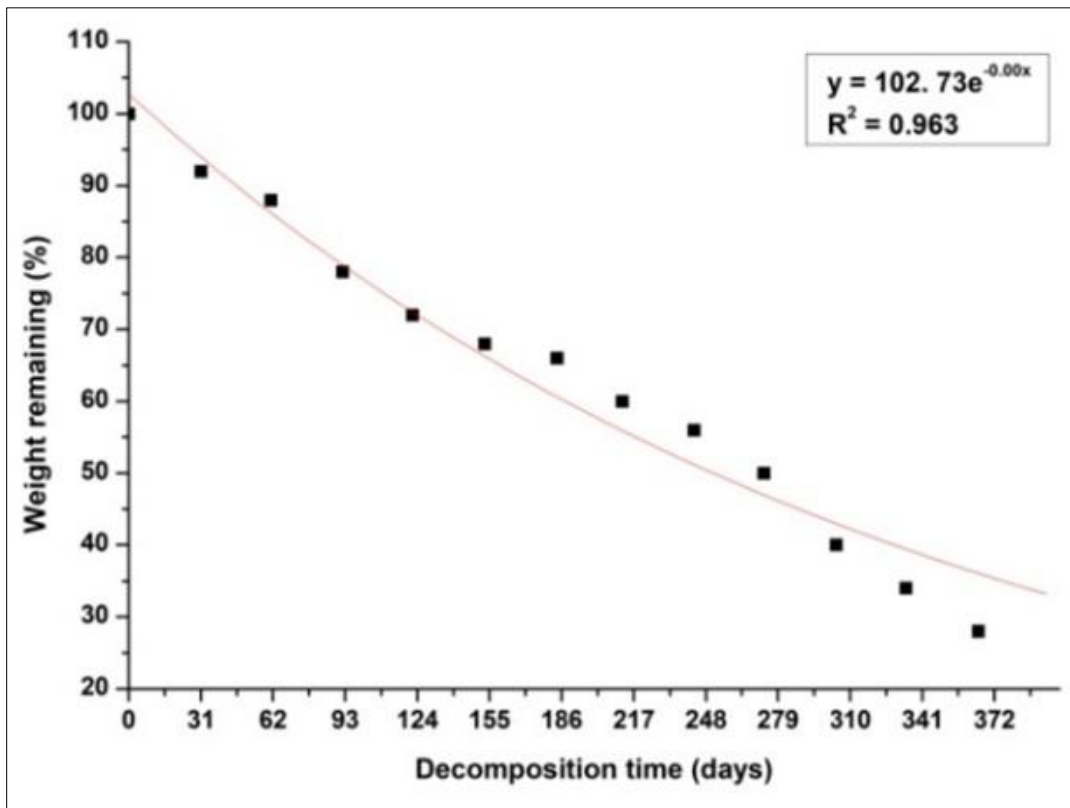


Fig 5: Remaining leaf litter mass (as % of the initial mass i.e., 100%) of *M. azedarach* during decomposition.

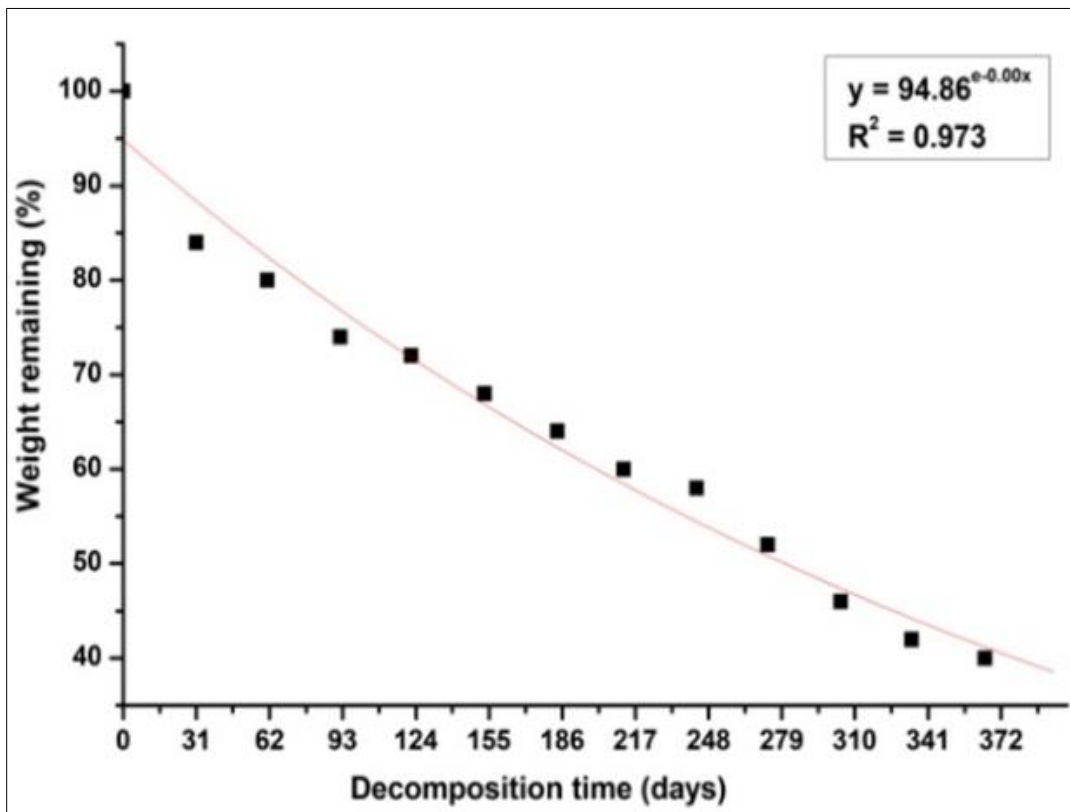


Fig 6: Remaining leaf litter mass (as % of the initial mass i.e., 100%) of *T. chebula* during decomposition.

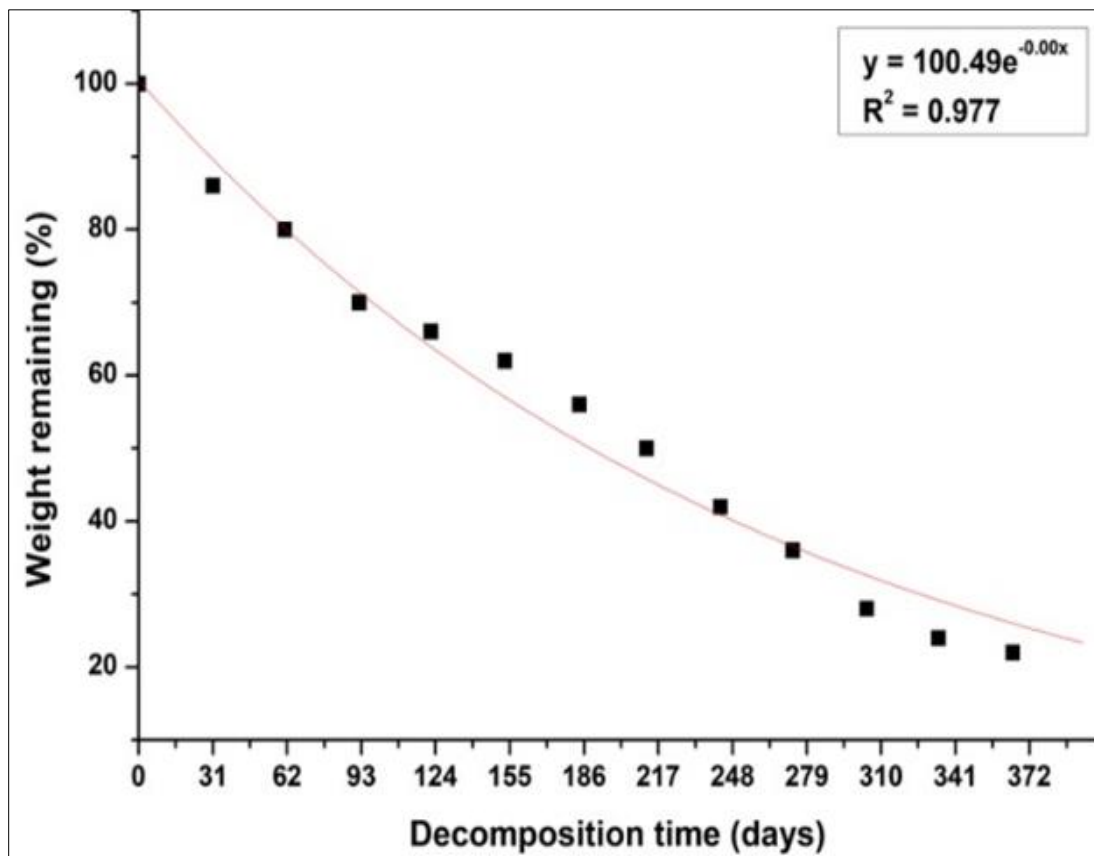


Fig 7: Remaining leaf litter mass (as % of the initial mass i.e., 100%) of *D. grandiflora* during decomposition.

Conclusions

From the present study it can be concluded that maximum total annual litter fall was contributed by *M. azedarach* followed by *T. chebula* and *D. grandiflora*. *D. grandiflora* decomposed at the faster rate followed by *M. azedarach* and *T. chebula*. It appears that the early successional stage of the tree in riparian forest contribute to more of litterfall. The studies provide information about the sustainability of the riparian forest in terms of productivity of litterfall and leaf litter decomposition. Hence, these tree species can be used in restoration purpose of the degraded patches of riparian forest for ecological maintenance. However, simultaneous analysis of initial chemical composition and nutrient released from leaf litter can reveal additional information about the nutrient dynamics of these three tree species.

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