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RESEARCH ARTICLE

# Litterfall and nutrient dynamics in an eighteen-year-old teak plantation

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## Abstract

A study on litterfall and nutrient dynamics in an 18-year-old teak (*Tectona grandis* Linn. f.) plantation was carried out at Forest College and Research Institute, Mettupalayam. The total litterfall for the entire one-year study period was found to be 11255 kg $ha^{-1}$, of which the leaf litter alone accounted the maximum share of 81.90 % to the total litterfall, followed by the twigs (6.50%), fruits (6.30 %) and flowers (5.30 %). A total of, 110.26 kg $ha^{-1}$ of nitrogen (N) was returned to the soil through the total litterfall. The total annual P return through litterfall was 17.50 kg $ha^{-1}$ of which leaves accounted for 75.00 % to the total return, followed by flowers (12.60 %), fruits (10.70 %) and twigs (5.10 %). The total annual potassium (K) return from various litter components was 35.03 kg $ha^{-1}$ of which, the major share was from leaf litter (79.80 %). The annual total return of calcium (Ca) from litterfall was 348.97 kg $ha^{-1}$ and magnesium (Mg) return was 78.46 kg $ha^{-1}$. This study concluded that leaf litter was the primary source of nutrients. Among the return of nutrients, Ca was returned to the soil in greater quantities, followed by N > Mg > K > P.

## Keywords

flowers; fruits; leaves; litterfall; nutrient return; teak

## Introduction

In any woodland ecosystem, litterfall plays an important role in nutrient cycling and involves various factors and processes within it. A considerable amount of nutrients is added to the soil through litterfall in the form of leaves, twigs, bark, flowers and fruits, which are then made available for reabsorption by the vegetation after decomposition (1). In a forest ecosystem, the return of nutrients through litterfall and precipitation are the main sources of inputs to the nutrient cycling process. Generally, nutrients in the vegetation pool are transferred to the soil pool relatively and rapidly either by throughfall, stemflow and litterfall of leaves and litter components by decomposition. Among them, a major part of the nutrients is added through litterfall to the forest floor. Litterfall and subsequent decomposition of litter represents an important set of energy flows and nutrient transfer. Studies of litterfall and nutrient return via litterfall are vital to the understanding of nutrient cycling processes in plantation ecosystems (2). Teak (*Tectona grandis* Linn. f.), the tree species of the present study is a large deciduous tree with a rounded crown with large leaves and tall cylindrical bole under favourable conditions. It rarely develops buttressed, though older trees have fluted stems. Its moderately hard wood is highly durable and fairly easy to work which makes it a carpenter's delight. Being a

deciduous tree, it sheds leaves and accumulates more litter in the forest floor.

The litter on the soil surface acts itself as an input-output system receiving input from the vegetation which in turn, decomposes and release nutrients to the soil and plants. The nature and amount of organic matter produced after decomposition of litterfall depends on the dominating tree species present and the site characteristics of the area, which regulate the physical and physico-chemical properties of soil like increase in soil pH, moisture holding capacity and organic matter content etc. Hence, the percentage return of nutrients varies according to taxa, habitat conditions and plant age (3). The amount and composition of litterfall can vary seasonally. For example, leaf litterfall is typically higher during certain months, contributing the most to the total annual litterfall. And, the different components of litterfall have varying nutrient contents. The decomposition of litterfall enriches the soil with essential nutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). This process supports the growth and health of the teak trees and other vegetation in the plantation and hence, litterfall is a vital component of the nutrient cycling process in teak plantations, helping to maintain soil fertility and support the ecosystem's overall health. In this context, the present study was conducted to have a thorough knowledge on litterfall and addition of nutrients to soil in an 18-years-old teak plantation at Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam, Coimbatore district, Tamil Nadu, India.

## Materials and Methods

The field experiment was conducted at the 'J' block of Forest College and Research Institute, Mettupalayam. The experimental field is situated at 11°19'N latitude and 77°56'E longitude at an altitude of 300 m above MSL. The climate is classified as semi-arid tropical, characterised by hot summers and cold winters. The dry season extends from early February to mid-July and wet season from mid-August to early November. The average annual rainfall is 900 mm, with the northeast monsoon contributes 80 % of the rainfall and balance 20 % of rainfall is from southwest monsoon and the summer showers. The average temperature range in this place is between 37 °C (maximum) and 25 °C (minimum). The soil of the experimental site belongs to Inceptisol (*Typic Ustropept*), sandy loam in texture (coarse sand: 41.30 %, fine sand: 28.90 %, silt: 11.80 %, clay: 17.70 %), red, non-calcareous, neutral in reaction, non-saline, low in available N (213.00 kg ha$^{-1}$) and organic carbon (0.48 %) and medium in available P (10.00 kg ha$^{-1}$) and K (167.00 kg ha$^{-1}$).

### *Litterfall collection and nutrient analysis*

An 18-years-old teak plantation with a 4 m x 2 m spacing was selected for the present study. The average height and girth at breast height of the teak plantation was 9.0 m and 55.0 cm, respectively. The litter was collected from the tree stands using litter traps of 1 m x 1 m size at monthly intervals. The collected litter was separated into leaves, twigs, flowers and fruits. Dry weight of each component was determined by drying to constant weight at 60 °C and the total monthly value for each plot was worked out on a unit area basis (kg ha$^{-1}$) with standard procedure.

The raw and decomposed litter samples were powdered in a Wiley mill, labelled and stored in butter paper covers for analysis. The total Nitrogen (N) in litter samples was analyzed using Micro-Kjeldahl Di Acid Extraction (4) and the total phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) were analyzed by Tri Acid Extraction methods (5).

## Results and Discussion

### *Litterfall collection*

The data on various components of litter fall *viz*., leaves, flowers, fruits and twigs of teak (*Tectona grandis*) were recorded at monthly intervals and are presented in Table 1. The contribution of leaf litter to the total litterfall was significant and it ranged from 93 kg ha$^{-1}$ during October to 1703 kg ha$^{-1}$ during February. The leaf litterfall during February and March was on par with each other and significantly higher than in the remaining months. Almost similar values of leaf fall could be observed during January and June months with respective values of 1014 and 1020 kg ha$^{-1}$ followed by May (938 kg ha$^{-1}$) and April (953 kg ha$^{-1}$). From the overall analysis of different litter components, the contribution of leaf litter was significantly higher from January to June (938 to 1703 kg ha$^{-1}$) than the second half of the year (93 to 566 kg ha$^{-1}$). This study clearly indicated that 80 per cent of leaf litterfall occurred during the dry months of the year (January to June) to the total annual leaf litter production (9216 kg ha$^{-1}$). This might be due to water stress that triggers the synthesis of abscissic acid in the foliage of plants, which in turn, could stimulate senescence of leaves and other parts. Hence, changes in the endogenous hormonal balance can be a possible explanation for higher litterfall during summer months.

The contribution of the flowers to the total litterfall was found to start from the month of September (39 kg ha$^{-1}$) and exhibited a progressive increase and reached the peak during December (147 kg ha$^{-1}$). A value of 133 kg ha$^{-1}$ of flower fall during January got reduced to 44 kg ha$^{-1}$ during February and 60 kg ha$^{-1}$ during March. However, no contribution by the flowers could be observed to the total litterfall from April to August months as there was no flowering observed during these months.

The fruit fall among the months ranged from 16 to 195 kg ha$^{-1}$. The month of March recorded the highest fruit fall of 195 kg ha$^{-1}$ which was significantly superior over the other months. The fruit fall from April to June rated to be the next best with a range of 106 to 144 kg ha$^{-1}$.The differences that could be observed during December, January and February months were only within narrow range with on par values of 16, 20 and 34 kg ha$^{-1}$, respectively. No fruit fall was observed from August to November.

There was no contribution through twigs from August to October as also during January and February months. A substantial contribution could be observed during the remaining months and the values differed significantly. The

**Table 1.** Monthly litterfall (kg ha$^{-1}$) in the teak plantation during the study period

| Month | Leaves | Flowers | Fruits | Twigs | Total |
|---|---|---|---|---|---|
| January | 1014 ± 134 | 133 ± 34 (135) | 20 ± 11 (22) | 0.0 (2.0) | 1167 ± 149 |
| February | 1703 ± 332 | 44 ± 12 (46) | 34 ± 24 (36) | 0.0 (2.0) | 1780 ± 342 |
| March | 1602 ± 389 | 60 ± 32 (62) | 195 ± 83 (197) | 183 ± 80 (185) | 2040 ± 495 |
| April | 953 ± 346 | 0.0 (2.0) | 144 ± 64 (146) | 133 ± 27 (135) | 1229 ± 364 |
| May | 938 ± 114 | 0.0 (2.0) | 106 ± 58 (108) | 128 ± 22 (130) | 1171 ± 124 |
| June | 1020 ± 135 | 0.0 (2.0) | 135 ± 57 (137) | 141 ± 20 (143) | 1297 ± 137 |
| July | 566 ± 240 | 0.0 (2.0) | 57 ± 14 (59) | 56 ± 13 (58) | 679 ± 246 |
| August | 417 ± 118 | 0.0 (2.0) | 0.0 (2.0) | 0.0 (2.0) | 417 ± 118 |
| September | 434 ± 112 | 39 ± 8 (41) | 0.0 (2.0) | 0.0 (2.0) | 474 ± 110 |
| October | 93 ± 28 | 63 ± 11 (65) | 0.0 (2.0) | 0.0 (2.0) | 156 ± 32 |
| November | 149 ± 31 | 121 ± 28 (123) | 0.0 (2.0) | 45 ± 12 (47) | 314 ± 51 |
| December | 328 ± 65 | 147 ± 48 (149) | 16 ± 7 (18) | 41 ± 9 (43) | 531 ± 85 |
| Total | 9216 ± 699 | 607 ± 75 (631) | 707 ± 187 (731) | 726 ± 115 (750) | 11255 ± 742 |
| SEd | 85.2 | 9.3 | 15.1 | 11.5 | 95.5 |
| CD (5%) | 169.0 | 18.0 | 30.0 | 29.0 | 189.0 |

± - Standard deviation

(Values in parenthesis are transformed values using X+2 transformation)

twig fall was the highest during March (183 kg ha$^{-1}$) and it excelled all the other months. The twig fall was 45 and 41 kg ha$^{-1}$ during November and December, respectively. April to June contributed to the range of 133 to 141 kg ha$^{-1}$ through twigs and was on par with each other.

With regard to the total litterfall, similar to leaf litter, January to June proved the superiority by recording 1167 to 2040 kg ha$^{-1}$ over the second half of the year (July to December) which recorded a range of 156 to 679 kg ha$^{-1}$. The highest total litter fall of 2040 kg ha$^{-1}$ was recorded during the month of March and was significantly superior over other months. The total litter fall during the month of February rated to be the next best by recording 1780 kg ha$^{-1}$. The lowest total litterfall of 156 kg ha$^{-1}$ was observed during October followed by November (314 kg ha$^{-1}$) which was on par with each other.

The total leaf fall in a year was 9216 kg ha$^{-1}$ followed by 726 kgha$^{-1}$ by twigs, 707 kg ha$^{-1}$ by fruits and 607 kg ha$^{-1}$ by the flowers. This has clearly indicated that leaf litter was the major contributor to the total litterfall followed by twigs, fruits and flowers to a smaller extent. In teak plantation, the total litterfall for a period of one year was found to be 11,255 kg ha$^{-1}$; of which the leaf litter alone accounted for 81.9 % to the total litterfall, followed by the twigs (6.5 %), fruits (6.3 %) and flowers (5.3 %). With regard to the percentage contribution of different litter components in the total litter, the results obtained in the present study was in agreement with those of previous studies (6, 7) that the leaf litter contributed the major portion. One research report also reported that the leaf litter contributed higher share to the total litter production in 30 years old teak plantation (8).

### *Nitrogen addition to soil through litterfall*

Among the various litter components, the N return was in the order of leaves > flowers > fruits > twigs. In total, 110.26 kg ha$^{-1}$ of N was returned to the soil through the total litterfall of 11255 kg ha$^{-1}$. The return through flowers and fruits were only seasonal and therefore contributed lesser quantities than the leaf litter.

Return of N through leaves ranged from 0.63 to 16.18 kg ha$^{-1}$ (Table 2). The highest return of N through leaves was recorded during March (16.18 kg ha$^{-1}$). The N return through leaves was higher during January to June and only little amount was added during July to December. Similar kind of results also reported that N return through leaf litter was the highest during summer months (January to June) than the rest of the year in a teak plantation (9).

N return through flowers varied from 0.92 to 3.67 kg ha$^{-1}$. The major share of N return through flowers was recorded during the months of January, November and December. The highest N return of 3.67 kg ha$^{-1}$ was recorded during December and was on par with January. The return of N through fruits ranged between 0.27 kg ha$^{-1}$ (December) and 2.86 kg ha$^{-1}$ (March). The contribution of N return was higher during March to June as compared to the rest of the study period.

The highest N return from twigs was recorded during March (2.60 kg ha$^{-1}$) followed by April (2.20 kg ha$^{-1}$), May (1.76 kg ha$^{-1}$) and June (1.58 kg ha$^{-1}$). There was a decreasing trend of N return from March to December. The monthly mean data clearly brought forth the fact that the highest N return through the litter components was recorded during March (23.15 kg ha$^{-1}$) and the least during October (2.13 kg ha$^{-1}$). The first half of the year (January to June) contributed more N return than the latter half.

**Table 2.** Nitrogen return to soil through different litter components in teak plantation (kg ha$^{-1}$)

| Month | Leaves | Flowers | Fruits | Twigs | Total |
|---|---|---|---|---|---|
| January | 9.43 ± 1.24 | 3.26 ± 0.84 (5.26) | 0.35 ± 0.18 (2.35) | 0.0 (2.0) | 13.04 ± 1.74 |
| February | 14.30 ± 2.79 | 0.94 ± 0.28 (2.94) | 0.55 ± 0.38 (2.55) | 0.0 (2.0) | 15.79 ± 3.01 |
| March | 16.18 ± 3.93 | 1.51 ± 0.80 (3.51) | 2.86 ± 1.22 (4.86) | 2.60 ± 1.14 (4.60) | 23.15 ± 5.78 |
| April | 6.57 ± 2.39 | 0.0 (2.0) | 2.44 ± 1.08 (4.44) | 2.20 ± 0.44 (4.20) | 11.22 ± 2.86 |
| May | 6.84 ± 0.83 | 0.0 (2.0) | 1.48 ± 0.81 (3.48) | 1.76 ± 0.31 (3.76) | 10.08 ± 1.20 |
| June | 7.04 ± 0.93 | 0.0 (2.0) | 2.19 ± 0.92 (4.19) | 1.58 ± 0.23 (3.58) | 10.81 ± 1.25 |
| July | 4.13 ± 1.75 | 0.0 (2.0) | 0.69 ± 0.17 (2.69) | 0.73 ± 0.17 (2.73) | 5.56 ± 1.83 |
| August | 2.80 ± 0.79 | 0.0 (2.0) | 0.0 (2.0) | 0.0 (2.0) | 2.80 ± 0.79 |
| September | 3.00 ± 0.77 | 0.92 ± 0.18 (3.92) | 0.0 (2.0) | 0.0 (2.0) | 3.91 ± 0.75 |
| October | 0.63 ± 0.19 | 1.50 ± 0.27 (3.50) | 0.0 (2.0) | 0.0 (2.0) | 2.13 ± 0.35 |
| November | 1.00 ± 0.21 | 3.14 ± 0.73 (5.14) | 0.0 (2.0) | 0.69 ± 0.19 (2.69) | 4.83 ± 0.82 |
| December | 2.46 ± 0.49 | 3.67 ± 1.20 (5.67) | 0.27 ± 0.12 (2.27) | 0.54 ± 0.12 (2.54) | 6.93 ± 1.29 |
| Total | 74.38 ± 5.91 | 14.94 ± 1.88 (38.94) | 10.83 ± 2.84 (34.83) | 10.11 ± 1.61 (34.11) | 110.26 ± 7.76 |
| SEd | 0.72 | 0.22 | 0.24 | 0.15 | 0.93 |
| CD (5%) | 1.42 | 0.44 | 0.47 | 0.30 | 1.87 |

± - Standard deviation

(Values in parenthesis are transformed values using X+2 transformation)

### *Phosphorus addition to soil through litterfall*

The month wise P return to the soil through various components of litter is presented in Table 3. The total monthly P return from litter components ranged between 0.37 kg ha$^{-1}$ (October) and 3.18 kg ha$^{-1}$ (March). The return of P through leaves accounted for 75.00 % to the total return through litterfall, followed by flowers (12.60 %), fruits (10.70 %) and twigs (5.10 %).

Among the litter components, P return through leaves was significantly higher, followed by flowers, fruits and twigs. The P return through leaves ranged from 0.14 kg ha$^{-1}$ (October) to 2.47 kg ha$^{-1}$ (February). A significant P contribution of 79 % was recorded during January to June over rest of the months.

In flowers, the P return ranged from 0.13 to 0.56 kg ha$^{-1}$.The highest return ofP (0.56 kg ha$^{-1}$) was recorded during December and significantly superior over the rest of the months. There was an increasing trend in P return from September to December months. The return of P from fruits ranged between 0.05 kg ha$^{-1}$ (December) and 0.66 kg ha$^{-1}$ (March). The return of P through fruits was the highest during

**Table 3.** Phosphorus return to soil through different litter components in teak plantation kg ha$^{-1}$)

| Month | Leaves | Flowers | Fruits | Twigs | Total |
|---|---|---|---|---|---|
| January | 1.42 ± 0.37 | 0.49 ± 0.13 (2.49) | 0.08 ± 0.04 (2.08) | 0.0 (2.0) | 1.99 ± 0.44 |
| February | 2.47 ± 0.96 | 0.16 ± 0.05 (2.16) | 0.11 ± 0.08 (2.11) | 0.0 (2.0) | 2.74 ± 1.00 |
| March | 2.08 ± 1.01 | 0.20 ± 0.11 (2.20) | 0.66 ± 0.28 (2.66) | 0.24 ± 0.10 (2.24) | 3.18 ± 1.29 |
| April | 1.48 ± 1.07 | 0.0 (2.0) | 0.47 ± 0.21 (2.47) | 0.19 ± 0.04 (2.19) | 2.14 ± 1.14 |
| May | 1.36 ± 0.33 | 0.0 (2.0) | 0.18 ± 0.10 (2.18) | 0.14 ± 0.02 (2.14) | 1.68 ± 0.33 |
| June | 1.07 ± 0.28 | 0.0 (2.0) | 0.24 ± 0.10 (2.24) | 0.14 ± 0.02 (2.14) | 1.45 ± 0.28 |
| July | 0.60 ± 0.50 | 0.0 (2.0) | 0.09 ± 0.02 (2.09) | 0.08 ± 0.02 (2.08) | 0.77 ± 0.51 |
| August | 0.62 ± 0.34 | 0.0 (2.0) | 0.0 (2.0) | 0.0 (2.0) | 0.62 ± 0.34 |
| September | 0.52 ± 0.27 | 0.13 ± 0.03 (2.13) | 0.0 (2.0) | 0.0 (2.0) | 0.65 ± 0.26 |
| October | 0.14 ± 0.08 | 0.23 ± 0.04 (2.23) | 0.0 (2.0) | 0.0 (2.0) | 0.37 ± 0.10 |
| November | 0.22 ± 0.09 | 0.45 ± 0.10 (2.45) | 0.0 (2.0) | 0.06 ± 0.02 (2.06) | 0.73 ± 0.16 |
| December | 0.53 ± 0.21 | 0.56 ± 0.18 (2.56) | 0.05 ± 0.02 (2.05) | 0.05 ± 0.01 (2.05) | 1.19 ± 0.30 |
| Total | 12.51 ± 1.77 | 2.21 ± 0.28 (26.21) | 1.88 ± 0.49 (25.88) | 0.90 ± 0.15 (24.90) | 17.50 ± 1.89 |
| SEd | 0.12 | 0.03 | 0.05 | 0.01 | 0.21 |
| CD (5%) | 0.25 | 0.06 | 0.09 | 0.03 | 0.42 |

± - Standard deviation (Values in parenthesis are transformed values using X+2 transformation)

March and performed better than the other months. There was an increasing trend in P return from January to March and thereafter a decline.

P return from twigs was the highest in March (0.24 kg ha$^{-1}$) and gradually declined until July. The total P return from litter components was the 3.18 kg ha$^{-1}$) during March which was significantly superior over the rest of the months. The similar kind of results were also reported from one study that the highest return of P was by leaf litter than the other litter components in a teak forest of western ghats (10).

### *Potassium addition to soil through litterfall*

The monthly return of K through various litter components is given in Table 4. Overall, the K return from litter components was higher from January to June than the remaining months. The highest K return through litter components was recorded during March (6.67 kg ha$^{-1}$) and the lowest during October (0.54 kg ha$^{-1}$). The total annual K return from various litter components was 35.03 kg ha$^{-1}$ of which, 79.8 % was contributed by leaves, 8.6 % by flowers, 8.3 % by fruits and 3.3 % by twigs.

The K return through leaves was ranged from 0.30 to 5.79 kg ha$^{-1}$. The highest return of K was registered during the month of February (5.79 kg ha$^{-1}$) followed by March (5.13 kg ha$^{-1}$). An overall analysis of K return revealed that the contribution of leaf litter for K input was higher from January to June (2.04 to 5.79 kg ha$^{-1}$) than the rest of the year.

In flowers, the K return was the highest during December (0.76 kg ha$^{-1}$) and the values decreased from January to March. The lowest K return was recorded during September (0.15 kg ha$^{-1}$) and K return gradually increased from September to December. In case of fruits, the K return was recorded only during January to July and December months and the values ranged between 0.11 kg ha$^{-1}$ during July and 1.01 kg ha$^{-1}$ during March.

The K return through fruits increased from January to March and then decreased until July. The K return through twigs ranged between 0.06 kg ha$^{-1}$ each during November and December to 0.31 kg ha$^{-1}$ during March. An overall analysis showed that, during summer months the contribution of K from twigs was higher than winter months.

### *Calcium addition to soil through litterfall*

The Ca return through various litter components to the soil from January to December are given in Table 5. The total Ca return from the litterfall ranged from 4.71 kg ha$^{-1}$ during October to 64.13 kg ha$^{-1}$ during February followed by March (54.32 kg ha$^{-1}$). The months from January to June contributed a major share of 78.10 % return as compared to the second half of the year. The annual return of Ca from litterfall was 348.97 kg ha$^{-1}$, of which leaf litter alone contributed 311.91 kg ha$^{-1}$ (89.4 %), flowers 15.05 kg ha$^{-1}$ (4.3%), twigs 11.51 kg ha$^{-1}$ (3.3%) and fruits 10.50 kg ha$^{-1}$ (3.0 %).

The return of Ca from leaves ranged from as low as 3.14 kg ha$^{-1}$ to as high as 62.65 kg ha$^{-1}$. The highest value was recorded during February and excelled over the rest of the months, which was followed by March (46.93 kg ha$^{-1}$) and January (38.43 kg ha$^{-1}$). The contribution of Ca during January to June was significantly superior over the rest of the year.

The Ca return from flowers ranged between 0.91 and 3.60 kg ha$^{-1}$. The highest Ca return was recorded during December and was on par with January. There was a progressive increase in the values from September to December months. For fruits, Ca return ranged between 0.24 kg ha$^{-1}$ during December and 2.81 kg ha$^{-1}$ during March. In twigs, the highest return of Ca (3.02 kg ha$^{-1}$) was recorded during March and showed superiority over the rest of the months followed by April (2.12 kg ha$^{-1}$) and June (2.10 kg ha$^{-1}$). A decreasing trend was observed from March to July. The lowest Ca return was recorded in December (0.65 kg ha$^{-1}$) similar to November (0.74 kg ha$^{-1}$) and July (0.83 kg ha$^{-1}$).

**Table 4.** Potassium return to soil through different litter components in teak plantation (kg ha$^{-1}$)

| Month | Leaves | Flowers | Fruits | Twigs | Total |
|---|---|---|---|---|---|
| January | 4.11 ± 0.54 | 0.71 ± 0.18 (2.71) | 0.18 ± 0.10 (2.18) | 0.0 (2.0) | 5.00 ± 0.42 |
| February | 5.79 ± 0.73 | 0.25 ± 0.07 (2.25) | 0.27 ± 0.19 (2.27) | 0.0 (2.0) | 6.31 ± 0.71 |
| March | 5.13 ± 0.68 | 0.22 ± 0.12 (2.22) | 1.01 ± 0.43 (3.01) | 0.31 ± 0.14 (2.31) | 6.67 ± 0.82 |
| April | 2.48 ± 0.90 | 0.0 (2.0) | 0.60 ± 0.27 (2.60) | 0.17 ± 0.03 (2.17) | 3.21 ± 0.48 |
| May | 2.25 ± 0.27 | 0.0 (2.0) | 0.28 ± 0.16 (2.28) | 0.20 ± 0.04 (2.20) | 2.74 ± 0.29 |
| June | 2.04 ± 0.27 | 0.0 (2.0) | 0.33 ± 0.14 (2.33) | 0.25 ± 0.04 (2.25) | 2.62 ± 0.28 |
| July | 1.36 ± 0.26 | 0.0 (2.0) | 0.11 ± 0.03 (2.11) | 0.09 ± 0.02 (2.09) | 1.56 ± 0.13 |
| August | 1.29 ± 0.37 | 0.0 (2.0) | 0.0 (2.0) | 0.0 (2.0) | 1.29 ± 0.21 |
| September | 1.30 ± 0.33 | 0.15 ± 0.03 (2.15) | 0.0 (2.0) | 0.0 (2.0) | 1.45 ± 0.33 |
| October | 0.30 ± 0.09 | 0.24 ± 0.04 (2.24) | 0.0 (2.0) | 0.0 (2.0) | 0.54 ± 0.10 |
| November | 0.56 ± 0.12 | 0.68 ± 0.16 (2.68) | 0.0 (2.0) | 0.06 ± 0.02 (2.06) | 1.30 ± 0.22 |
| December | 1.34 ± 0.28 | 0.76 ± 0.25 (2.76) | 0.13 ± 0.06 (2.13) | 0.06 ± 0.01 (2.06) | 2.29 ± 0.40 |
| Total | 27.95 ± 2.08 | 3.01 ± 0.38 (27.01) | 2.92 ± 0.74 (26.92) | 1.15 ± 0.19 (25.15) | 35.03 ± 2.33 |
| SEd | 0.25 | 0.04 | 0.07 | 0.02 | 0.36 |
| CD (5%) | 0.51 | 0.08 | 0.13 | 0.04 | 0.72 |

± - Standard deviation

(Values in parenthesis are transformed values using X+2 transformation)

**Table 5.** Calcium return to soil through different litter components in teak plantation (kg ha$^{-1}$)

| Month | Leaves | Flowers | Fruits | Twigs | Total |
|---|---|---|---|---|---|
| January | 38.43 ± 5.06 | 3.47 ± 0.89 (5.47) | 0.29 ± 0.15 (2.29) | 0.0 (2.0) | 42.19 ± 5.39 |
| February | 62.65 ± 12.21 | 0.97 ± 0.29 (2.97) | 0.50 ± 0.35 (2.50) | 0.0 (2.0) | 64.13 ± 12.40 |
| March | 46.93 ± 11.41 | 1.57 ± 0.83 (3.57) | 2.81 ± 1.19 (4.81) | 3.02 ± 1.32 (5.02) | 54.32 ± 13.02 |
| April | 33.53 ± 12.18 | 0.0 (2.0) | 1.91 ± 0.85 (3.91) | 2.12 ± 0.43 (4.12) | 37.56 ± 12.32 |
| May | 31.03 ± 3.77 | 0.0 (2.0) | 1.52 ± 0.83 (3.52) | 2.05 ± 0.36 (4.05) | 34.60 ± 3.75 |
| June | 35.39 ± 4.68 | 0.0 (2.0) | 2.32 ± 0.97 (4.32) | 2.10 ± 0.31 (4.10) | 39.81 ± 4.56 |
| July | 16.60 ± 7.04 | 0.0 (2.0) | 0.91 ± 0.23 (2.91) | 0.83 ± 0.19 (2.83) | 18.34 ± 7.12 |
| August | 13.35 ± 3.78 | 0.0 (2.0) | 0.0 (2.0) | 0.0 (2.0) | 13.35 ± 3.78 |
| September | 14.82 ± 3.80 | 0.91 ± 0.18 (2.91) | 0.0 (2.0) | 0.0 (2.0) | 15.73 ± 3.77 |
| October | 3.14 ± 0.93 | 1.57 ± 0.28 (3.57) | 0.0 (2.0) | 0.0 (2.0) | 4.71 ± 1.01 |
| November | 4.69 ± 0.99 | 2.96 ± 0.68 (4.96) | 0.0 (2.0) | 0.74 ± 0.20 (2.74) | 8.39 ± 1.40 |
| December | 11.36 ± 2.27 | 3.60 ± 1.17 (5.60) | 0.24 ± 0.10 (2.24) | 0.65 ± 0.14 (2.65) | 15.85 ± 2.69 |
| Total | 311.91 ± 22.65 | 15.05 ± 1.87 (39.05) | 10.50 ± 2.81 (34.50) | 11.51 ± 1.86 (35.51) | 348.97 ± 23.00 |
| SEd | 2.84 | 0.22 | 0.23 | 0.17 | 2.92 |
| CD (5%) | 5.62 | 0.44 | 0.45 | 0.34 | 5.85 |

± - Standard deviation

(Values in parenthesis are transformed values using X+2 transformation)

### *Magnesium addition to soil through litterfall*

The return of Mg to the soil through various litter components is presented in Table 6. In general, the return of nutrients by various components of litter was higher during January to June. This was coincided with higher litterfall during these months and contributed the highest share to the total annual litterfall. This is in accordance with the previous findings (11). Among the components of litter, the leaf litter alone contributed the major share for all the nutrients. The Mg return through leaves was the highest during March (12.81 kg ha$^{-1}$) and was significantly higher than the rest of the months. The first half of the year (January to June) recorded the highest return compared to the second half of the year (July to December). The lowest return of Mg (0.69 kg ha$^{-1}$) was recorded during October.

In flowers, an increasing trend was observed from September to December (0.28 kg ha$^{-1}$ to 0.98 kg ha$^{-1}$) and a decreasing trend from January to March (0.73 to 0.31 kg ha$^{-1}$). The highest return of 0.98 kg ha$^{-1}$ was recorded during December and was superior over the other months. The lowest

**Table 6.** Magnesium return to soil through different litter components in teak plantation (kg ha$^{-1}$)

| Month | Leaves | Flowers | Fruits | Twigs | Total |
|---|---|---|---|---|---|
| January | 6.08 ± 0.80 | 0.73 ± 0.19 (2.73) | 0.09 ± 0.05 (2.09) | 0.0 (2.0) | 6.91 ± 0.88 |
| February | 8.68 ± 1.69 | 0.32 ± 0.09 (2.32) | 0.15 ± 0.11 (2.15) | 0.0 (2.0) | 9.15 ± 1.76 |
| March | 12.81 ± 3.11 | 0.31 ± 0.16 (2.31) | 1.05 ± 0.45 (3.05) | 1.41 ± 0.62 (3.41) | 15.58 ±3.75 |
| April | 7.05 ± 2.56 | 0.0 (2.0) | 0.86 ± 0.38 (2.86) | 0.85 ± 0.17 (2.85) | 8.76 ± 2.65 |
| May | 7.50 ± 0.91 | 0.0 (2.0) | 0.51 ± 0.28 (2.51) | 0.95 ± 0.17 (2.95) | 8.95 ± 0.95 |
| June | 7.14 ± 0.94 | 0.0 (2.0) | 0.77 ± 0.32 (2.77) | 0.86 ± 0.12 (2.86) | 8.77 ± 0.93 |
| July | 5.38 ± 2.28 | 0.0 (2.0) | 0.32 ± 0.08 (2.32) | 0.36 ± 0.08 (2.36) | 6.06 ± 2.32 |
| August | 3.88 ± 1.10 | 0.0 (2.0) | 0.0 (2.0) | 0.0 (2.0) | 3.88 ± 1.10 |
| September | 3.21 ± 0.83 | 0.28 ± 0.06 (2.28) | 0.0 (2.0) | 0.0 (2.0) | 3.49 ± 0.82 |
| October | 0.69 ± 0.20 | 0.44 ± 0.08 (2.44) | 0.0 (2.0) | 0.0 (2.0) | 1.13 ± 0.23 |
| November | 1.32 ± 0.28 | 0.62 ± 0.14 (2.62) | 0.0 (2.0) | 0.31 ± 0.08 (2.31) | 2.25 ± 0.38 |
| December | 2.19 ± 0.44 | 0.98 ± 0.32 (2.98) | 0.09 ±0.04 (2.09) | 0.25 ± 0.05 (2.25) | 3.52 ± 0.57 |
| Total | 65.95 ± 5.48 | 3.67 ± 0.44 (27.67) | 3.85 ± 1.00 (27.85) | 4.98 ± 0.84 (28.98) | 78.46 ± 5.52 |
| SEd | 0.63 | 0.05 | 0.08 | 0.08 | 0.63 |
| CD (5%) | 1.25 | 0.11 | 0.17 | 0.16 | 1.25 |

± - Standard deviation (Values in parenthesis are transformed values using X+2 transformation)

Mg return was during September (0.28 kg $ha^{-1}$), which was on par with February (0.32 kg $ha^{-1}$) and March (0.31 kg $ha^{-1}$).

The Mg return through fruits ranged between 0.09 kg $ha^{-1}$ (January and December) and 1.05 kg $ha^{-1}$ (March). The highest return was registered during March and was excelled over the other months. The Mg return by twigs ranged between 0.25 kg $ha^{-1}$ (December) and 1.41 kg $ha^{-1}$ (March). The Mg return through various litter components ranged from 1.13 kg $ha^{-1}$ in October to 15.58 kg $ha^{-1}$ in March. The first half of the year contributed a major share of Mg return (74.0 %) than the rest of the period. The total annual Mg return through litterfall was 78.46 kg $ha^{-1}$ of which leaf litter contributed 65.95 kg $ha^{-1}$, twigs 4.98 kg $ha^{-1}$, fruits 3.85 kg $ha^{-1}$ and flowers 3.67 kg $ha^{-1}$.

Among the nutrients, Ca was returned in greater quantities (348.97 kg $ha^{-1}$) followed by N, Mg, K and P with respective values of 110.26, 78.46, 35.03 and 17.50 kg $ha^{-1}$. One research report also reported that among the various nutrients studied in teak litter, the return was higher with Ca and lower with P (11). A research report also reported that the return of nutrients by leaf litter was higher than the other litter components (12). Similar results were also reported by many workers (13-20).

## Conclusion

Among the various litter components, leaf litterfall occurred throughout the year with wide variations among different months. The peak leaffall occurred during the month of February and it was higher during January to June contributing 80.00 % to the total annual leaf fall. Flowers recorded the highest value during December, while in case of fruits and twigs it was during March. The litterfall was higher during January to June months contributing 77.00 % to the total annual litterfall.

Nitrogen return through leaf litter was well pronounced during January to June with a contribution of 81.20 % to the total annual return by leaf litter. The total N return by the litter components was significant during January to June which contributed 76.30% to the total annual return. Among the litter components, the contribution of leaf litter to the total annual return by the litter components was the highest (67.50 %). The contribution of leaf litter, flowers, fruits and twigs for P return were 71.60 %, 12.60 %, 10.70 % and 5.10 %, respectively to the total annual return. Leaf litter, flowers, fruits and twigs for K return was 79.80 %, 8.60 %, 8.30 % and 3.30 %, respectively to the total annual return. The Ca return through leaf litter was tremendous during January to June (79.50 %). The contribution of leaf litter, flowers, fruits and twigs for Ca return to the total annual return was 89.40 %, 4.30 %, 3.00 % and 3.30 % respectively. The contribution of leaf litter, flowers, fruits and twigs to Mg return were 84.10 %, 4.70 %, 4.90 % and 6.30 % respectively. From the present study its concluded that, litter fall in teak plantation and its further decomposition results in the improvement of soil health through nutrient cycling process which in turn enhances the crop productivity.

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## Authors' contributions

MS carried out the research and drafted the manuscript of the article. CFC and VS contributed to design and analysis of the data. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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