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Litter production and nutrient return in tropical dry deciduous teak forests of Satpura plateau in central India

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Abstract: Present study deals with quantification of litter production, seasonal variations in litter nutrient concentration and nutrient return to the forest floor as influenced by insect defoliation and past disturbances in some tropical dry deciduous teak (*Tectona grandis* Linn.) forests of Satpura plateau in Chhindwara forest division in Madhya Pradesh, India. On the basis of density-diameter relationship of trees, the forest stands were categorised as least disturbed (site-I) and highly disturbed (site-III). Site-I and III were the most and least disturbed sites, respectively. Site-II was heavily attacked by teak defoliator (*Hyblaea puera* Cram) and skeletonizer (*Eutectona machaeralis* Walker) that caused premature leaf fall in the month of September. The magnitude (kg ha^{-1}) of annual leaf fall followed the order: 4149 (II) > 2868 (I) > 2576 (III), while annual litter fall (kg ha^{-1}) followed the order: 4536 (II) > 3305 (I) > 3276 (III). The contribution of leaf litter in total litter fall ranged between 79% (III) – 91% (II) among the three sites. Site-II which is attacked by insect pest, showed higher contribution of leaf litter to the total litter fall. The peak leaf and litter fall periods were January and March for all the sites. Site-II showed bimodal leaf fall pattern due to heavy attack of insect pest. Concentration of Ca and N were higher than K, Mg and P in all fractions of litter irrespective of sites. Return of nutrients was in the order: Ca>N>K>Mg>P. The amount of nutrients returned due to insect pest attack on the trees have implications on the patterns of nutrient cycling and forest productivity.

Resumen: El presente estudio trata de la cuantificación de la producción de hojarasca, las variaciones estacionales en las concentraciones de nutrimentos en la hojarasca y la reincorporación de nutrientes al suelo del bosque, y la influencia que tiene sobre estos procesos la defoliación causada por insectos y los disturbios pasados en algunos bosques tropicales secos deciduos de teca (*Tectona grandis* Linn.) en la meseta de Satpura, en la división forestal Chhindwara en Madhya Pradesh, India. Con base en la relación densidad-diámetro de los árboles, los rodales de bosque fueron clasificados como el menos perturbado (sitio I) y muy perturbado (sitio III). Los sitios I y III fueron el más y el menor perturbado, respectivamente. El sitio II sufrió un fuerte ataque por el defoliador de la teca (*Hyblaea puera* Cram) y un esquelotonizador de esta especie (*Eutectona machaeralis* Walker), los cuales causaron la caída prematura de las hojas en el mes de septiembre. La magnitud (kg ha^{-1}) de la caída anual de hojas mostró el siguiente orden: 4149 (II) > 2868 (I) > 2576 (III), mientras que la caída anual de hojarasca (kg ha^{-1}) siguió el orden: 4536 (II) > 3305 (I) > 3276 (III). La contribución de la caída de hojas a la caída total de hojarasca fluctuó entre 79% (III) y 91% (II) entre los tres sitios. El sitio II, que fue el atacado por la plaga de insectos, mostró la mayor contribución de hojarasca foliar a la hojarasca total. Los picos de caída de hojas y hojarasca en todos los sitios tuvieron lugar en enero y marzo. El sitio II mostró un patrón bimodal de caída de hojas debido al fuerte ataque de la plaga de insectos. Las concentraciones de Ca y N fueron más altas que las de K, Mg y P en todas las fracciones de la hojarasca, independientemente del sitio. La reincorporación de nutrientes se presentó en el orden: Ca > N > K > Mg > P. La cantidad de nutrientes reincorporados debida al ataque de la plaga de insectos sobre los árboles tiene implicaciones en los patrones de reciclaje de nutrientes y la productividad del bosque.

Resumo: O estudo presente trata da quantificação da produção de folhada, variações estacionais na concentração de nutrientes da folhada e respectivo retorno ao solo da floresta em resultado do desfolhamento provocada por insectos e de distúrbios passados em algumas das florestas tropicais decíduas de teca (*Tectona grandis* Linn.) do planalto de Satpura na divisão florestal de Chindwara em Madhya Pradesh, Índia. Na base das relações densidade-diâmetro das árvores, as parcelas florestais foram categorizadas em menos disturbadas (estação I) e fortemente disturbadas (estação III). A estação-I e III foram as estações mais e menos disturbadas, respectivamente. A estação-II foi fortemente atacada por um desfolhante (*Hyblaea puera* Cram) e do esqueletizador (*Eutectona machaeralis* Walker) que causa a queda prematura das folhas no mês de Setembro. A grandeza (kg ha^{-1}) da queda anual de folhas seguiu a seguinte ordem: 4149 (II)>2668 (I)>2576 (III), enquanto a queda de folhada (kg ha^{-1}) foi de: 4536 (II)>3305 (I)>3276 (III). A contribuição da queda de folha no conjunto da folhada total oscilou entre os 79% (III) e os 91% (II) entre as três estações. A estação II que foi atacada pela praga de insectos, mostrou uma maior contribuição da queda de folhas para o conjunto da folhada. Os períodos de pico de queda de folhas e de folhada foram Janeiro e Março para todas as estações. A estação II evidenciou um padrão de queda de folha bimodal devido à praga intensa de insectos. As concentrações em Ca e N foram maiores do que em K, Mg e P em todas as fracções da folhada independentemente das estações. O retorno de nutrientes foi da seguinte ordem: Ca>N>K>Mg>P. O teor de nutrientes retornados devido ao ataque dos insectos nas árvores tem implicações nos padrões da reciclagem de nutrientes e na produtividade da floresta.

Key words: Disturbance, forest floor, litter fall, nutrient return, teak defoliator, teak.

Introduction

Disturbance is a prevalent factor in the tropical dry deciduous teak forests of Satpura plateau and has led to believe that long term ecosystem dynamics of these forests are consequences of patterns of periodic disruptions. Factors like climate, season, canopy architecture, timing of canopy gap formation and insect out breaks govern the dynamics of these forests in terms of their structure and function of these ecosystems (Sukumar *et al.* 1992). Litter fall is a major functional part of any ecosystem as it plays a vital role in regulating nutrient cycling and organic matter content. A substantial amount of organic matter returns to the forest floor through litter fall. Leaves constitute about 70-90% of the total litter fall in various forest ecosystems. It plays a significant role in transfer of energy to the major heterotrophs which inhabited in the forest soils. Litter fall, thus, exerts a great influence on physical, chemical and biological characteristics of soil. Studies have been carried out on litter fall dynamics and nutrients in various types of forest ecosystems with little information on the biotic disturbance factors on litter fall and nutrient dynamics in teak forests. This study was aimed at quantifying litter production, seasonal variations in litter nutrient concentration and nutrient return to the forest floor as influenced by insect defoliation and other disturbances in some tropical dry deciduous teak forests of Satpura plateau.

Materials and methods

The site

The site was located in Sellevani range and Khutama beat of Chhindwara forest division. The study area is situated between 20° 28′ to 22° 49′ N latitude and 78° 40′ to 79° 24′ E longitude at an elevation of 410 – 457 m above msl in Chhindwara district, Madhya Pradesh (India). As per the classification of Champion & Seth (1968), the forests of the area are categorised under group 5A/(1b) as 'tropical dry deciduous forest'. The study site is located on undulating rock of decan trap.

The climate of the area is monsoonal with seasonal rainfall. Total precipitation recorded during 1998 was 1247 mm with a maximum of 235 mm during September. The annual mean maximum and minimum temperatures were 29°C and 20°C, respectively, with an average mean temperature of 25°C. June (34°C) and December (17°C) were the hottest and coldest month of the year.

The soil is sandy loam and alluvium along the 'nalas'. Soil pH ranges between 7.95 (I) to 7.99 (II & III). Total N (kg ha^{-1}) was 71 (I) and 413 for site-II and III, however, total P (kg ha^{-1}) followed the order; 19.8 (I) >19.2 (III) >18.2) (II). The other important features of the site are given in Table 1.

Three sites have been selected as per the degree of past disturbances. The disturbances was quantified by estimating coefficient of determiners (R^2) between density diameter relationships (Robertson *et al.* 1978; Schmelz & Lindsey 1965). Besides, intensity of insect attack was considered as another factor of disturbance. Three communities were identified on these three sites on IVI basis. *Tectona grandis – Lagerstroemia parviflora – Ougeinia oojeinensis* (site – I); *T. grandis - Diospyros melanoxylon – Butea monosperma – Miliusa tomentosa* (site-II) and *T. grandis Chloroxylon swietenia – L. parviflora – D. melanoxylon* (site – III) were three communities at their respective sites. Most of the shrub layer composed of the saplings of *T. grandis, D. melanoxylon, L. parviflora,* and *B. monosperma* in all the sites. *Triumfetta rhombifolia, Indigofera trifoliata, Oplismenus burmanii, Cyperus kyllingia, Sida rhombifolia, Indigofera trifoliate, Sida rhombifolia, S. acuta* were common herb species of all the sites.

Table 1. Characteristics of site.

Site	Tree productivity (kg $ha^{-1}yr^{-1}$)	Total biomass (kg ha^{-1})	NEP (kg $ha^{-1}yr^{-1}$)	Annual decomposition constant
I	3462	96817	879.1	2.26
II	4969	88496	1259.4	3.33
III	2645	37122	814.25	2.57

Decomposition constant (k), the value of k is calculated using l/Xss, where l is litter production and Xss litter accumulation (Olson 1963); soil depth is 0-20 cm, NEP is bole production.

Hemidesmus indicus, Achyranthes aspera, Hyptis suaveolens, Ageratum conzoides, well known medicinal plants, were recorded from these sites. The density of trees (three ha^{-1}) was in the order: 1630 (III) >950 (II) >690 (I), however, T.B.C. (cm^2 ha^{-1}) values followed the order: 155487 > 148823 >95643. Highest mean basal area (cm^2 $tree^{-1}$) was recorded for site-I (225) followed by site-II (157) site-III (59).

Methods of study

Litter trap method was not applied in the present study because of heavy anthropogenic and other biotic disturbances. These disturbances cause dislocation and loss of traps from the experimental sites. Forest floor sampling (litter plot method) generally underestimate litter fall because of continuous decomposition process on the forest floor. However, it provides near to accurate estimate while studying in deciduous forest, especially, where the major leaf fall period is during winter season. The weight loss is very slow during winter as microbial activity is ceased due to low soil moisture and temperature. Moreover, time interval of litter sampling is one month, which does not allow much scope for underestimation of litter production due to decomposition. Five permanent litter plots of 5 x 5 m size were randomly placed at each site. All plots were initially cleared and swept of any deposited debris. Monthly estimation of litter fall was made by collecting the litter from these plots and then sorting into leaves and twigs. The miscellaneous litter, which consists of leaf litter of other than of main species and other unidentified organic matter, was included in leaf litter. Triplicate samples of leaf and twig litter fractions were collected and brought to the laboratory for determining oven dry weight (80°C) from each litter plot (Sharma & Pande 1989). Biomass studies were conducted during 1998 using 'Harvested method of stratified tree technique' (Peterken & Newbould 1966). Twenty quadrats (size, 10 x 10 m) for trees were laid randomly along the transect on each site. The diameter (dbh) and height of each tree was measured, individually. In order to have better distribution of sample trees over the population, the whole number of trees was divided into different diameter classes. Sample trees for each diameter class were selected as being nearest to the average of each class (Ovington *et al.* 1967). These sample trees were felled and roots were excavated for underground biomass. In all 23 trees of different species were harvested for determination of biomass. The whole tree biomass without foliage was recorded for different components viz. twigs, branches, bole and roots and presented on oven dry weight basis. The calculated biomass of each sample tree of each diameter class was divided by age. Age was determined by volume tables and further confirmed by counting growth rings. The density of that diameter class was multiplied by this value. This exercise was done for each species. Finally, all the values were summed. Annual litter production was measured and was added to get NPP tree. NEP was calculated as bole production of trees (Turner *et al.* 1995). NPP_{tree} is derived from bole, bark, twigs, course root and litter production, while NEP is bole production of trees.

Phosphorus was determined by ammonium – molybdate-blue method (Vogal 1961). K and Ca were determined flame photometerically and Mg by atomic absorption spectrophotometer. Nitrogen was determined by Kjeldhal method. All the results are expressed on oven dry weight basis.

The degree of past disturbances was estimated by calculating coefficient of determiner (R^2) between density diameter relationship (Robertson *et al.* 1978; Schmelz & Lindsey 1965). The magnitude of 'R^2' indicates the degree to which a stand approximates a balanced structure. The values of 'R^2' closer to '1' means the system is more balanced (Robertson *et al.* 1978). Examination of R^2 values for all tree species, the degree of disturbance followed the order: 0.58 (III) <0.18 (II) <0.05 (I). These R^2 values are non-significant for both negative power and negative exponential function. However, site-III is the least disturbed and site-I is the most disturbed site.

Results and discussion

Leaf and litter fall patterns

Fig. 1. shows monthly leaf and litter fall patterns for all the three sites. Site-I and III showed unimodal pattern of leaf fall. The peak periods of leaf fall were January-February (85.38%) for site-I and January-March (80.38%) for site-III. Two peak periods of leaf fall were recorded for site-II. First peak was observed during February-March (57%) and second was during September (32%). The higher leaf fall on site-II was also due to the addition of leaf litter by unusual second peak (September). It contributed 1333 kg ha^{-1} to the total leaf fall (4149 kg ha^{-1}), which is 32% of the total leaf fall in the site. The emergence of second peak was the result of premature leaf fall caused by heavy attack of teak defoliator (*Hyblaea Puera* Cram) and followed by skeletonizer (*Eutectona machaeralis* Walker). The period of attack of defoliator was noticed during the months of June-July while the attack of skeletonizer was noticed during July-September. Consequently, new foliage emerged during October-November to compensate the heavy loss of canopy foliage. Total tree productiv-

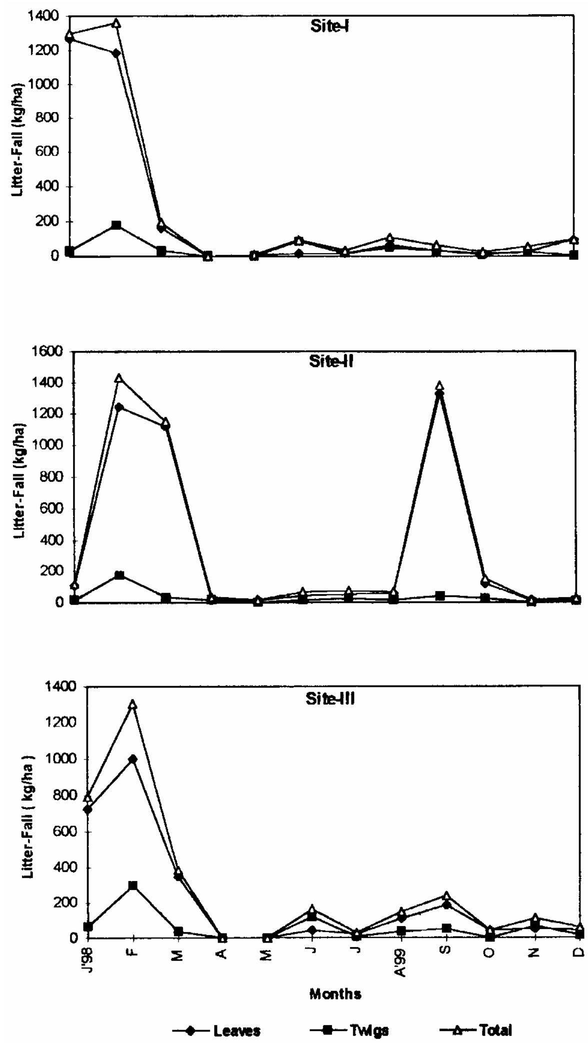

Fig. 1. Monthly variations in litter production in three teak forests at Chhindwara (Madhya Pradesh) during August, 1998 to January, 1999.

ity and bole production (NEP) for site-II was 4969 kg ha^{-1} yr^{-1} and 1259 kg ha^{-1} yr^{-1}, respectively. The unusual peak for the month of September was 1333 kg ha^{-1}. It is interesting to note that unusual leaf fall was about 26.8% of net primary productivity of trees and 105% of bole production (net ecosystem productivity, NEP) (Table 1). It seems that 26.8% of the energy was again diverted for the formation of compensatory foliage mass instead of other plant parts viz., bole, reproductive parts, twigs etc. in site II. This view is further supported by the study of Nair *et al.* (1986), where they recorded 44% timber increment loss by the attack of teak defoliator and skeletonizer in 4 to 9 years old plantations. Further, the attack of teak leaf defoliator and skeletonizer not only disturbed the phenology of teak but also caused great reduction in timber increment and other plant parts.

The magnitude of annual leaf fall (kg ha^{-1}) followed the order: 4149 (II) >2868 (I) 2575 (III). The contribution of leaf litter (%) to the total litter fall was in the order: 91 (II) >87 (I) >79 (III). The order of importance for annual twig fall (kg ha^{-1}) was 699 (III) > 437 (I) >385 (II). It contributed 13.2%, 8.5% and 21.3% to the annual litter fall for site-I, II and III, respectively. The annual litter fall (kg ha^{-1}) followed the order: 4536 (II) >3305 (I) >3276 (III). Maximum litter fall occurred during January-February (80%) at site-II and January-March (76%) at site-III. The monthly total litter and leaf fall followed more or less similar pattern. The relatively higher leaf-fall at site-I than of the site-III may be attributed to the higher disturbances and maturity of stand. Higher litter fall in mature plantations is also reported by Pande (1985). Unimodal pattern of leaf fall in *T. grandis* plantation during February-March was reported by Shanmughavel & Francis (1998) at Talavadi (India). Site-III showed lower litter fall than of the other sites despite higher tree density. It may be the reflection of the lower TBC (95643 cm^2 ha^{-1}) as compared to site-I (155487 cm^2 ha^{-1}) and site-II (148823 cm^2 ha^{-1}). The litter (%) of the total biomass was in the order: 8.82 (III) >5.12 (II) >3.41 (I). The higher percent of the litter fall of the total biomass in the site-III is probably due to the younger age of the stand (site-III) as indicated by lower MBA (59 cm^2 tree^{-1}) (mean basal area) as compared to site-I (225 cm^2 tree^{-1}) and site-II (157 cm^2 tree^{-1}). Total basal cover corresponds to the tree productivity except site-II, which registered higher production rate. It is due to unusual higher leaf-fall influenced by the insect pest attack.

The lower leaf: twig ratio at site-III (3.86) than that of the site-I (6.57), is indicative of the fact that self pruning of branches taken place at site-III, which is also at the younger age compared to the other sites (Table 1).

Litter nutrient concentration

Mean annual status of nutrients in leaf litter along with their standard error are given in Table 2. Invariably, leaf litter showed higher concentration of nutrients than that of twig litter. Generally, Ca and N were higher than of K, Mg and P in all fractions of litter, irrespective of sites. Higher concentration of Ca and N in the leaf litter of tropical trees have also been reported (Sharma & Pande 1989; Vitousek 1984). Site-II showed higher values of nutrient concentrations and their marginal variations as compared to other sites. Higher mean leaf litter nutrient concentration of site-II, is attributed to the irregular leaf fall pattern due to the heavy insect pest attack.

Considerable monthly variations in the concentration of leaf litter nutrients were recorded in all the sites. The low nutrient concentrations in twig litter may be related to non-photosynthetic: photosynthetic tissue ratio and tissue longevity. Low nutrient concentration in perennial tissues have also been reported by many workers (Attiwill *et al.* 1978; Gosz *et al.* 1972; Sharma & Pande 1989).

Table 2. Annual percent mean nutrient concentration ± SE is leaf (L) and twig (T) litter at different sites.

Site/ Nutrient		N	P	K	Ca	Mg
I	(L)	0.99 ± 0.046	0.20 ± 0.012	0.32 ± 0.012	1.97 ± 0.06	0.43 ± 0.03
	(T)	0.53 ± 0.02	0.20 ± 0.007	0.18 ± 0.01	1.95 ± 0.06	0.58 ± 0.061
II	(L)	1.38 ± 0.046	0.32 ± 0.020	0.38 ± 0.013	1.61 ± 0.04	0.56 ± 0.021
	(T)	0.74 ± 0.03	0.17 ± 0.012	0.15 ± 0.01	1.86 ± 0.12	0.46 ± 0.031
III	(L)	0.89 ± 0.11	0.24 ± 0.013	0.37 ± 0.010	1.55 ± 0.033	0.58 ± 0.022
	(T)	0.67 ± 0.07	0.19 ± 0.005	0.18 ± 0.01	1.80 ± 0.14	0.47 ± 0.026

Nitrogen concentration in leaf litter increased to a maximum during April then declined and again increased in July in site-II. The lowest concentration of N was noticed during March. It was almost consistent from May to December in site-I, whereas in site-III, the higher values were obtained during August-November. In site-I and III, the variations in N was more marked. The higher values in P concentration were observed during May, September and June in site-I, II and III, respectively. The higher K concentration was initiated from August-September and thereafter declined in all the sites, however, higher values of Ca concentration were noticed during January in site-I, March in site-II and July to December in site-III. Higher values of Mg concentration were recorded during the months of November-December, irrespective of sites. Though, the leaf litter showed considerable monthly variations in the concentration of different nutrients yet the pattern was not consistent except for nitrogen at site-I, where it was significantly correlated with monthly magnitude of leaf fall. No consistent patterns in the variations of monthly nutrient concentration were noticed for twig litter. Monthly leaf litter nitrogen concentrations were correlated with monthly magnitude of leaf fall. The regression equation showing the relationship is given as:

$$\text{Log } Y = 5.530 - 3821 X \ (r = -0.83^{***}, P < 0.1)$$

Table 3. Seasonal mean (%) nutrient concentration ± standard error (SE) during different season.

Site/Nutrient		N	P	K	Ca	Mg
I	Winter	0.90 ± 0.3	0.19 ± 0.22	0.30 ± 0.004	1.61 ± 0.43	0.39 ± 0.08
	Summer	0.96 ± 0.1	0.14 ± 0.04	0.31 ± 0.07	1.95 ± 0.08	0.51 ± 0.05
	Rainy	1.11 ± 1.0	0.20 ± 0.003	0.36 ± 0.02	1.89 ± 0.08	0.41 ± 0.03
II	Winter	1.34 ± 0.05	0.29 ± 0.01	0.39 ± 0.01	1.54 ± 0.07	0.61 ± 0.03
	Summer	1.36 ± 0.1	0.33 ± 0.13	0.35 ± 0.02	1.70 ± 0.03	0.52 ± 0.03
	Rainy	1.45 ± 0.1	0.34 ± 0.02	0.39 ± 0.30	1.56 ± 0.08	0.55 ± 0.03
III	Winter	0.89 ± 0.15	0.21 ± 0.01	0.36 ± 0.02	1.59 ± 0.07	0.57 ± 0.05
	Summer	0.69 ± 0.02	0.31 ± 0.002	0.33 ± 0.13	1.39 ± 0.04	0.51 ± 0.06
	Rainy	1.25 ± 0.1	0.23 ± 0.02	0.39 ± 0.02	1.59 ± 0.08	0.60 ± 0.31

where, log Y is log converted values of monthly leaf fall and X is monthly percent nitrogen concentration.

Monthly nutrient concentration variations without showing any pattern, could be associated to leaching and/or re-translocation of nutrients prior to leaf fall (Gosz *et al.* 1973; Sharma & Pande 1989). The significant negative correlation of N with monthly magnitude of leaf fall for site-I, suggests the retrieval back of this nutrient prior to leaf fall to the living tissue as this site is also poor in nitrogen i.e. 71 kg ha^{-1} as compared to other sites (413 kg ha^{-1}). The internal cycling of nutrients also established itself in deficient/poor nutrient sited (Sharma & Pande 1989; Vitousek 1984). Variations in K concentration may be accounted for leaching (Gosz *et al.* 1973; Sharma & Pande 1989; Tucky 1970).

Seasonal variations in leaf litter nutrient concentration is given in Table 3. Invariably, higher leaf litter nutrient concentrations were observed during rainy season. Peak period of leaf fall in teak occurred during winter season and new leaves appear on the onset of rainy season. Consequently, stored nutrients in the branches are transferred to the newly expanded foliage mass, which forms litter for rainy season and showed higher concentration of nutrients. This may be probable reason for higher nutrient concentration in leaf litter during rainy season. Besides, higher variations of nutrient concentrations in rainy season in site-II, might be reflection of insect pest caused premature leaf fall on the site during this period.

Nutrient return through litter fall

Annual monthly mean nutrient return is tabu-

Table 4. Annual nutrient return (kg ha^{-1}) through litter components in different sites.

Nutrient/Site	Components	N	P	K	Ca	Mg
I	Leaves	23.42	6.07	8.78	61.66	8.89
	Twigs	2.29	0.78	0.67	8.25	2.64
	Total	25.71	6.85	9.45	69.92	11.53
II	Leaves	52.88	14.54	16.56	69.91	25.08
	Twigs	2.80	0.39	0.66	7.09	1.64
	Total	55.68	14.93	17.22	77.00	26.72
III	Leaves	21.26	5.98	8.97	39.44	15.13
	Twigs	4.90	1.32	1.21	13.08	3.53
	Total	26.16	7.30	10.18	52.52	18.66

lated in Table 4. The highest mean annual monthly nutrient return was recorded for Ca and followed by N, Mg, K and P, irrespective of sites. Site-II registered highest mean nutrient return and their variations as compared to other sites. This might be the impact of insect pest attack on the site. The higher mean monthly Ca-return, irrespective of sites, is due to its higher concentration in leaf litter. Twig litter showed less variations in nutrients than of the leaf litter. The annual return of nutrient was in the order of Ca>N>Mg>K>P, irrespective of sites. Total annual nutrient return (kg ha^{-1}) for different sites followed the order: II (191.5) >I (128) >III (114.8). The annual return of individual nutrient viz. N, P, K, Ca and Mg was 25.7, 6.8, 9.4, 69.9 and 16.1 for site-I; 55.7, 14.9, 17.2, 77 and 26.7 for site-II and 26.2, 7.3, 10.2, 52.5 and 18.7 for site-III, respectively. The order of importance for annual N, P, K and Mg return (kg ha^{-1}) for different sites was II>III>I, while for Ca, the order was II>I>III. Further, the highest monthly return was recorded during January for site-I, February and September for site-II and February for site-III, irrespective of nutrients. In general, the magnitude of total nutrient return was in the order to the total litter fall at different sites. The higher nutrient return at site-II was associated with higher litter fall and litter nutrient concentrations. Further, the order of importance in terms of magnitude of nutrient return was Ca>N> Mg>K>P. The higher values of Mg return in the present study as compared to other studies may be attributed to the higher concentrations of this nutrient in the litter. The lower nutrient return in the present study as compared to reported elsewhere in literature for tropical forests and teak plantations of India (Pande 1985; Singh 1968; Srivastava *et al.* 1972; Shanmughavel & Francis 1998), may be attributed to the poor site quality, disturbances in the forests and differences in the climatic conditions.

In conclusion, site-II, which was influenced by insect pest attack, registered higher leaf fall, nutrient concentration and higher nutrient return to the forest floor. This is also true for the highly disturbed site-I. The disturbance caused bimodal leaf fall pattern, higher turn over rate (Table 1) and higher nutrient return to the forest floor at site-II, will result asynchronous-nutrient related feed back links. Because in this case, growth period would be not synchronised with leaf fall periods. Besides, the premature leaf fall due to heavy insect pests (*H. puera* and *E. macheralis*) attack in site-II not only reduce the timber increment significantly but also affect the phenology of the plant due to diversion of energy flux towards the production of compensatory new foliage mass.

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