Effect of disturbance on litter dynamics in moist tropical forest of eastern Nepal

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Abstract
Litterfall is an important vector of nutrient and carbon recycling in forest ecosystems. Present study was conducted in moist tropical forest of eastern Nepal to understand the effect of disturbance on litter dynamics. Litterfall was estimated at monthly intervals from one litter trap (1 m × 1 m) at each of the 70 sampling plots while litter mass accumulated at each sampling plot was collected once every season from one 1 m × 1 m plot. The total annual litterfall in undisturbed forest (UF) was 11.8 Mg ha^{-1} yr^{-1} which decreased by 54.2% in disturbed forest (DF). Leaves accounted for 69% (UF) to 76% (DF) of total litterfall while non-leaf litter formed the rest. Seasonal pattern exhibited a concentrated litterfall in summer season during March to June when more than 70% litterfall occurred in both stands. Forest floor litter mass also decreased due to forest disturbance. The total input of nutrients to the soil through litterfall in UF was more than double as compared to DF. The nutrient stocks in litter mass were in the order: N > K > P in both stands. Key disturbance activities like lopping, litter removal, tree felling, grazing, fire etc. in the peripheral part of the forest should be strictly prohibited by imposing rules and regulations so that status of biodiversity would be restored.

Key words: Litter fall, Litter mass, Nutrient stocks, Sunsari District

Introduction
Senesced leaves, dead twigs, bark, flowers and fruits fall to the ground comprise aboveground litter whereas fine roots constitute the belowground litter. Both types of litter serve as the forest nutrient pool link-

ing inputs, output and turnover of nutrients. Litter determines the amount of light reaching the soil, controls temperature, moisture, and also prevents the growth of young shoots, release chemical compounds on the soil and controls microbial activities.

Litter is a key factor in structuring plant populations, through positive or negative interactions (Baltzinger *et al.*, 2012). Thick layer of litter found in temperate forests alters the growth of seedlings and adult plants, thereby reducing the species diversity and biomass of ground vegetation. On the other hand, the thin layer of litter due to readily decomposition in moist tropical forests favours the growth of seeds and seedlings and increase the species diversity and biomass.

Litterfall not only constitutes a large fraction of net primary production (NPP) but also serves as a medium for nutrient cycling between the vegetation and soil. It contributes over 80% of the nitrogen and phosphorus, and 77–100% of the calcium returns to the soil (Hansen *et al.*, 2009). Litterfall is suggested to drive soil properties and ecosystem biogeochemistry (Freschet *et al.*, 2012). Litter decomposition, a major pathway of nutrient fluxes, determines the organic matter input to soils, influences forest productivity and soil nutrient status (Vesterdal *et al.*, 2008). As the litter decomposes, the nutrients contained within it enter the soil and become available for uptake by the vegetation or are lost to lower soil layers or forest streams through leaching.

The amount of litterfall closely parallels the biomass of foliage. Litterfall has been used as an index of NPP in a variety of plant communities. For example, Bray and Gorham (1964) found that annual leaf fall approximates total NPP if multiplied by 4.9 for temperate evergreen forest, by 3.7 for temperate deciduous forest and by 3.3 for equatorial forest. Aragao *et al.* (2009) opined that the total NPP is close to 3.1 times of total litterfall for the tropical forests of Amazonia. Therefore, precise estimation of litterfall rate is essential for the evaluation of ecosystem NPP and nutrient cycling. The quality of litter controls the rate of NPP. Tree species producing high quality litter (lower C:N ratio) result in a higher rates of nutrient availability in the soil and in turn a higher rate of primary productivity.

The major factors affecting litter production are the temperature, age of the stand, species composition and soil fertility. Generally, the total litterfall declines with the maturity of the forest. Soil fertility promotes both total and foliar litterfall (Hansen *et al.*, 2009). Chave *et al.* (2010) reported a positive relationship between litterfall seasonality and rainfall seasonality across 47 forest plots of tropical South America. Moreover, the addition of P significantly increased the fine-litter production in humid lowland forest of Panama (Wright *et al.*, 2011).

In Nepal, only few studies have been made regarding the litter dynamics in tropical forest (Mandal, 1999) but the litter dynamics with respect to forest disturbance is not available. Therefore, present study was carried out in undisturbed and disturbed stands of moist tropical forest ecosystem in the eastern Nepal with following objectives: 1) to estimate the level of litterfall and litter mass in undisturbed and disturbed stands; 2) to understand the seasonal and monthly pattern of litterfall; 3) to assess the C content in litter and 4) to understand the contribution of litterfall to nutrients cycling in both forest stands.

Materials and methods

Study area

The study was conducted in a Sal (*Shorea robusta*) dominated moist tropical forest of Sunsari District, eastern Nepal (latitude 26°41′ N to 26°50′ N and longitude 87°09′ E to 87°21′ E), within the altitude range of 220 to 370 m above msl (Fig. 1). The forest lies in the catchment area of Koshi River, one of the largest rivers in Nepal. The total area occupied by the forest is 11394 ha.
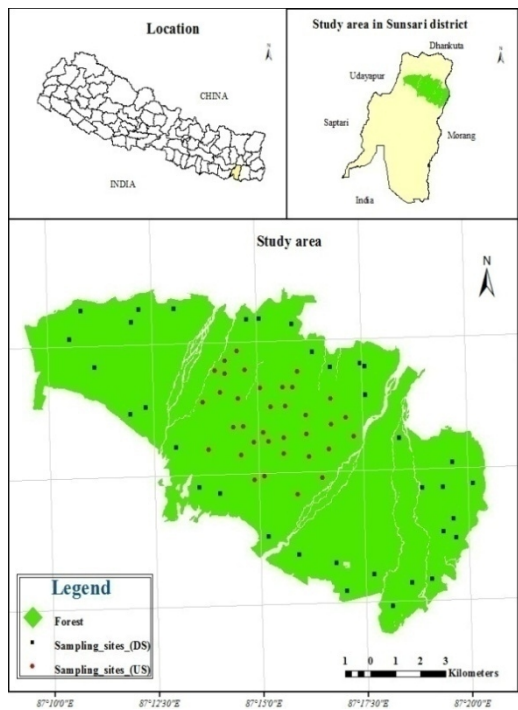

Figure 1. Map of the study area (tropical forest of Sunsari district, eastern Nepal).

The central part (core area) of the forest is relatively undisturbed, while the peripheral part is affected by disturbance activities as removal of timber, livestock grazing, fuel-wood and litter collection, tree lopping, removal of poles for house-hold constructions and forest fires. These distur-bances have caused deforestation, forest fragmentation and degradation and subse-quent invasion of exotic species like *Mikania micrantha*, *Lantana camara* and *Chromolaena odorata*, which adversely affect the native plant diversity in the forest.

The climate is tropical and monsoon type with three distinct seasons: dry and warm summer (March to May), wet and warm rainy (June to October), and dry and cool winter (November to February). The mean monthly minimum and maximum air temperature during 2005-2014 ranged from 10.9°C to 25.3°C and 22.6°C to 33.2°C, respectively. The average annual rainfall for the period was 1998.6 mm (Fig. 2). Rel-ative humidity was higher in rainy season with highest value in August (92%).
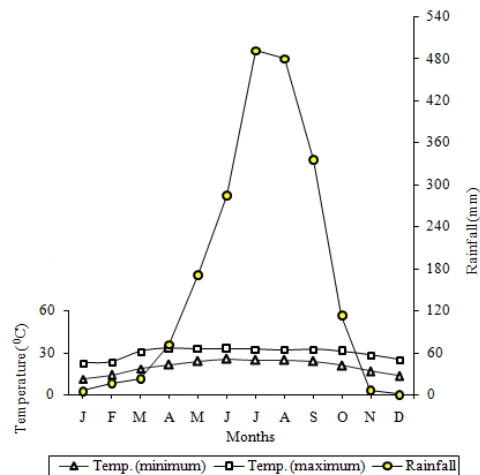
Figure 2. Ombrothermic representation of the cli-mate of moist tropical forest region of Sunsari dis-trict, eastern Nepal. The data pertain to the period 2005–2014 (Source: Department of Meteorology, Dharan, Nepal).

The forest is bordered by the *Siwalik* hill in the north and the Gangetic alluvial plains in the south. The area has been formed from soft erodible sediments of the

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Siwaliks and is characterized by the presence of boulder beds mixed with sand, silt, clay imparting a porous nature. The soil mainly consists of deep alfisols.

The forest tree layer is dominated by Sal. Other main associates are *Haldina cordifolia*, *Lagerstroemia parviflora*, and *Terminalia alata*. *Clerodendron viscosum* and *Murraya koenigii* are some of the main shrub species while *Chromolaena odorata* and *Achyranthes aspera* are dominant herbs.

Litterfall and litter mass estimation

The forest was divided into 2 parts: i) the relatively undisturbed core area (treated as undisturbed forest stand; UF), and ii) the disturbed peripheral area (treated as disturbed forest stand; DF). Because of the following characters the core area was considered as UF: canopy area ranged between 153.8 and 226.9 m^2, crown cover ranged from 70%–80%, density of the tree was 466.4 individuals·ha^{-1} and tree stumps were absent. The peripheral part of the forest is disturbed because of following characters: canopy area ranged between 28.3 and 77.5 m^2, crown cover ranged from 30%–40%, tree density was 234.3 individuals·ha^{-1} and tree stump density was 70 stumps·ha^{-1}.

The litterfall and litter mass was estimated using 70 randomly established sample plots, 35 each in UF and DF. For the estimation of litterfall one litter trap (1 m × 1 m) was fixed on the forest floor at each of the seventy sampling plots. Litterfall was collected at monthly intervals from April 2011 to March 2012 and categorized into leaf and non-leaf components. Litter mass accumulated at each sampling plot was collected once every season from one 1 m × 1 m plot.

The turnover rate (k) of litter was calculated following Jenny et al. (1949) as: k = A / (A + F), where A is the annual litterfall and F is the mass of litter at steady state. In the present study, the F value for leaf litter was assumed to be equal to the partly decayed leaf litter mass during the winter season, and for non leaf, equal to the non-leaf litter mass during the winter season. For total litter (leaf + non-leaf), F was assumed to be the sum of partly decayed leaf and non-leaf litter mass during the winter season. Turnover time, the reciprocal of turnover rate was expressed as: t = 1 / k.

Carbon estimation in litter

The litter (leaf and non-leaf) samples were collected from each sampling plot. All the samples were oven dried at 80°C to constant weight, powdered and used separately for C analyses. Carbon present in plant materials was estimated by ash content method. Carbon concentrations were assumed to be approximately 50% of ash free weight (McBrayer and Cromack, 1980). In this method oven dried litter components were burnt separately in electric furnace at 400°C. Ash content (inorganic elements in the form of oxides) left after burning was weighed and carbon concentration was calculated by using the following equation: % Carbon = (Initial weight − Ash weight) × 100/2

The C stock in litter components was calculated by multiplying C concentration (a conversion factor) to dry weight. The conversion factors of 0.453 and 0.468 were obtained and used for leaf and non-leaf litter, respectively.

Litter chemical analysis

Litterfall samples (leaf litter and non-leaf litter) collected from the litter traps at

monthly intervals were pooled together in proportion to their volume to represent annual samples for each site. The samples were oven dried at 80°C to constant weight and ground separately and passed through 1 mm mesh screen. Three separate samples of each component were analyzed for each site.

The total N concentration was determined by micro-Kjeldahl method (Peach and Tracey, 1956). Using the method outlined by Allen *et al.* (1974), a portion of the plant sample was digested in triacid mixture (1:5:1, perchloric : nitric : sulphuric acid) and P was determined colorimetrically, and K and calcium (Ca) by atomic absorption spectrophotometer. Calcium was determined only in fresh green leaf and leaf litter samples. Lanthanum chloride was added in the samples used for the determination of Ca.

Computation procedure

The stocks of nutrients in the litter components were computed by multiplying the dry weights of components and their mean nutrient concentrations. The turnover rate (k) for each element on the forest floor was calculated as k=A/(A+F), (Jenny *et al.*, 1949), where A is the amount of nutrient added to the forest floor annually by litterfall and F is the nutrient content of the lowest value of standing crop of litter in the annual cycle. Turnover time (t) is the reciprocal of the turnover rate (k) and is expressed as t =1/ k.

Statistical analysis

Statistical test (ANOVA) was carried out in SPSS (IBM Statistics, ver. 20) package to compare the mean litterfall between forest type (UF and DF) and season (Summer, rainy and winter).

Results

Litterfall, litter mass and turnover

The total annual litterfall in UF was 11.8 Mg ha^{-1} yr^{-1} which decreased by 54.2% in DF (Tab. 1). Leaves accounted for 69% (UF) to 76% (DF) of total litterfall while non-leaf litter formed the rest. Seasonal pattern exhibited a concentrated litterfall in summer season during March to June when more than 70% litterfall occurred in both stands (Figs. 3–5). The variation in litterfall due to the difference in forest type and season was significant (P < 0.001) (Tab. 2). The proportion of litterfall was highest during April (more than 27%) followed by March (more than 21%) in both stands. Compared to leaf fall, a greater proportion of annual non-leaf litterfall (30% in DF and 42% in UF) occurred during the rainy season.

Forest floor litter mass also decreased due to forest disturbance. The variation in litter mass due to the difference in forest type and season was significant (P < 0.001). In litter mass, fresh litter mass accounted 64% while partly decayed litter mass comprised 36% in both stands (Tab. 3). The turnover rate (per yr) of the total litter ranged from 0.79 in DF to 0.83 in UF (Tab. 4). The turnover time (the reciprocal of turnover rate) of the total litter ranged between 1.21 and 1.26 years in UF and DF indicating 83% and 79% replacement of litter on the forest floor each year in these sites respectively.

Nutrient return through litterfall

The concentrations of all nutrients in leaf litter were higher than in non-leaf litter in both stands (Tab. 5). The total input of nutrients (kg ha^{-1} yr^{-1}) to the soil through litterfall in UF was more than double (99.7 N,

Table 1. Annual litterfall (Mg ha^{-1} yr^{-1}) with their carbon stocks (Mg C ha^{-1} yr^{-1}) in undisturbed and disturbed stands of moist tropical forest in Sunsari district, eastern Nepal.

Litter components	Undisturbed forest			Disturbed forest		
	Litterfall	Carbon stocks	%	Litterfall	Carbon stocks	%
Leaf	8.1 ± 0.50	3.67	69	4.1 ± 0.06	1.86	76
Non-leaf	3.7 ± 0.03	1.73	31	1.3 ± 0.01	0.59	24
Total	11.8 ± 0.70	5.40	100	5.4 ± 0.13	2.45	100

Table 2. F values of the effects of forest stand, season and litter type on litterfall as obtained by analysis of variance (at 95% confidence interval).

Factors	F values	Significance level
Forest type	2101.3	P < 0.001
Season	4753.7	P < 0.001
Forest type * Season	693.8	P < 0.001
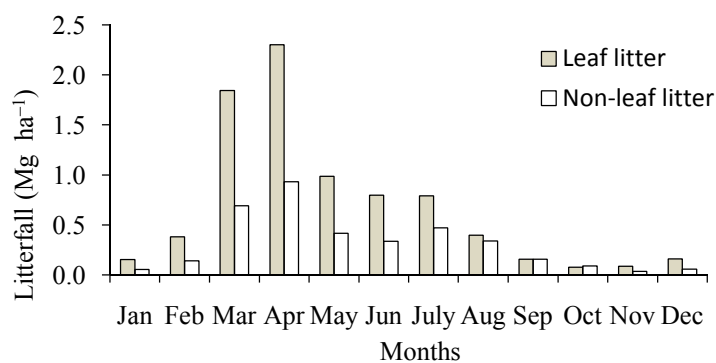
Figure 3. Monthly litterfall in undisturbed stand of moist tropical forest in Sunsari district, eastern Nepal.
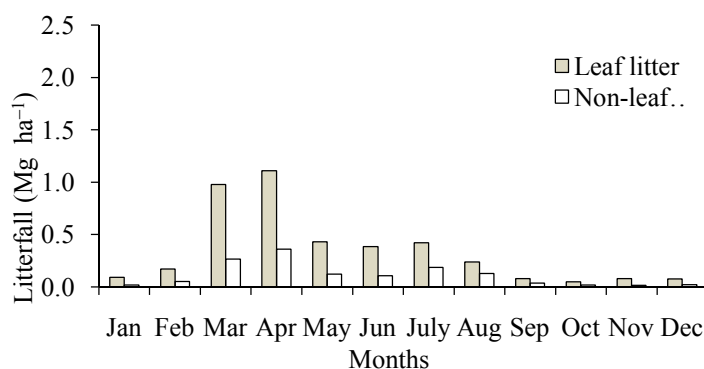
Figure 4. Monthly litterfall in disturbed stand of moist tropical forest in Sunsari district, eastern Nepal.
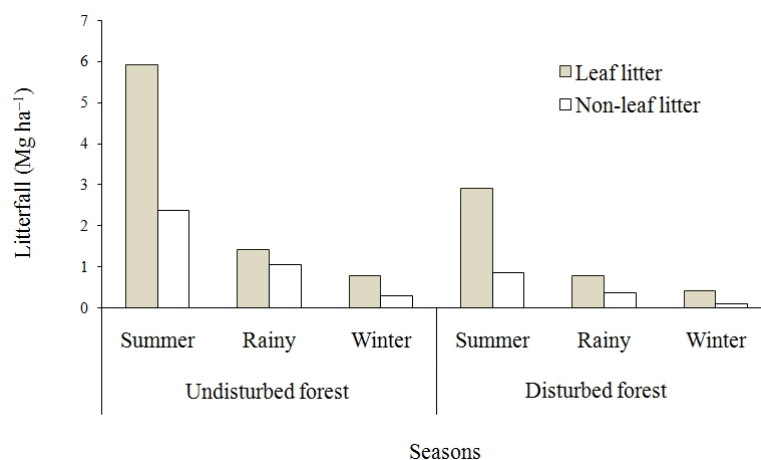
Figure 5. Seasonal variation in litterfall in undisturbed and disturbed stands of moist tropical forest in Sunsari district, eastern Nepal.

Table 3. Forest floor litter mass (Mg ha^{-1} ± SE, average of three seasons) in tropical moist forest of eastern Nepal. Values in parentheses are percentage of the total.

Litter mass components	Undisturbed forest		Disturbed forest	
	Litter mass	% of total	Litter mass	% of total
Fresh leaf	2.7	40	1.5	42
Non-leaf	1.6	24	0.77	22
Partly decayed leaf	1.4	21	0.83	23
Partly decayed non-leaf	1	15	0.47	13
Total	6.7 ± 0.35	100	3.6 ± 0.22	100

Table 4. Turnover (rate and time) of litter in tropical moist forest of eastern Nepal.

Turnover	Undisturbed forest			Disturbed forest		
	Leaf litter	Non-leaf litter	Total	Leaf litter	Non-leaf litter	Total
Rate (k/year)	0.85	0.77	0.83	0.82	0.73	0.79
Time (t, years)	1.17	1.3	1.21	1.22	1.38	1.26

Table 5. Concentration of nutrients (%) (mean ± SE) in litter of moist tropical forest in Sunsari district, eastern Nepal.

Components	N	P	K	Ca
Leaf litter				
Trees	0.85±0.05	0.08±0.003	0.62±0.04	1.13±0.08
Shrubs	1.1±0.09	0.09±0.007	0.65±0.05	1.03±0.06
Herbs	0.81±0.04	0.07±0.006	0.8±0.05	1.03±0.07
Mean	0.92±0.05	0.08±0.005	0.69±0.06	1.06±0.06
Non leaf litter				
Trees	0.66±0.05	0.05±0.003	0.22±0.01	
Shrubs	0.7±0.07	0.05±0.003	0.24±0.02	
Mean	0.68±0.05	0.05±0.004	0.23±0.01	

Table 6. Amount of nutrients (kg ha^{-1} yr^{-1}) in litterfall in undisturbed and disturbed stands of moist tropical forest of Sunsari district, eastern Nepal (mean ± SE).

Components	Undisturbed forest				Disturbed forest		
	N	P	K		N	P	K
Leaf	74.5±6.5	6.5±0.4	55.9±5.6		37.7±2.8	3.3±0.1	28.3±2.4
Non leaf	25.2±1.6	1.9±0.1	8.5±0.7		8.8±0.5	0.7±0.05	3.0±0.02
Total	99.7±8.0	8.3±0.7	64.4±4.1		46.6±3.3	3.9±0.2	31.3±2.6

8.3 P, and 64.4 K) as compared to DF (46.6 N, 3.9 P, and 31.3 K) (Tab. 6). The contribution of different nutrients in the input to the soil through litterfall was in the order: N > K > P in both stands. Of the total annual nutrient input through litterfall, leaf litter accounted for 78–87% in UF and 85–90% in DF.

Nutrients in litter mass and turnover of nutrients on forest floor

Litter on the forest floor (litter mass) varies seasonally with litterfall. Standing state of nutrients in litter mass decreased with forest disturbance. The nutrient stocks in litter mass were in the order: N > K > P in both stands (Tab. 7). Leaf litter contributed 68-82% of total nutrients in UF and 72-85% in DF. Of the total nutrients in litter mass, 63-65% nutrients were present in fresh litter and rest in partly decayed litter.

The values of turnover rate and turnover time for different litter nutrients on the forest floor are given in Table 8. The turnover rate of nutrients ranged 0.67-0.69 for N, 0.66-0.68 for P and 0.64-0.66 for K. The turnover rates were slightly higher in the UF and lower in the DF. The turnover time of litter nutrients ranged 1.45-1.49 for N, 1.47-1.51 for P and 1.53-1.55 for K. Turnover time for all nutrients were relatively higher in DF which may be due to immobilization of these nutrients in litter mass by the microorganisms.

Discussion
Litterfall and litter mass

Litterfall and fine roots are important vectors of nutrient and C recycling in forest ecosystems. Total C input into soil through litter plus root turnover in present forest was previously reported by Gautam and Mandal (2016). Their turnover is usually determined by biotic factors (species, age groups, canopy cover) and weather conditions.

Table 7. Standing state of nutrients (kg ha^{-1}) (mean ± SE) in litter layer in moist tropical forest of Sunsari district, eastern Nepal.

Components	Undisturbed forest				Disturbed forest		
	N	P	K		N	P	K
Total littermass	55.4±4.3	4.6±0.3	34.3±2.8		29.9±1.5	2.5±0.1	18.9±1.1
Fresh leaf litter (%)	45	47	54		46	48	55
Partly decayed leaf litter (%)	23	24	28		26	27	30
Fresh non-leaf litter (%)	20	17	11		18	15	9
Partly decayed non-leaf litter (%)	12	11	7		11	9	6

Table 8. Turnover rate (*k*) and turnover time (*t*) of litter nutrients on forest floor in moist tropical forest of Sunsari district, eastern Nepal.

Turnover rate and time	Undisturbed forest				Disturbed forest		
	N	P	K		N	P	K
Rate (per yr)	0.69	0.68	0.66		0.67	0.66	0.64
Time (yr)	1.45	1.47	1.53		1.49	1.51	1.55

Table 9. Litterfall (Mg ha^{-1} yr^{-1}) in different forests of the World.

Locality and forest types	Leaf litter	Total litter	References
India (Uttarakhand)	–	6.25 ± 0.26	Rawat (2012)
South America (Tropical)	–	8.61 ± 1.91	Chave *et al.* (2010)
South America (Tropical)	–	8.01 ± 3.41	Chave *et al.* (2010)
India (Sub-tropical)	–	5.47	Pandey *et al.* (2007)
India (Tropical)	–	3.9–5.2	Swamy *et al.* (2010)
Indonesia (Borneo)	5.1–11.0	–	Paoli and Curran (2007)
India (Dry tropical)	–	13.27–13. 51	Pragasan and Parthasarathy (2005)
Brazil (Tropical)	8.55–11.01	12.32–14.74	Schessl *et al.* (2008)
Nepal (Moist tropical, Plateau Sal)	7.2 ± 0.31	10.3 ± 0.61	Mandal (1999)
Nepal (Moist tropical)	4.1–8.1	5.4–11.8	Present study

Mean annual litterfall of the forest combining both UF and DF amounted to 8.6 Mg ha^{-1} yr^{-1} (equivalent to 3.93 Mg C ha^{-1} yr^{-1}). More than double litter production in UF of the studied forest compared to DF suggests that leaf litter production is susceptible to the forest disturbance which may have effects on overall forest dynamics. The total litterfall in UF is in lower range for that in tropical forests of Panama and Brazil, while it is convincingly higher than the value for tropical old-growth and secondary forests of South America, and other forests of Asia (Tab. 9). The NPP allocation to the annual litterfall of UF is almost equal to that of Amazonian forests (Malhi *et al.*, 2014, 4.94–5.39 Mg C ha^{-1} yr^{-1}; Doughty *et al.*, 2013, 4.52–5.03 Mg C ha^{-1} yr^{-1}), and lowland tropical rain forest of Central French Guiana (Chave *et al.*, 2008, 4.65 Mg C ha^{-1} yr^{-1}).

The contribution of leaf litter to total litterfall ranged between 69% (at UF) to 76% (at DF). Malhi *et al.* (2014) reported almost same range of 72–74% allocation in leaf fall while Girardin *et al.* (2014) reported a range of 69–73%. The higher percentage of leaf litter and lower percentage of non-leaf litter in DF as compared to UF may be linked to the lopping of tree twigs for fodder which prevents the plant from flowering and fruiting, thereby reducing the quantity of non-leaf litter. On the other hand, in poor soils as in DF, forests tend to invest less into the construction of reproductive organs relative to photosynthesis but when resources are well supplied the excess in resources is made available for reproduction (Chave *et al.*, 2010).

Litter production showed distinct seasonality peaking during dry summer season. Same trend was also reported in

past studies (Pragasan and Parthasarathy, 2005; Doughty *et al.*, 2013; Malhi *et al.*, 2014). This is likely to be related to the low soil moisture level during this period resulted due to a strong and continuous solar radiation. Moreover, water stress stimulates the synthesis of abscissic acid in the leaf, which in turn leads to senescence and finally to leaf fall.

The annual litter turnover rate was faster in UF as compared to DF (Tab. 3). It may be associated with the higher microbial biomass and their activities in the soil of UF (Gautam and Mandal, 2014). Relatively faster turnover rate of leaf litter than that of the non-leaf litter in both stands may be due to the presence of relatively lower amount of lignified tissues (low lignin and high nitrogen) in leaves as compared to non-leaf components. Annual litter turnover value of present forest is comparable to the wet tropical evergreen forest of India i.e. 0.92–0.96 as reported by Swamy *et al.* (2010).

In the present study, turnover time of litter ranged between 1.21 (in UF) and 1.26 years (in DF) which is in range to the several tropical forests of World (Vogt *et al.*, 1986). However, these values are slightly higher than the values reported for tropical wet evergreen forests (1.04 and 1.08 years) of Western Ghats India (Swamy *et al.*, 2010).

Nutrient retranslocation and nutrient-use efficiency

Litter fall is a major functional part of any ecosystem as it plays a key role in regulating nutrient cycling and organic matter content. Nutrient return to the soil pool is mainly defined by litterfall (62–64% for N, 64–66% for P and 57–58% for K), and rest is contributed by fine roots. Of the total annual nutrient input through litter fall, leaf litter accounted for 75–87% in UF and 81–90% in DF.

Nutrient return via litterfall in the present study was in the range as reported by Vitousek and Sanford (1986) for several moist tropical forests and by Mandal (1999) in the Sal forest ecosystem of Nepal Himalaya. Rapid turnover of litter in the UF may continually regenerate the available N, P and K to support a high net production of vegetation on UF (Gautam and Mandal, 2016).

Conclusions

Present study tried to disclose the functional aspect of moist tropical forest ecosystem in context of disturbance in ecologically fragile and socially marginal environment in the foothills of the Himalayas in eastern Nepal. Forest disturbance has reduced the litterfall, and consequently nutrients and carbon pools in substantial amounts. Human intervention in terms of lopping, litter removal, tree felling, grazing, fire etc. have been identified as key forest disturbances responsible for degradation of forest in peripheral parts adjoining human habitation. Such activities should be strictly prohibited by imposing rules and regulations so that status of biodiversity would be restored. Further, the information on carbon content in litterfall will be useful to mitigate climate change issues as per the objective of REDD[+] (Reducing Emissions from Deforestation and Forest Degradation).

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