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Litterfall dynamics in Boter-Becho Forest: Moist evergreen montane forest of Southwestern Ethiopia

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Litterfall in the forest is essential for balanced ecosystem processes. The present study determined seasonal variations of litterfall in the Boter-Becho forest, Southwestern Ethiopia. Based on forest disturbance level, two sites were selected: Low and high. Litterfall production in the high and low disturbed forest sites averaged 6.6 and 10.8 t ha^{-1} $year^{-1}$, respectively. Significant differences ($P<0.001$) in litterfall were manifested between wet (0.6 ton ha^{-1} $month^{-1}$) and dry (0.8 tons ha^{-1} $month^{-1}$) seasons. Higher litterfall was associated with the dry compared with the wet season. Both litterfall and its fractions including leaf litter, reproductive parts and twigs followed a multimodal distribution pattern. Litterfall peaked during March, April, December, January and February with maximum peaks during March and December respectively. Monthly rainfall and temperature directly influenced litterfall production. Litterfall was strongly but negatively correlated with rainfall compared to ambient temperature. Although the present study provided useful information on the effects of low and high disturbance on litterfall production of the Boter Becho forest, further studies are required to quantify and understand the impact of disturbance on nutrient cycling specific to this forest.

Key words: Seasonal variation, site disturbance, leaf litter, reproductive parts, twigs.

INTRODUCTION

Litterfall production is an important component of forest ecosystem functioning (Aragao et al., 2009; Clark et al., 2001). It transfers nutrients from aboveground biomass to the soil (Vitousek and Sanford, 1986). In the forest ecosystem, litterfall reduce bulk density, increase water holding and the cation exchange capacity of the soil. Xu et al. (2013) also suggested that greater litterfall inputs increase the soil carbon sink despite higher rates of carbon release and transformation. In addition, litter on the forest floor plays a significant role in determining the moisture status,runoff pattern and release of mineral elements accumulated in the aerial parts of the

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vegetation (Parsons et al,, 2014; Kumar and Tewari, 2014; Yang et al., 2005).

Litterfall production in the forest ecosystem is also essential in the exchange of carbon from terrestrial ecosystems to the atmosphere, and forms a major contribution to seasonal variations in the terrestrial carbon cycle of the tropical forest biome (De Weirdt et al., 2012; Bousquet et al., 2000). It also provides nutrient input and organic matter replenishment and hence, an important stage in habitat conservation (Rawat et al., 2009; Wurzburger and Hendrick, 2009).

Recent studies indicated that litterfall production in forest system formed an important source of nutrients and organic matter over the past decades (Carnol and Bazgir, 2013; Meier et al., 2005; Vitousek and Sanford, 1986; Vitousek, 1984). However, climate, seasonality, tree species composition, stand structure, soil fertility, elevation and latitude alter the litterfall production pattern between ecosystems (Aerts, 1997; Becker et al., 2015; Simmons, 1996; Vitousek and Sanford, 1986; Parsons et al., 2014). According to Spain (1984), the most extreme variability of litterfall is seen as a function of seasonality. He reported that individual species of plants have seasonal losses of some parts of their body and can be determined by the collection and classification of plant litterfall throughout the year. Qiu et al. (1998) also observed that abiotic factors such as rainfall, temperature and light play an important role in litterfall, flushing among dominant canopy species in the forest.

Other workers reported that seasonal litter production is highest in dry months and lowest in the wet months of a year particularly in tropical forests (Arunachlam et al., 1998; Sundarapandian and Swamy, 1999). According to Zhang et al. (2014), seasonal variation in litterfall production results in large variation in the amount of litter on the soil in most tropical forests. Zhang et al. (2014) and Scheer et al. (2009) also indicated that seasonal patterns of litterfall show unimodal, bimodal or irregular modes, and the litter peaks might occur in several months of the year. Consequently, this phenomenon may affect the dynamics of ecosystem carbon and nutrient cycling (Xu et al., 2004; Das and Ramakrishnan, 1985).

Ethiopia exhibits a wide range of ecological conditions ranging from arid lowlands in the east to rainforests in the west and southwest. Ethiopia is also known for high endemism of wild plants and animal species (FAO, 1996). It possesses high altitude Afroalpine vegetation in the central, south eastern and northern highlands. The Ethiopian highlands contribute to more than 50% of the African land area with afromontane vegetation (Tamrat, 1994).

Although many studies have been done on the Ethiopian flora and species diversity, studies related to litterfall and nutrient dynamics is lacking (Ambachew et al., 2012; Nigatu and Michelsen, 1994). Understanding litterfall and nutrient dynamics of Ethiopian Forests is important to their management. The objective of the present study was to determine the effects of seasonal variation on litterfall production and the effect of rainfall and temperature on litterfall components (total and fractions) under low and high disturbance conditions in Boter-Becho forest located in southwestern part of Ethiopia.

MATERIALS AND METHODS

Site description

Location

Boter-Becho forest (08°21'56.4" N and 037°16'25.4"E) is one of the national forest priority areas located in Jimma Zone of Oromia Regional State, Ethiopia (Figure 1). It lies in Chora Boter district of Jimma zone and 223 km southwest of Addis Ababa, the capital city of Ethiopia. The study site lies along a volcanic mountain ridge, running almost north to south, and rising to a series of small peaks, the highest of which is 3,100 m above sea level. The Eastern part of the ridge is sharply steep, but more gradual in western side. The hills are divided by numerous valleys. The forest is dominated by Acacia wood land in the lower altitude, high montane forest on slopes and in the valleys up to around 2 900 m above sea level. Most of the valleys along the forest ridge contain only seasonal water course but remain dry from December to March. Boter Becho forest covers approximately a total area of 32 000 ha (Figure 1).

Vegetation

The forest vegetation in Boter Becho comprises a mixture of tree species including *Olinia rochetiana, Polyscias fulva, Pouteria adolfi-friedricii, Schefflera volkensii, Syzygium guineense Subsp. afromontanum. Allophylus abyssinicus, Croton macrostachyus, Juniperus procera, Hagenia abyssinica* and other small trees that grade into an open *Erica arborea* zone around the highest peak. Moreover, it contains a number of medium sized trees and large shrubs, a mixture of *Podocarpus falcatus* and broad-leaved species as emergent trees in the canopy including *P. adolfi-friederici*. There are some patches of *Arundinaria alpina* in wet, sheltered valleys. There are several streams forming rivers in mountains of Boter-Becho and are drained by the Gilgel Gibe to the west, which forms a wide valley supporting the lower parts of the forest, and the main Gibe River to the north and east.

Climate

In order to construct the climate diagram of Boter Becho forest, the 15 years climate data (2001-2015) was obtained from the Ethiopian Metrological Service Agency (NMSA, 2016). Boter-Becho has a warm and temperate climate. According to the climadiagram depicted in Figure 2, Boter-Becho has mean annual rainfall of 1434 mm and mean annual temperature of 14.6°C. Boter-Becho possess unimodal rainfall pattern with long rainy seasons from March to September of which the highest rainfall is recorded during the months of June and August. The area posses short dry season from October to February where it gets relatively smaller rainfall. Mean monthly rainfall in the area is 183.6 and 29.6 mm in wet and dry season, respectively. Mean annual temperature is 14.9 and 14.2°C in wet and dry season respectively. The mean annual temperature

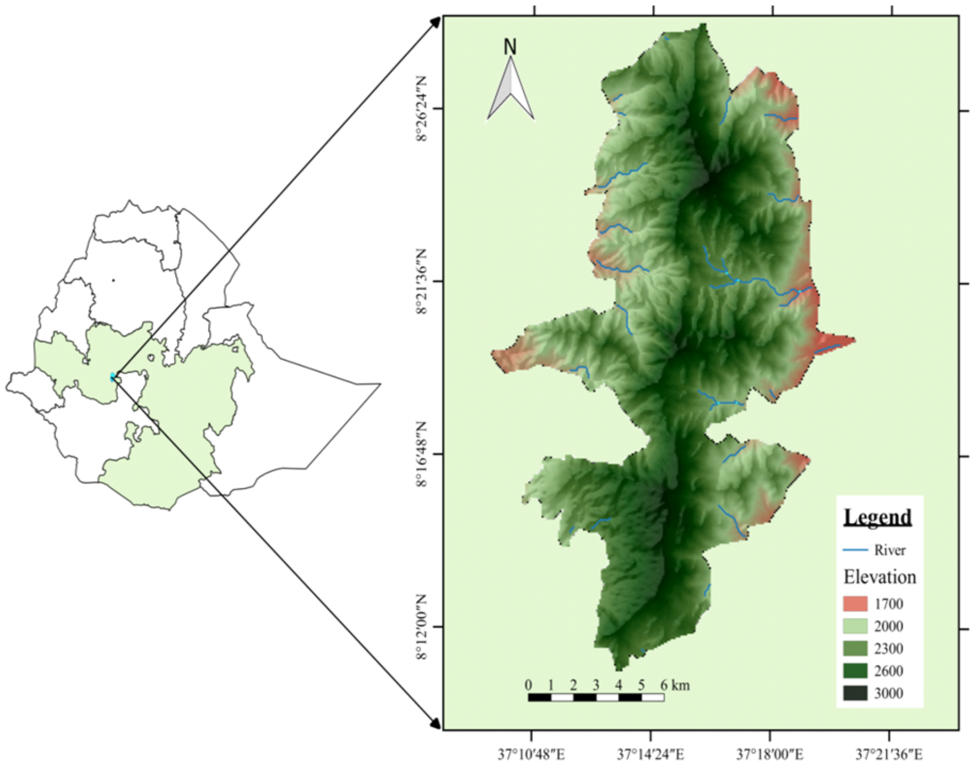

Figure 1. Location map of the study area.

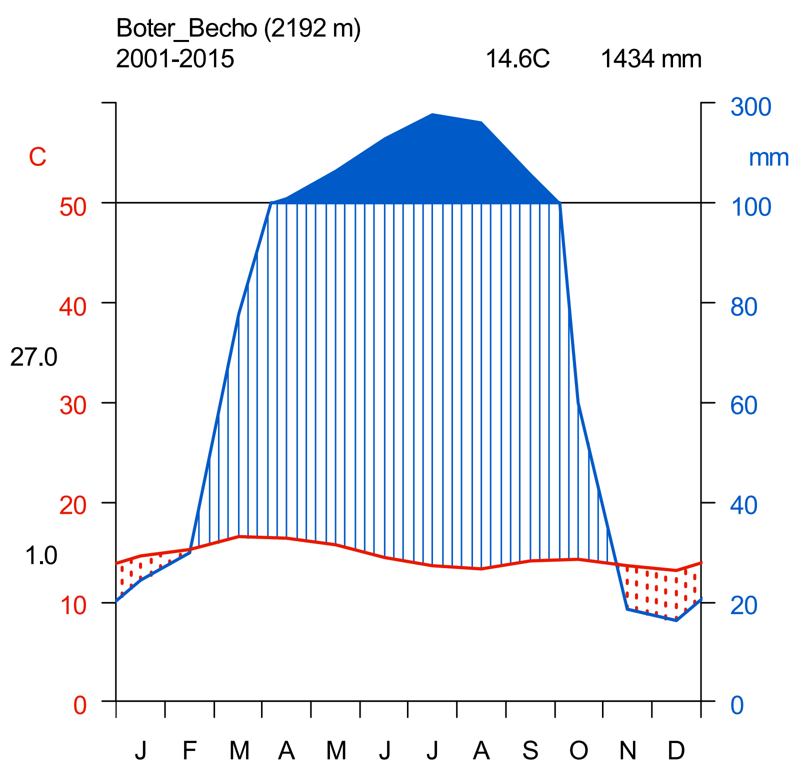

Figure 2. Climadiagram of Boter-Becho station from 2001-2014 (NMSA, 2015).

Table 1. Density, height and total basal area of tree species in LD site.

Scientific Name	LD site		
	Density	**Height**	**Total BA**
Allophylus abyssinicus	311.11	10.4 ± 2.9	29.26
Croton macrostachyus	140.74	18.9 ± 8.0	11.94
Chionanthus mildbraedii	296.31	3.68 ± 1.13	0.7
Ficus sur	85.15	16 ± 3.2	12.43
Macaranga capensis	88.91	18 ± 4.23	21.02
Milletia ferruginea Subsp. *darassana*	177.78	13.15 ± 4.11	12.8
Olea capensis subsp. *macrocarpa*	503.7	21.73 ± 3.49	32.13
Olinia rochetiana	214.81	10.9 ± 2.82	16.89
Podocarpus falcatus	311.11	16.13 ± 3.53	12.98
Polyscias fulva	133.33	11.32 ± 2.45	6.87
Pouteria adolfi-friedricii	162.96	19.2 ± 2.76	18.34
Schefflera volkensii	166.67	12 ± 3.72	14.87
Syzygium guineense Subsp. *afromontanum*	466.67	21 ± 4.22	33.56

Table 2. Density, height and total basal area of tree species in HD site.

Scientific name	HD site		
	Density	**Height**	**Total BA**
Albizia gummifera	200.00	15.3 ± 9.6	16.8
Apodytes dimidiata	77.70	15.4 ± 5.5	29
Brucea antidysentrica	125.90	8 ± 3.4	8.6
Calpurnia aurea	281.48	5.75 ± 2.11	2.1
Celtis africana	129.62	6.97 ± 3.7	2.86
Chionanthus mildbraedii	292.60	5.5 ± 2.3	0.81
Clausena anisata	251.85	3.7 ± 2.1	1.08
Croton macrostachyus	77.80	14.67 ± 3.76	4.88
Ehretia cymosa	92.59	4.3 ± 1.8	4.62
Milletia ferruginea Subsp. *darassana*	225.92	13.6±3.27	6.46
Oxyanthus speciosus	88.89	4.5±1.25	0.76
Podocarpus falcatus	59.26	21±4.3	6.62
Pouteria adolfi-friedricii	85.18	18±4.89	5.63
Teclea nobilis	125.90	5.3±2.3	1.2

of the area in the wet season is greater than in the dry season which drives the rapid ecosystem processes in the forest system. The climatic seasonality data presented in this section was used to determine the effects of seasonal variation on litterfall production reported in this study.

Sampling technique for site selection

A reconnaissance survey was conducted in December and January 2014 to observe the topography, type and different structural features of the Boter Becho forest. The forest is classified as moist evergreen montane forest where rainfall in the wet season is usually higher than that of dry season (Friis et al., 2010). The climadiagram of the area depicts that seven months of the year gets higher rainfall with the remaining five months receiving relatively smaller amounts of rainfall. Two local sites called ‘Bore’ and ‘Getemi’ within the Boter-Becho forest are hereafter referred to as low and high disturbed. These two sites were randomly selected on the basis of their level of disturbance. Characteristics of the low disturbance (LD) level includes no logging, browsing, grazing and relatively protected despite the human trampling that was observed throughout the area. In contrast, the high disturbance (HD) site shows features that include distinct human trampling, browsing and grazing by domestic animals, in addition to the illegal practice of deliberate cutting of large trees for either fuel or honey by local people. Another distinction between the two sites is the nature of the forest canopy which is distinctly half open in HD site compared to a half open to closed canopy in the LD site respectively. The density (no of stems ha^{-1}), mean of height ± sd (standard deviation) and total basal area (m^2 ha^{-1}) of dominant tree species in the study plots of LD and HD sites are given in Tables 1 and 2.

Figure 3. Litter trap for litter collection in the forest.

Litter traps preparation

For the litterfall collection, litter traps (1 m^2) made of wooden frame was constructed (Figure 3). The 1 m^2 traps were supported at each corner by wooden stakes so that at the rim they were 80 cm above the ground. Each trap consisted of a wooden frame which was suspended a net with a mesh size of 2 mm allowing for the rapid drainage of rainwater.

Sampling for litter-trap installation

Five plots of 900 m^2 (30 m × 30 m) each were randomly selected from *LD* and *HD* sites of the forest. Two litter traps were installed within each plot with a total of ten traps in each site of the forest. Litter traps were installed on 4th February, 2014 on all sites of the forest. Litterfall was collected at monthly intervals for 12 months (4th March 2014 to 3th February, 2015) giving a total of 240 collections throughout the whole sampling period. However, the average of two replicates in each plot was taken as one in each sampling period for data analysis.

Litterfall was transported to the laboratory where it was oven-dried at 80°C for 24 h to constant weight. Litter was then sorted into four litterfall fractions (components) including leaf, twigs < 2 cm in diameter, reproductive parts (flowers, fruits, and seeds) and fine litter/trash (any material passing through a 2-mm sieve, hereafter referred to as "other". These fractions were oven dried at 80°C to a constant weight and weighed on a digital balance.

Data analysis

The collections in each month were combined to obtain litterfall data per month. To calculate the amount of litterfall production per plot, all the oven-dry weights of the litterfall from a plot was added up to get the total litter mass (gram). Then, mass unit conversions were made to express the value in ton $ha^{-1}year^{-1}$ basis (1 g m^{-2} = 0.01 t ha^{-1}).

The mean monthly dry weights of litterfall in wet and dry season were compared between each other and also between low disturbed (LD) and high disturbed (HD) sites of the forest. A monthly dry weight of litterfall (ton ha^{-1}) from each site was analyzed for mean variation using independent samples t-test. The Percent contributions of each fractions of litterfall to the total litterfall were calculated. Simple linear regression analysis was used to determine the effect of mean annual rainfall and mean annual temperature on a given litter variables. Moreover, one way ANOVA was used to test the significance difference in different categories between the low and high disturbed sites of the study forest. Significance level was determined at 95% CI. All the statistical analysis was done using $R_{3.1.1}$ (R Core Team, 2013).

RESULTS

Litterfall production

Significant differences (P < 0.01) in litterfall production between the LD and HD sites were detected (Figure 4). Annual litterfall production in the LD and HD sites averaged 10.76 and 6.64 ton $ha^{-1}year^{-1}$ respectively (Figure 4). Litterfall production of the Botor Becho forest averaged 8.7 ton $ha^{-1}year^{-1}$.

Litter fractions: Leaf litter, reproductive parts, other, and twigs

The level of disturbance between sites significantly ($P < 0.01$) affected the proportion of litter fractions (Tables 3 and 4). Leaf litter in the LD and HD sites averaged 42 and 49% whereas both twigs and reproductive parts averaged 58 and 50% of the total annual litterfall, respectively (Table 4). Leaf litter contributed the most (45%) to litterfall production compared to reproductive parts (24.13%), other (15.92%), and twigs (14.95%), respectively (Table 5). The generally higher proportion of reproductive parts during March, April, December,

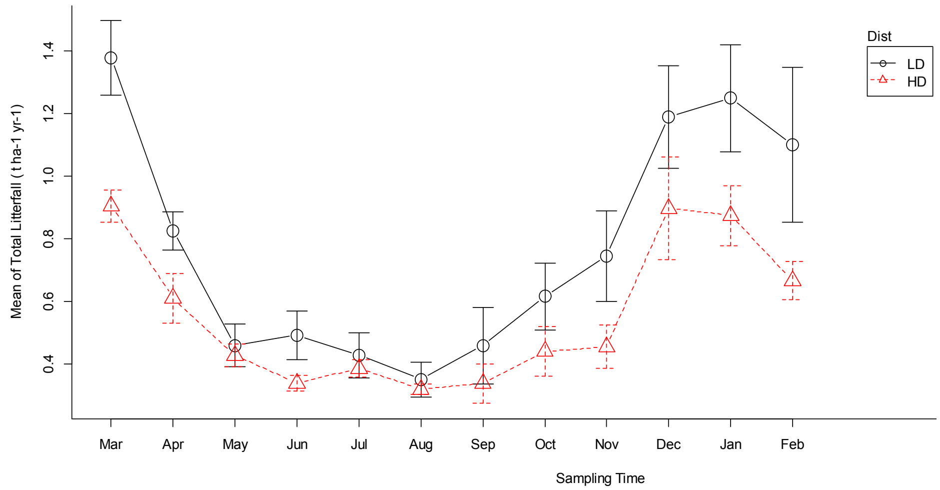

Figure 4. Monthly litterfall production associated with LD and HD sites. Vertical bars indicate the s.e. of the means.

Table 3. ANOVA test for the mean litterfall (t ha^{-1}) fractions between LD and HD sites.

Litter fractions	$F_{1,118}$	***P* value**
Total litterfall	11.830	0.001**
Leaf	8.787	0.004**
Reproductive parts	26.04	< 0.001**
Twigs	17.118	< 0.001**
Other	8.436	0.004**

**Significant at P < 0.01.

Table 4. Annual litter fall variation in the study sites.

Sites	**Litterfall (t ha^{-1}year^{-1})**					
	Leaves	**Rep. parts**	**Twigs**	**Other**	**Total**	**No. of samples**
LD	4.54	2.69	1.60	1.92	10.76	60
HD	3.28	1.51	1.00	0.85	6.64	60
Total	7.83	4.20	2.60	2.77	17.40	120
Percent	45.00	24.13	14.95	15.92	100	

January and February in both LD and HD sites of the forest may indicate that flowering and fruiting is occurring in some of the forest species.

Apparently, both wet and dry seasons significantly (*P < 0.05*) affect litterfall production in the forest ecosystem (Table 5). Total litterfall in both sites followed a multimodal distribution pattern in which litterfall peaks occurred in March, April, December, January and February with higher peaks in March and December (Figure 4) where March indicates the onset of wet season and December indicates the onset of the dry season. The components and the total litterfall also showed significant difference between wet and dry season in the forest (Table 5). Monthly litterfall in the wet season averaged 0.5586 ± 0.04 ton ha^{-1} compared with 0.844 ± 0.06 ton/ha in the dry season.

The effect of climatic variables on litterfall dynamics

Both litterfall components and litterfall production were significantly correlated to mean monthly temperature and

Table 5. ANOVA test for the mean litterfall (ton ha^{-1}) fractions between wet and dry season.

Litter fractions	$F_{1,118}$	*P* value
Total litterfall	15.811	<0.001**
Leaf	10.983	0.001**
Reproductive parts	11.393	0.001**
Twigs	23.790	0.001**
Other	19.144	<0.001**

**Significant at P < 0.01.

Table 6. Coefficients of correlation (Pearson's) and R^2, *F* and *P* value between mass of litterfall and mean monthly rainfall of the *Boter Becho* forest.

Litter type	*R*	R^2	$F_{1,118}$	*P* value
Leaf	0.546	0.298	50.2	<0.001**
Rep. parts	0.516	0.266	42.87	<0.001**
Twigs	0.564	0.296	49.54	<0.001**
Other	0.494	0.244	38.11	<0.001**
Total	0.551	0.318	55.05	<0.001**

**Significance level at P<0.01, Rep.parts = reproductive parts.

Table 7. Coefficients of correlation (Pearson's), R^2, *F* and *P* value between mean monthly temperature and litterfall.

Litter type	*R*	R^2	$F_{1,118}$	*P* value
Leaf	0.293	0.086	11.073	0.001**
Rep. parts	0.258	0.067	8.443	0.004*
Twigs	0.077	0.006	0.712	0.400^{ns}
Other	0.070	0.005	0.576	0.449^{ns}
Total	0.215	0.046	5.716	0.018*

**Significance level at P ≤ 0.001, ns = not significant, * significance level at P<0.05.

mean monthly rainfall (Tables 6 and 7). The regression model explained (30.4%) of the variation in total litterfall in the forest. However, from the analysis rainfall had a relatively more significant (P < 0.001) effect on the amount of litterfall than temperature.

DISCUSSION

Litterfall production in the moist evergreen montane forest of Boter Becho averaged 8.7 ton $ha^{-1}year^{-1}$. Litterfall production in both the LD and HD sites of the forest peaked in March, April, December, January and February. Maximum litter production occurred during March and April. In both sites, the leaf litter fraction contributed the highest portion to total litter production followed by the reproductive parts fraction. Litterfall production was strongly correlated with both seasonal rainfall and ambient temperature.

The average litterfall production of 8.7 t ha^{-1} $year^{-1}$ reported in this study for the Boter Becho forest is in agreement with results reported by other workers (Staelens et al., 2011; Chave et al., 2010; Yang et al., 2005; Murphy and Lugo, 1986; Rai and Proctor, 1986; Singh et al., 1999; Vituosek and Sanford, 1986; Williams and Gray, 1974). Apparently, the amount of total litterfall production reported in this study is in range with that reported for other tropical moist forests; 3.6 to 12.4 t ha^{-1} $year^{-1}$ (Vituosek and Sanford (1986). Litterfall production ranging between 9.7 to 12.6 t $ha^{-1}year^{-1}$ for broad-leaved plantation species and natural forest found in southern Ethiopia (Ambachew et al., 2012) is in agreement with results reported in this study. In equatorial rainforests litterfall production ranged between 5.5 and 15.3 t ha^{-1}

year^{-1} (Williams and Gray, 1974). Our results also concur with those reported from China where litterfall production ranged between 4.89 and 11.45 t ha^{-1} (Wang et al., 2008).

However, in India where dry tropical conditions prevail litterfall production ranged between 4.88 and 6.71 t ha^{-1}year^{-1} (Singh, 1992) which is considerably less than values reported in the present study. This difference may be attributed to differences in forest environments e.g. dry or moist tropical forests.

In the present study, the leaf litter fraction averaged 46% of the total litterfall production. This is considerably less than that reported by Gawali (2014) for Indian forests (46%) located in the sub-humid tropics and Wang et al. (2008) for Chinese forests (68%), respectively. Evidence of the greater contribution of leaf litter to total litterfall production in tropical and temperate forests is reported by other workers (Ewel, 1976; Hoque et al., 2015; Kumar and Tewari, 2014; Oziegbe et al., 2011) who also highlighted the importance of leaf litter in nutrient cycling in forest ecosystems.

Seasonal patterns of litterfall production

The observed monthly variation in litterfall production under both LD and HD in the Boter Becho forest may be attributed to prevailing seasonal factors particularly rainfall and ambient temperature. According to Liu (2012), both rainfall and temperature are good predictors of litterfall. The highest variation in the amount of annual litterfall in the Boter Becho is predominantly due to rainfall pattern as it was highly significant compared to temperature. It has been suggested that rainfall may have a two-fold influence on litter production as it may induce water stress in dry periods which increases shedding of senescent leaves whereas heavy rainfall at some time of a year force the shedding of non-senescent leaves. This cycle of events provides a nutrient pulse through higher qualities of leaf litter (Cuevas and Lugo, 1998; Johansson 1995; Morrison, 1991; Parker, 1983; Gosz et al., 1976).

It is also known that litter production follows a seasonal pattern with lowest values during wet seasons and highest values in dry seasons in tropical forest ecosystem (Sanches et al., 2008; Zhang et al., 2014; Scheer et al., 2009). The results are in agreement with this seasonal prediction, because litterfall production across all levels of disturbance was higher in the dry compared with the wet season. Similar results were reported under tropical conditions within the dry season (Ewel, 1976; Gawali, 2014; Arunachlam et al., 1998; Sundarapandian and Swamy, 1999). As expected, disturbance affected the rate of litterfall production which was greater in the LD compared with the HD sites. Similar studies were done previously support this finding (Barnes et al., 1998; Didham, 1998).

Conclusion

It is concluded that litterfall production in the Boter Becho moist evergreen montane forest followed multimodal distribution pattern in which litterfall peaked in March, April, December, January and February with maximum peaks observed in March and December. It is also concluded that even if the mean annual air temperature in wet season was relatively higher than that of dry season, the dry weight of the total litterfall and its fractions in dry season were significantly higher in both sites of the forest. Of the fractions in the total litterfall in both sites, leaf litter contributed the highest portion followed by the reproductive parts in the forest. A seasonal and annual variation in litterfall production was mainly driven by rainfall variation. Accordingly, future changes in seasonal rainfall patterns in response to anthropogenic disturbance as well as climate change will likely have direct and indirect impacts for the litter dynamics of Boter Becho forest. Consequently, monitoring litterfall production of the Boter Becho forest does not only provide a biological gauge of its health status but also provides essential biological information for decision-makers to develop appropriate management measures for its conservation or sustainability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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