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Forest Litterfall Production, Nutrient Analysis and Litter Turnover at Mt. Apo Permanent Plot, North Cotabato, Philippines

VICTORIA T. QUIMPANG
ORCID No. 0000-0003-1992-6359
vtquimpang@yahoo.com.ph

FLORFE M. ACMA
ORCID No. 0000-0002-0453-8575
flmacma@gmail.com

NOE P. MENDEZ
ORCID No. 0000-0002-6965-944X
npolomendez@gmail.com

DIANA ROSE Y. JACALAN
ORCID No. 0000-0002-6393-6389
everianajacalan@gmail.com

AURFELI D. NIETES
ORCID No. 0000-0003-1461-8883
aunietes0812@gmail.com

FULGENT P. CORITICO
ORCID No. 0000-0003-3876-6610
cfulgent@gmail.com

VICTOR B. AMOROSO
ORCID No. 0000-0002-1699-7760
victorbamoroso@gmail.com

Central Mindanao University
Bukidnon, Philippines

ABSTRACT

Litterfall is an important component of the nutrient cycle in forest ecosystems. Thus, this study was carried out to assess the litterfall production, analyze the leaf nitrogen (N), phosphorus (P) and potassium (K) contents, and compute the litter turnover in the established 2-ha permanent plot of the Long Term Ecological Research (LTER) site in Mt. Apo, North Cotabato, Philippines. Plant litter were collected from the traps installed below the dominant tree species, processed at the laboratory, and oven-dried between November 2012 – June 2013 and January – October 2015. The leaves (62%) contributed the largest fraction to total litterfall production, followed by woody (21%), reproductive (12%) and miscellaneous (5%) parts. Mean annual litterfall production was 758.41 g ODW/m^2 which had an estimated mean daily litterfall production of 1.99 g ODW/m^2. *Phyllocladus hypophyllus* Hook.f. contributed the highest litterfall production with 24.35% and least by *Lithocarpus apoensis* (Elmer) Rehder with 16.89%. The order of nutrient contents in leaves was highest in N, followed by K and lowest in P. The highest content of N was observed in *L. apoensis* (3.04%) and lowest in *P. hypophyllus* (2.10%). Amount of K was also highest in *L. apoensis* (1.70%) and lowest in *A. philippinensis* (0.58%), and the highest amount of P was also observed in *L. apoensis* (0.143%) and lowest in *P. hypophyllus* (0.076%). Litter turnover rate was faster in *L. apoensis* (3.29%) which will decompose within 68.38 days whereas slower in *A. philippinensis* (2.91%) which will decompose within 89.69 days. The mean annual litterfall production in Mt. Apo falls within the range of evergreen tropical forest studies and is dominated by gymnosperm species. Further, this study implies that Mt. Apo, having evergreen trees, is an old forest ecosystem as its aboveground leaf component accounts for less than 70% of the total litterfall production.

Keywords: gymnosperms, leaf N, P and K, litter turnover, oven-dry weight, tropical forest

INTRODUCTION

The forests are the major sources of primary production and are important for their economic goods and environmental services. The productivity of the forest just like any other biotic systems as wetlands is affected by fluctuating climatic conditions and land use (Anteau, 2012). One method of estimating forest primary productivity is the determination of tree litterfall production which is more than 50% of the net primary production (Bunt and Boto, 1979). Forest litterfall is the deposition of leaves, twigs, reproductive tissue, and other organic matter from the forest canopy onto the forest floor (Heineman et al., 2015). It is the major pathway of the nutrient cycling and serves as the primary link between producers and decomposers, in which by measuring the amount of litterfall, we can measure the primary productivity of the forest (Ukonmaanaho et al., 2008).

Litterfall is an important component of the nutrient cycle in forest ecosystems and the knowledge of these processes is essential for sustainable forest management (Novak et al., 2014). Litter on the soil surface intercepts and stores a certain amount of precipitation, thus reduce run-off and soil erosion (Rawat et al., 2009). It is also important as food source for some heterotrophic organisms which help in maintaining biodiversity, energy flow and productivity of the forest ecosystem (Florece and Melven, 1997). Evaluation of litterfall production is also important for understanding the nutrient cycling, carbon fluxes and disturbance ecology (Rawat et al., 2009).

The establishment of the Long Term Ecological Research (LTER) sites to assess and monitor forest primary production also provide a monitoring scale on the level and pattern of climate change and land use in the area. The monitoring of litterfall production was conducted in Mt. Apo Natural Park, which is one of the 13 Philippine LTER sites and the highest mountain in the Philippines reaching 2,954 masl (9,692 ft.).

FRAMEWORK

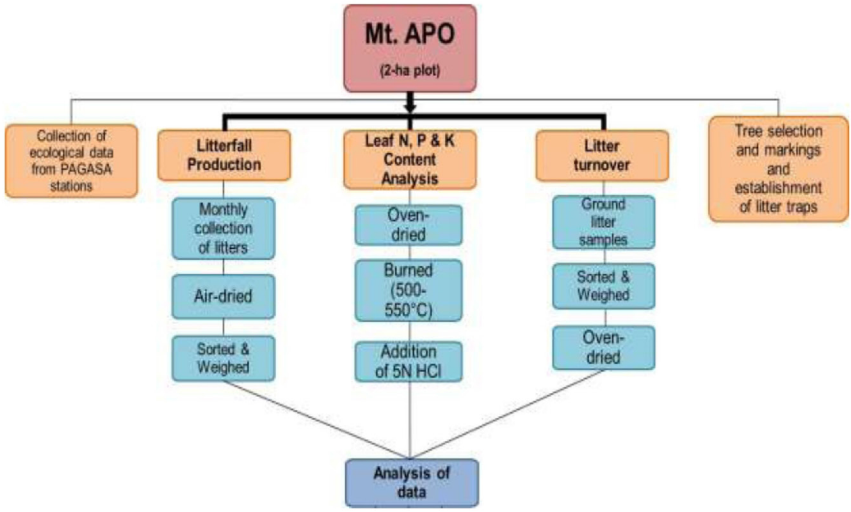

Figure 1. Overall framework of the study.

This study revolves on the nutrient cycling of the Mt. Apo 2-ha permanent plot which was determined from litterfall production and its litter turnover. These parameters characterized the estimated time on which the nutrients from the plants are returned to the soil for nutrient cycling process. The nutrients of the dominant trees of Mt. Apo were likewise analyzed to assess the nitrogen (N), phosphorus (P) and potassium (K) of the leaves (Figure 1).

OBJECTIVES OF THE STUDY

This study was conducted to: (1) classify the forest litterfall components and determine percentage composition; (2) compute the daily and annual litterfall; (3) describe the annual pattern of litterfall; and (4) estimate litter turnover in Mt. Apo permanent plot.

MATERIALS AND METHODS

Litterfall monitoring was conducted within the established 2-ha permanent plot in Mt. Apo (6°59'47.04"N 125°15'12.18"E), Kidapawan City, North Cotabato, Philippines at an elevation of 1,944 masl between November 2012 – June 2013 to January – October 2015 (Figure 1). It falls within the Type IV climate (almost even distribution of rainfall throughout the year) of CORONAS classification (1951-2003) of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA 2011). The forest characteristics including the climatological features were obtained to monitor the microclimate, such as the temperature and relative humidity using the HOBOware Data Logger.

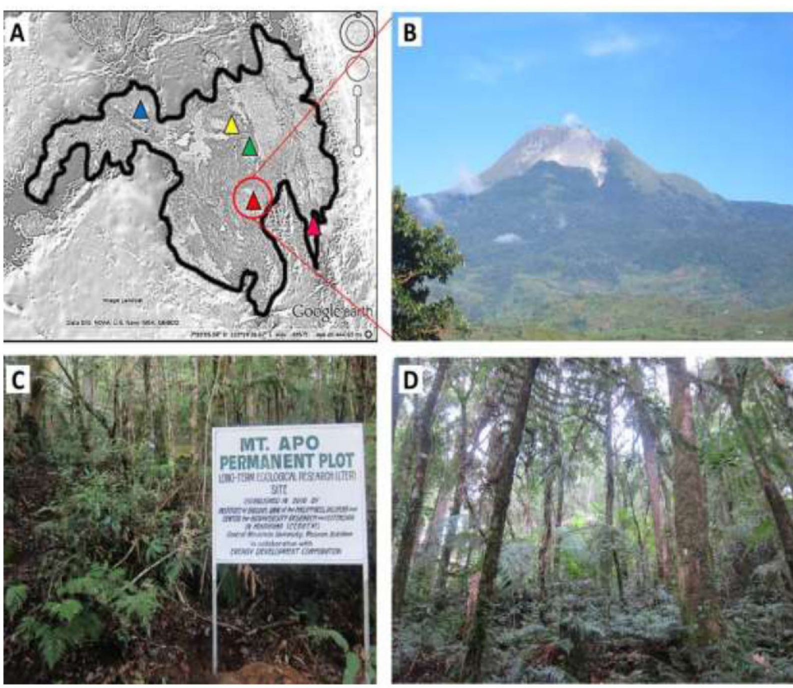

Figure 2. Study site. A) Map of the Mindanao Island showing the locations of the five Mindanao LTER sites; B) Panoramic view of Mt. Apo; C) Mt. Apo permanent plot; D) Mt. Apo forest trees.

Installation of litter traps and selection of dominant tree species

The permanent plot was delineated and a total of 20 litter traps were installed with the help of a geodetic engineer. The traps were made of 1 mm nylon mesh with a dimension of 1x1 m^2 and 0.25 m depth and were suspended using ropes about 0.5 m above the ground and tied to neighboring trees.

Five dominant and co-dominant tree species with four individuals for each species were chosen based on the tree species' diversity and diameter at breast height (DBH). The biggest was *Phyllocladus hypophyllus* Hook.f. (64.15 cm) wherein the smallest was *Cinnamomum mercadoi* S.Vidal (13.4 cm) (Table 1). All tree species near the installed litter traps that may contribute to the collected samples were also identified.

Table 1

Selected dominant and co-dominant tree species tagged for litter collection in Mt. Apo LTER mountain site.

Tree Species	Local Name	Family	Mean DBH and range (cm)
Agathis philippinensis	Almaciga	Araucariaceae	49.80 (25-116)
Phyllocladus hypophyllus	Tungog	Podocarpaceae	64.15 (15-137)
Lithocarpus apoensis	Ulayan	Fagaceae	37.20 (17-92)
Syzygium hutchinsonii	Malatambis	Myrtaceae	16.85 (13-21)
Cinnamomum mercadoi	Kalingag	Lauraceae	13.40 (4-31)

Litterfall Collection

Litter shed by the trees were collected monthly from the traps by handpicking and were placed inside labeled collecting bags (Li et al., 2005). The samples were weighed (fresh weight) using a digital weighing scale (1.0 g sensitivity), air-dried, weighed again (air-dry weight), and sorted out into leaves, woody, reproductive, and miscellaneous parts (i.e., dead insects, plants and others). Each sorted component was weighed again, placed in a labeled bag, and oven-dried at a temperature of 70–80°C for three days or until the litter became brittle. After drying, oven-dried litter were weighed again. Litter turnover was expressed in grams oven-dry weight (g ODW).

Analysis of Leaf N, P, and K contents

Fresh samples of green leaves were also taken from the five tree species and sealed inside zip-lock cellophane bags. The samples were submitted to the Soil and Plant Analysis Laboratory (SPAL) of the College of Agriculture, Central Mindanao University, Musuan, Bukidnon for N, P and K content analysis. To obtain the amount of nutrients contributed by the litter of the tree species to the soil/environment, the collected samples were oven-dried and the ground samples were burned at 500–550°C between 4–5 hours and followed by the addition of ashing aids (5N HCl).

Analysis of Litter Turnover

Litter turnover rate was obtained by installing 0.25 m^2 wooden frame on the ground below the litter traps of which the ground litter (free of soil) which were enclosed within the wooden frame were collected. The fresh weight of collected ground litter samples was measured, air-dried, weighed, and oven-dried. The litter turnover rate in percent per day (%/day) was calculated by dividing litterfall (g ODW/m^2/day) by litter standing crop multiplied by 100 and turnover time in days by dividing litter standing crop by litterfall (Zieman et al., 1979).

Litter Turnover Rate: % per day:

$$\frac{\text{LF g ODW/ m}^2\text{/day}}{\text{LSC g ODW/m}^2} \text{X100}$$

Litter Turnover Time: # of day:

$$\frac{\text{LSC g ODW/m}^2}{\text{LF g ODW/m}^2\text{/day}}$$

Statistical Analysis

All monthly collected litter in oven-dry weight were expressed in grams oven-dry weight per m^2 per month (g ODW/m^2/month). Descriptive analysis was used for litter quality, data comparison and determining relationship between variables. Percentage of litter component was determined by:

% of litter:

$$\text{Dry weight of leaves (\%)} = \frac{\text{Total weight of dried leaves of Sp1}}{\text{Total weight of all litter components of Sp1}}$$

% of species litter:

$$\text{Sp1 \% species litter} = \frac{\text{All dry weight of Sp 1}}{\text{Total dry weight of all litter of all tree species}} \text{ X100}$$

RESULTS AND DISCUSSION

Site Description

The dominant trees resulting to a close canopy cover in Mt. Apo permanent plot were the gigantic gymnosperms, such as *Agathis philippinensis* Warb. and *P. hypophyllus* and also the angiosperm species *Lithocarpus apoensis* (Elmer) Rehder. The permanent plot is a montane forest which has an elevation of 1,200 to 1,950 masl and mostly composed of *Syzygium hutchinsonii* (C.B.Robinson) Merr. (Malatambis), *Dacrycarpus* sp. (Banyas), *Podocarpus* sp. (Igem), *L. apoensis* (Ulayan), and an endemic species *A. philippinensis* (Almaciga). Temperature was highest in April 2013 (16.42°C) wherein minimum in February 2015 (14.90°C) (Fig. 3A). The highest humidity was recorded in June 2013 (97.63%) wherein lowest in February 2013 (87.35%) (Fig. 3B), and the maximum annual rainfall was recorded in June 2013 (181 mm) wherein minimum in March 2013 (97 mm) (Fig. 3C).

Mt. Apo with its mountain forest remained stable during the study. This study assessed and monitored five dominant trees. These trees were chosen based from the report of Higuera and Martinez (2006) that litterfall of the trees that dominate the canopy has a great influence in the availability of nutrients in the ground under their tops.

Litterfall Components

The leaves (62%) comprised the highest percentage of litter component, followed by woody (21%), reproductive (12%) and miscellaneous (5%) parts. This finding supported Cuevas and Lugo (1998) and Liu et al. (2004) that leaves account as a major component of the total litterfall and respond rapidly to climatic change. This study also supported Lebret et al. (2001) that leaves in older forests normally accounts for 70% or less in the aboveground litterfall. The proportions of the leaves in total above ground litterfall may provide good indication on the successional stage of tropical forests (Averti and Dominique, 2011). This is because older forests allocate more production to fruits, flowers, and seeds, and have more branch production than younger forests. This implies that Mt. Apo is an older ecosystem as its leaf component reaches less than 70% of the total litterfall production. On the other hand, the study of Quimpang et al. (2017) in Mt. Hamiguitan reported that the studied mountain site is a younger ecosystem as the leaves comprised 88% of the total litter production.

Species Litter Contribution

Phyllocladus hypophyllus contributed the biggest percentage of litter production, followed by *C. mercadoi, A. philippinensis, S. hutchinsonii*, and *L. apoensis*. These rates of litterfall are generally positively correlated with forest productivity (Adams and Attiwill, 1986; Araujo et al., 1989; George & Varghese, 1990; Adams & Attiwill, 1991; Thomas, 1992; Madeira et al., 1995; Moroni & Smethurst, 2003). However, based on the statistical analysis of the five dominant species, there was no significant difference in the litterfall production of these species. DBH of *P. hypophyllus* have the biggest measurement (64.15 cm) which contributed the highest litterfall production and percentage contribution of 24.35% among the five tree species. This is also true to the other gymnosperm species, *A. philippinensis* which ranked 2nd with biggest DBH (49.8 cm) and correlated as the 3rd highest contributing species (19.90%) next to *C. mercadoi*.

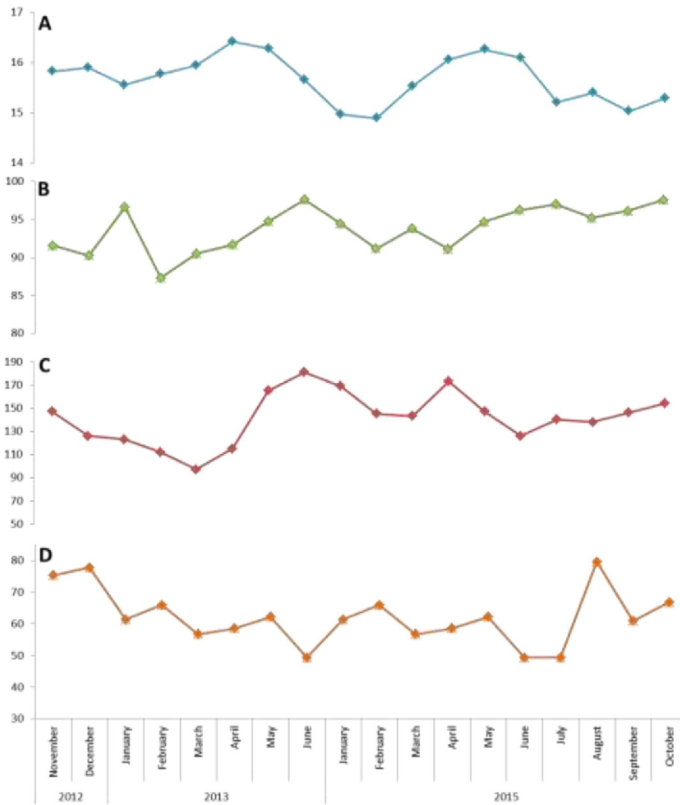

Figure 3. Monthly variation of parameters. A) Temperature, B) Relative Humidity, C) Rainfall, and D) Monthly patterns of litterfall production in Mt. Apo.

Daily litterfall production in Mt. Apo was observed descending and varied between the selected tree species with a mean average of 2.55 g. The highest peak was observed in August 2015 (Fig. 3D). The *P. hypophyllus* (2.29 g) was the most productive among the five selected tree species in terms of the litter production, wherein least in *L. apoensis* (1.44 g). Similarly, percentage contribution of the selected tree species in the litter production showed *P. hypophyllus* (24.35%) with the highest litterfall production but *L. apoensis* (16.89%) had the least contribution to the total litter production (Table 2).

Table 2

Percentage contribution of tree species in litterfall production in Mt. Apo

Five dominant tree species	Total	Mean (■)	Percentage (%)
Agathis philippinensis	1409.36	352.34	19.90
Phyllocladus hypophyllus	1724.30	431.07	24.35
Lithocarpus apoensis	1196.28	299.00	16.89
Syzygium hutchinsonii	1287.80	321.95	18.18
Cinnamomum mercadoi	1464.88	366.22	20.68

The litter production was descending in November 2012 (75.3 g) to July 2015 (49.28 g), but showed an increase in August 2015 (79.57 g). The increase could be due to tropical depressions/typhoons that had affected the Mindanao region. Mean annual litter production was 758.41 g ODW/m^2, in which this amount of production closely falls within the values obtained in other tropical forest studies of Gunadi (1992) with 900 g and 400 g in the two sites (Merapi and Merbabu sites) in Indonesia, Pandey et al. (2007) with 419.9 g and 547.7 g in the two forest types (plantation and forest) of northeastern India, and Wilcke et al. (2002) in tropical rainforest in Ecuador with 850–970 g.

The litterfall production in the present study is higher compared to other studies mainly because of some factors, such as the elevation, temperature and rainfall (annual 1,696 mm). As reported by many studies, the amounts of litterfall production were much higher in hot and wet months (e.g., April to September) than the rest of the year for all studied forests (Chen et al., 1992; Tu et al., 1993; Weng et al., 1993; Rawat et al., 2009). Pascal (1988) also reported that a heavy litterfall of leaf occurred during the dry season in evergreen forests of Attappadi, Western Ghats, India. Also, the generated data of Valenti et al. (2008) was affected by the season in tropical region because litterfall production is greater in dry season.

The tendency of litterfall to be concentrated in the cool and dry season is also related to a combination of decline in temperature and lowered soil moisture (Wang et al. 2008). However, monthly litterfall production pattern is still controlled mainly by community characteristics and environmental factors (Huebschmann et al., 1999; Sundarapandian and Swamy, 1999; Lu and Liu, 1988; Kavvadias et al., 2001; Pedersen and Hansen, 1999).

Leaf N, P, and K content

Nutrient analysis of leaves was recorded to be highest in N, followed by K, and least in P. The highest amount of N was observed in the leaves of *L. apoensis* (3.04%) and least in the leaves of *P. hypophyllus* (2.10%). The highest amount of K was observed in the leaves of *A. philippinensis* (1.70%) while least in the leaves of *A. philippinensis* (0.58%), and the highest amount of P was observed in the leaves of *L. apoensis* (0.143%) and least in the leaves of *P. hypophyllus* (0.076%) (Table 3).

Table 3

Leaf N, P, and K analysis on five selected tree species in Mt. Apo.

Five dominant tree species	Total N (%)	Total P (%)	Total K (%)
Agathis philippinensis	2.49	0.082	0.58
Phyllocladus hypophyllus	2.10	0.076	0.63
Lithocarpus apoensis	3.04	0.143	1.70
Syzygium hutchinsonii	3.01	0.093	0.75
Cinnamomum mercadoi	2.17	0.101	1.25

Many studies have suggested that initial N and P contents in leaf litter are good indicators of the decomposition rate (Sundarapandian and Swamy, 1999; Yang et al., 2004; Tateno et al., 2007). The nutrient analysis of leaves in Mt Apo forest having the order N>K>P resembles the data of Uma et al. (2014), but their study was in relation to ages of trees. This finding also supported Vitousek (1984) that P is the limiting nutrient in most tropical forest. The high N productivity inevitably leads to increase self-shading and thereby to an unfavorable light climate for leaves at the inner side of the canopy. This in turn, reduces the life expectancy of the leaves and increases nutrient losses (Aerts, 1990). The litter with low N concentration decayed faster than litter with high N concentration (Kaneko and Salamanca, 1999; Berg, 2000).

Overall, the tree species which had a greater contribution to total returns of N, P, and K, and its annual returns to soil systems via leaf litter were far greater contributed by *L. apoensis* than *P. hypophyllus*, as a result of both higher litter mass and higher nutrient concentrations in litter. This data was consistent to the study of Parrotta (1999) who found that the rates of nutrient return for N, P, and K were generally highest in mixed species than in single-species plantation.

Litter Turnover

The mean average of the five tree species in standing litter was 182.71 g, in which the highest was observed in *L. apoensis* (202.29g) and least in *S. hutchinsonii* (172.18 g). Mean average of turnover rate (%/day) was 3.16%/day, in which faster in *L. apoensis* (3.29%) which will decompose within 68.38 days wherein slower in *A. philippinensis* (2.91%) which will decompose within 89.69 days. Turnover time has a mean average of 74.64% (Table 4).

Table 4

Turnover rate and time of litter standing crop in Mt. Apo.

Five dominant tree species	Standing litter (g ODW/m^2)	Turnover Rate (%/day)	Turnover Time (Days)
Agathis philippinensis	179.66	2.91	89.69
Phyllocladus hypophyllus	182.74	3.12	76.43
Lithocarpus apoensis	202.29	3.29	68.38
Syzygium hutchinsonii	172.18	3.21	69.64
Cinnamomum mercadoi	176.71	3.26	69.05
Mean	182.71	3.16	74.64

Turnover rate is the percentage of litter standing crop to replace the litterfall every day. The mean average percentage turnover rate per day was faster in *L. apoensis* and the turnover time was faster in *A. philippinensis*. The higher the percentage of the turnover rate, the faster the decomposition and replacement of litterfall. Therefore, the faster the decomposition, the faster the productivity. The higher the rate of turnover time, the longer the litter turnover will stay on the ground. However, site conditions such as soil moisture, temperature, and fertility might also affect litter decomposition (Swift et al., 1979; Singh et al., 1999; Tripathi et al., 2006; Pandey et al., 2007).

Relating Litter Production to Environmental Parameters

The present study revealed that litterfall production in Mt. Apo has no correlation among the three parameters, namely temperature, relative humidity and rainfall. As shown in Table 5, there was no parameter which correlated the litterfall production. The coldest average temperature of Mt. Apo was 14.90°C and the average relative humidity was 76.31% and the maximum rainfall recorded was 181 mm in the month of June 2013. Total litterfall mass of all stands fall within the high range of values for moist tropical forests (Cuevas and Lugo, 1998).

Table 5

Correlation of litterfall production among temperature, relative humidity and rainfall

PARAMETER	Litterfall Production	Temperature	Relative Humidity	Rainfall
Litterfall Production	1			
Temperature	-0.087131518	1		
Relative Humidity	-0.372821671	-0.285097716	1	
Rainfall	-0.105440909	-0.229999659	*0.436591954	1

Litterfall production in forest ecosystem is determined by climatic condition, species composition, and successional stage in its development (Haase, 1999). It mainly depends on the site fertility, but the other factors such as air, temperature, soil water, and nutrient availability also determine the production of litter (Biswas and Khan, 2011). Cuevas and Lugo (1998) also added that there is significant positive correlation with maximum temperature in tropical species.

Temperature and precipitation are the most important climatic factors controlling ecological processes (Liu et al., 2004) and are related to litterfall (Martins and Rodrigues, 1999; Liu et al., 2004; Cianciaruso et al., 2006). However, litterfall production in this study has negative correlation with temperature, rainfall and relative humidity. The highest litter production was observed in August 2015 and descending from January–June 2013 and from March–July 2015 compared to the following months. The relative humidity and rainfall are almost uniform throughout the study. This data suggests that the climatic variables such as monthly mean and minimum temperatures and rainfall were not responsible for the patterns of monthly litterfall production. This supported Zhou et al. (2006) which indicated that their litterfall production in their five among the six studied communities was not significantly affected by precipitation in evergreen broadleaved forests.

Litterfall varies considerably between ecosystems, depending on climate, tree species composition, stand structure and soil fertility (Vitousek, 1986). Elevation might also strongly affect these parameters in montane ecosystems (Pabst et al., 2013; Becker et al., 2015; Ensslin et al., 2015) and is of particular importance regarding potential ecosystem shifts through climate change (Beniston, 2003). Therefore, the effect of elevation on litterfall is an important indicator for estimating future changes in ecosystem cycles (Becker et al., 2015). This might be the factor affecting the data in the present study; hence the three parameters did not correlate to the total litter production.

CONCLUSIONS

The leaves (62%) are the major contributor of the forest primary productivity in Mt. Apo, which comprised the highest percentage of total litter, followed by woody (21%), reproductive (12%) and miscellaneous (5%) parts. DBH measurement was significant in this study because those gymnosperms with bigger measurements were the ones with the highest production and percentage contribution to the total litter production. The Mt. Apo permanent plot has a mean annual litter production of 758.41 g ODW/m^2 which had an estimated daily litter production of 1.99 g ODW/m^2. Values for N, P, and K among the leaf samples of the tree species were quite similar, but the nutrients vary in their concentration. Returns of N, P and K via leaf litter were significant for nutrient cycling.

All tree species increase litter production and nutrient returns and are helpful in restoring soil fertility of the forest. Litter turnover rate was faster in *L. apoensis*

(3.29%) which will decompose within 68.38 days, wherein slower in *A. philippinensis* (2.91%) which will decompose within 89.69 days. The amount of litter that fell during the rest of the year and the contribution of other litterfall components with different nutrient concentrations was not significant. Data revealed that the mean annual litterfall production in Mt. Apo falls within the range of evergreen tropical forest studies and is dominated by gymnosperm species. Further, this study implies that Mt. Apo, having evergreen trees is an old forest ecosystem as its aboveground leaf component accounts for less than 70% of the total litterfall production.

RECOMMENDATIONS

The study needs a longer time of monitoring on the forest litterfall production to provide concrete information on the stability of the forest stands and its ability to sustain its multi-function by correlation. Results of the study must be disseminated to different stakeholders like the Department of Environment and Natural Resources (DENR) and to the respective Local Government Units (LGUs) as basis for their development plans and policy making.

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