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ORIGINAL RESEARCH PAPER

Ecology of litterfall production of giant bamboo *Dendrocalamus asper* in a watershed area

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ABSTRACT: Giant bamboo *Dendrocalamus asper* is recommended in environmental and livelihood programs in the Philippines due to its various ecological, economic and social benefits. However, there are limited data on the ecology of giant bamboo litterfall production, which contributes to soil nutrient availability. Bamboo also contributed in carbon sequestration. The study was conducted within the Taganibong Watershed in Bukidnon, Philippines. Nine litterfall traps measuring 1mx1m were established within the giant bamboo stand in the study area. Results show that giant bamboo litterfall is dominated by leaves. Biological characteristics of bamboo litterfall do no not influence litterfall production but temperature, wind speed and humidity correlate with the amount of litterfall. Findings of the study further revealed that fresh giant bamboo tissue contains high carbon content and the soil in the bamboo stand has higher organic matter than the open clearing. These data indicate the role of giant bamboo in carbon sequestration and soil nutrient availability.

KEYWORDS: *Leaf litter; bamboo stand; carbon sequestration; Pearson r; Philippines*

INTRODUCTION

While bamboo taxonomy is still incomplete, it has been recorded that 75 genera and 1250 species occur in the world, of which 55 species are found in the Philippines (Sharma, 1980; Sharma, 1987). According to Bystriakova *et al*. (2003), over 6.3 million km^2 of Asian forest potentially contains bamboo, with highest densities indicated from northeastern India through Burma to southern China, and through Sumatra to Borneo. *Dendrocalamus asper* (Schultes f.) Backer ex Heyne is planted throughout the South-East Asia from the lowlands up to about 1500 m-asl elevation (Dransfield and Widjaja, 2004). Globally, bamboo is recognized due to its ecological, economic and social benefits (Rivera, 1998; Ben-zhi *et al.,* 2005;Zhou *et al*., 2005; Kesari, 2006; Singh, 2008; Fu*et al.,* 2014). Razal*et al.,* (2012) stressed that bamboo resources in the Philippines provided people with income to support their families and improve their socio-economic status. In fact, ERDB (2016) specifically enumerated wide range of bamboo uses such as handicraft, furniture, engineered bamboo products for construction, chemical products such as beer, energy drink, textile for clothing and chemical products such as air freshener, disinfectant, deodorizer, biomass for energy and other products. Consequently, bamboo species are recommended in reforestation, forest rehabilitation and livelihood programs of the Philippine government agencies. This is due to its great potentials in protecting steep slopes, soils, and waterways (Mishra *et al*., 2014, Karbassi and Heidari, 2015). Despite the importance of bamboo in these efforts, data on the ecological benefits of bamboo are wanting. This study focuses on the role of bamboo in the ecology of an ecosystem, specifically

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on litterfall. Several studies have highlighted the role of litterfall in the development of soil and the growth and ecology of ecosystems (Gonzalez-Rodriguez, *et al.,* 2011; Ge *et al.*, 2014; Sharma and Sharma, 2004; Lowman, 1988; Gulis and Suberkropp, 2003; Tariq *et al.,* 2015). However, little is known about the litterfall dynamics of bamboo, which is seen to contribute to the development of soil. Thus, this study aims to analyse the litterfall production of a giant bamboo *Dendrocalamus asper* stand in a mixed reforestation site within the Taganibong Watershed in Bukidnon, Philippines. Specifically, it aims to: 1) determine the relationship between the amount of bamboo litterfall production with the height, diameter and number of bamboo culms; 2) correlate climatic factors with giant bamboo litterfall production; 3) determine the nutrient availability of fresh giant bamboo plant; and 4) compare soil nutrients between giant bamboo stand and the open clearing.

Literatures highlight the social, economic and ecological benefits of live bamboos but limited data on the contribution of litterfall, particularly on nutrient availability in the soil. This study focuses on the ecological services of bamboo litterfall production in terms of soil nutrient availability of a giant bamboo stand. Litterfall is not to be regarded simply as dead or decomposing materials because they contribute to restore soil productivity. This is a natural ecological process to reduce the economic cost of applying synthetic fertilizers to improve soil condition. The study has been performed as the part of the project entitled "Soil Erosion Management in Taganibong Watershed in Musuan, Bukidnon" with funding from the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development of the Department of Science and Technology (PCAARRD-DOST) and implemented by Central Mindanao University (CMU). As such study compares the nutrient availability of a giant bamboo stand and the adjacent open clearing.The study was carried out in in the watershed of Mindanao, Philippines from 2014 to 2015.

MATERIALS AND METHODS

This study was conducted within the Taganibong Watershed which lies between 124 °57 to 125° 35 East longitude and 748° 57 north latitude as shown in Fig. 1. The watershed is within the jurisdiction of the Municipality of Maramag, Bukidnon, south of the Philippines. The study area has a tropical rainy climate that falls under type A in the modified classification of PAGASA (Philippine Atmospheric, Geophysical and Astronomical Services Administration). Rainy months in Musuan, Bukidnon occur in June to October based on the data from Agromet Station of PAGASA located in CMU. Large tract is planted with stand trees such as *Gmelina arborea* while the rest are cultivated with agricultural crops such as sugarcane and corn.

The site for the litterfall production study is a giant bamboo *Dendrocalamus asper* stand within the study area. This bamboo stand is surrounded with secondary forest and grassland. The entire bamboo stand measures 0.92 hectares, with elevation of 392

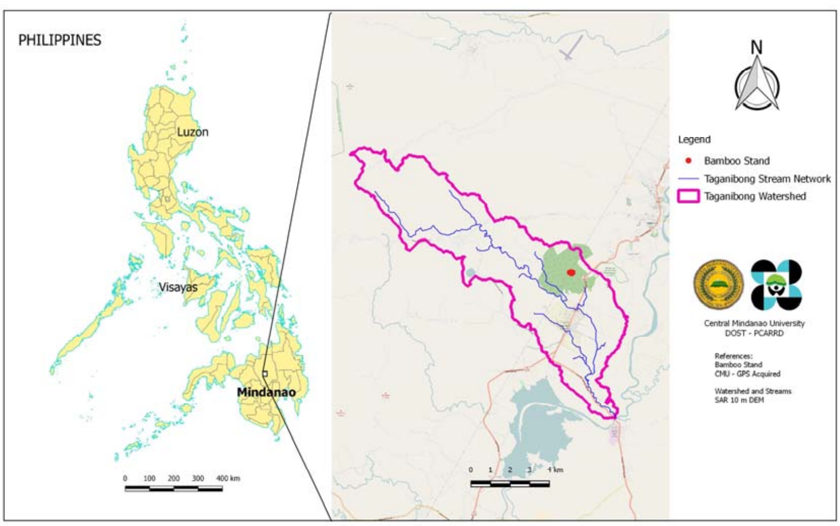

Fig. 1: Location of study area

masl and an average slope of 14% as shown in Fig. 2. Bamboos within the sampling site were described in terms of the number of culms (poles) per clump (cluster of poles); circumference, diameter and height of culm; and the circumference and diameter of clump. These data were used in the analysis of the amount of bamboo litterfall. Nine (9) litter traps measuring 1mx1m were randomly established within the giant bamboo stand. Litter samples were collected twice a month, with an interval of 2 weeks, from March 2014 to December 2015 to quantify the amount and composition of litterfall. The litter traps were made of net, which were perforated at the bottom to allow rain to drip out easily. Litter traps were placed five feet above the ground to capture litterfall and were regularly inspected in case of damage or loss. Collected samples were labelled with sample plot number and the date of collection. These were air dried and weighted with the use of digital weighing scale. Separate plastic bags were used for the segregation of dried litterfall and sorted into the following: twigs, stalks, branches, leaves and "others" or the unclassified, i.e. all remaining non-bamboo materials collected in the litterfall traps.

Grab sampling was used to analyse soil nutrients in the bamboo plantation and open area using soil auger. A total of nine soil samples were collected on the ground where the bamboo litterfall traps were established. To compare nutrients of the bamboo stand and an open clearing, a total of nine soil samples were also randomly collected in the adjacent open clearing. The clearing has a distance of 400 meters from the giant bamboo stand with an area of about 0.13 hectares. Soil samples were taken at a depth of 10cm and weigh about 0.5 kg. Samples were analysed at the Soil and Plant Analysis Laboratory (SPAL) at CMU for the following parameters; pH, organic matter (OM), available P, exchangeable K, particle density, bulk density and soil type. Tissue analysis of fresh giant bamboo plant parts were done to compare the amount of nutrients available in branch, leaf, sheath, stalk and twigs to determine which part contains the highest total N, P, K and carbon. Tissue samples were analyzed at SPAL-CMU.

Weather data were also collected using the established automatic weather station (AWS) located about 500 meters away from the study site for safety and security reasons. The AWS collected data on temperature, precipitation, wind speed and humidity. Data on the description of bamboo were analysed by obtaining the averages of the circumference, diameter and height of culms and clumps. Data on the amount of litterfall were analyzed using descriptive statistics such as summation and average while data on soil parameters used range values. Similarly, the amount of soil nutrients of bamboo plantation and the open clearing were compared. The amount of total N, P, K and carbon were compared in the tissues of fresh giant bamboo plant parts. Pearson r was used to determine relationship between litterfall production of bamboo with height, diameter and the number of culms per bamboo clump. This statistical tool was also employed to statistically correlate litterfall with climatic factors and soil quality.

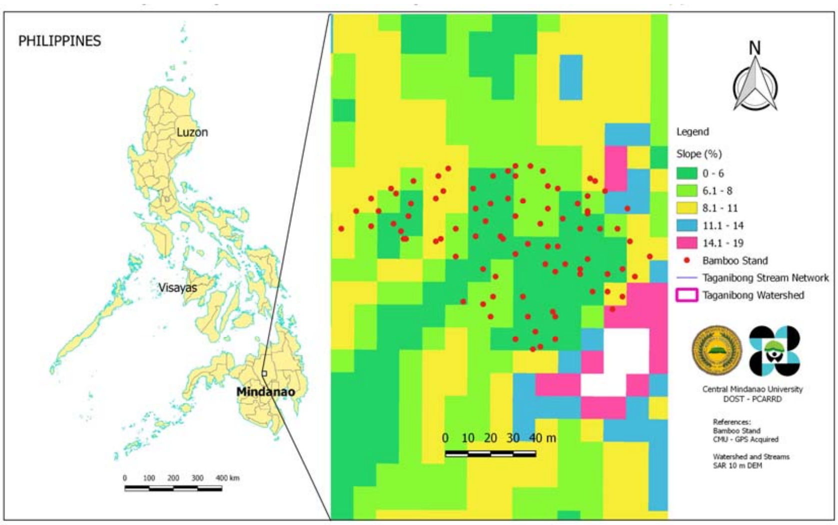

Fig. 2: Slope map of the location of the bamboo stand

RESULTS AND DISCUSSION

Distribution of Dendrocalamus asper in the study site

The *Dendrocalamus asper* stand in the study site was established in the production forest of CMU. Table 1 presents the characteristics of individual bamboo clump where the litterfall traps were established. Note that the height, diameter and circumference values do not differ considerably since the bamboos were planted at relatively the same time. Since its establishment, the bamboo stand has apparently accumulated litter on the surface of the ground that is dominantly composed of bamboo plant parts.

Dendrocalamus asper litterfall production

From March 2014 to December 2015, the total litterfall generated in the giant bamboo stand is 1,890.222 g or 201 g/m^2. The highest value reached 167.78g/m^2 obtained in April 2014 while the lowest value of 51.80g/m^{2}was collected in March 2014 (Fig. 3). Average litterfall per month is computed at 94.51g/m^2. In the study of Llejes (2013) on the giant bamboo litterfall in the same site, litterfall generated was 66.28 g/m^2/moduring the August to October 2014 sampling. The findings generated by Watanabe,*et al.* (2013) on Sasa dwarf bamboo in Northern Japan showed lower mean annual litterfall at 164 g/m^2/year, over the 3-year study period.

Based on the findings of this study, the giant bamboo litterfall generated is 945.1 kg/ha/yr.This is relatively low compared to the study conducted in a moso bamboo plantation in China in which litterfall before ice storm was 1,656.02 kg/haduring on-year and 1,927.92 kg/ha in off-year (Ge, *et al.*, 2014). On the other hand, Tu, *et al.* (2014) reported that the mean annual total aboveground litter production in a subtropical bamboo plantation in China ranged from

Table 1: Bamboo stand characteristics at the research site

Trap No.	No. of culms	Average culm circumference (cm)	Average culm diameter (cm)	Average culm height (m)	Average clump circumference	Average clump diameter (m)
1	29	33.00	10.50	17.0	9.73	3.10
2	41	37.50	11.94	14.5	12.80	4.07
3	36	43.25	13.77	18.5	12.71	4.04
4	50	52.00	16.55	21.5	12.29	3.91
5	33	42.00	13.37	21.0	10.85	3.45
6	24	44.00	14.00	20.0	10.57	3.36
7	50	42.00	13.37	21.5	9.88	3.14
8	27	45.00	14.32	18.0	7.99	2.54
9	22	42.00	13.37	17.0	6.00	1.91

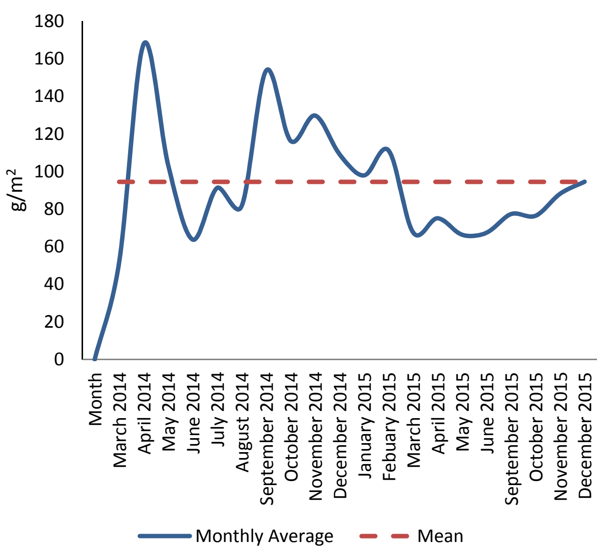

Fig. 3: Monthly mean bamboo litterfall from March 2014 to December 2015

494 to 434 g/m^{2}in two bamboo stands dominated by *Pleioblastus amarus* and a hybrid bamboo dominated by *Bambusa pervariabilis* and *Dendrocalamo psisdaii*. This is equivalent to an annual rate of 4,949 to 4,340 kg/ha for the said bamboo stand. Comparing the litterfall of bamboo stand with rainforest in Brazil, the annual litterfall deposition was 6,304 kg/ha and 6,527 kg/ha for the two thorn scrub forests with 300-350 masl elevation.

Analysis on the biological characteristics of bamboo culms and clumps where the nine (9) litter traps were placed revealed that the number of culms, circumference, diameter and height do not influence the production of litterfall as shown on Table 2. A similar finding was observed in the study of Llejes (2013) on giant bamboo litterfall production. This could be due to the fact that giant bamboos are planted, implying that these are of the same age and are uniformly distributed within the planted site.

Similarly with other studies on litterfall, this study also found out that leaves dominate the composition of litterfall accounting to 49.46% of the total litterfall generated during the entire sampling period, i.e. March 2014 – December 2015 as shown in Fig. 4. This is because leaves are lightweight that could easily be flown away when mature or dry. On the other hand, branches or bamboo poles only account 5% of the total litterfall generated due to its relatively heavy mass. This finding is consistent with the study of Llejes (2013) wherein leaf accumulates 72% while the lowest is "others" (1%) consisting of *Gmelina arborea* leaf that were deposited in the litter traps due to wind dispersion.

The study of Tu*et al.* (2014) indicates that ~80% litter production was contributed by leaf litter in two bamboo stands in China, followed by twigs and sheathes. This is consistent with the findings of Ge *et al.* (2014) wherein the mean annual percent of leaves in total litterfall was 99% at high elevation and 96% at low elevation all throughout the years of collection. Based from the study of Gonzalez-Rodriguez, *et al.* (2011), leaves composed 74% to 86% of total annual litter production in a rainforest of Brazil. The same was observed in the study of Lowman (1988) in a rainforest in Australia where leaf material averaged 54%, with 35% wood and 11%reproductive parts, over all sites and sampling duration. Lopes, *et al.* (2015) findings also corroborate with the data where leaves accumulated roughly 72% of the total litterfall of an arboreal/shrub (dryland) in Brazil. Furthermore, the study of Shanmughavel *et al.* (2000) have also consistent findings on *Bambusa*

Table 2: Pearson r correlation between bamboo stand characteristics and litterfall (g/sq.m.)

Plot Characteristics	Pearson r	P-value
Number of culms	0.205	0.597^{ns}
Average culm circumference (cm)	0.258	0.503 ^{ns}
Average culm diameter (cm)	0.258	0.503 ^{ns}
Average culm height (m)	-0.249	0.518 ^{ns}
Average clump circumference (m)	-0.028	0.942 ^{ns}
Average clump diameter (m)	-0.029	0.941 ^{ns}

ns = Not significant

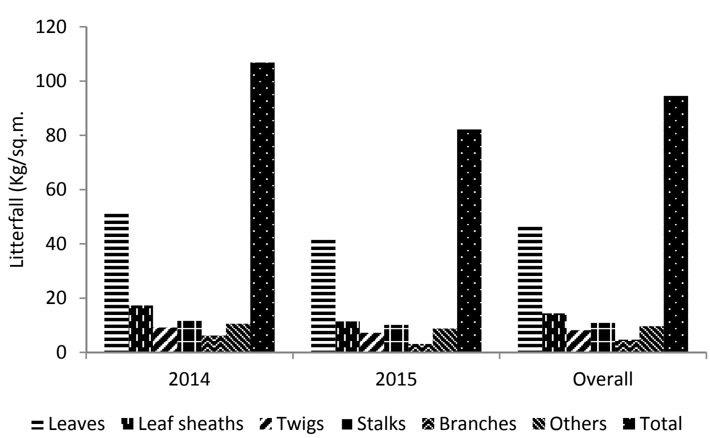

Fig. 4: Distribution of giant bamboo litterfall components

bambos where the total annual litter production is 58% for leaf-litters and the twig-litters accounts to 42%.

Statistical test using Pearson r further confirmed that there is a significant difference in the amount of litterfall generated among the components as presented in Table 3. The mean value of giant bamboo leaf litter is significantly higher as compared to the other components. Since the study site is a monoculture giant bamboo stand, then it is apparent that litterfall components are from the giant bamboo parts, with few composition from *Gmelina arborea* plant parts.

The influence of climate factors to Dendrocalamus asper litterfall

The monitoring of climatic factors such as temperature, precipitation, wind speed and humidity provided information on the influence of these factors to litterfall production. Fig. 5 presents the mean values of climate factors generated from the AWS established near the study site. The study site receives the highest precipitation in August and September 2015, i.e. 295 mm and 311 mm, respectively, and relatively dry during February and March 2015, i.e. 6mm and 10mm, respectively. In fact, a fire occurred in the site sometime in March 2015 that damage giant bamboo clumps in the site. The relatively dry and warm temperature triggered the fire occurrence due to human disturbance. Note that a sharp decline of litterfall production was recorded from March to December 2015 as shown in Fig. 3.

Data shown in Table 4 reveal that only temperature, wind speed and humidity have moderate to high correlation with litterfall production using Pearson r. This is similar to the findings of Fang *et al.* (2013) in which litterfall production is highly correlated with precipitation and wind speed for *Cunninghamia lanceolata* plantations (P0.05), followed by temperature and sunshine hours.

Table 4 also shows that there is a positive correlation with wind speed and giant bamboo litterfall. The action of the wind initiates movement of plant parts, especially leaves, resulting to litterfall. Constrastingly, there is a negative correlation with litterfall production and temperature, i.e. the higher the temperature, the lower the litterfall production. Note that the highest temperature of 29°C recorded in April and May 2015 coincided with the least amount of litterfall production. The succeeding decline of litterfall production may also be influenced by the occurrence of fire sometime in March 2015 that damage giant bamboo clumps. The

Table 3: Statistical comparison of giant bamboo litterfall by component

Component	Mean Litterfall (g/m^2)	F-value	p-value	Significantly Different Components
Leaves	46.74			Leaves vs. all
Leaf Sheath	14.37			Leaf sheath vs. leaves, twigs, and branches
Twigs	8.19	67.030	0.000*	Twigs vs. leaves and leaf sheath
Stalks	10.87			Stalks vs. leaves and branches
Branches	4.68			Branches vs. leaves, Leaf sheath, and stalks
Others	9.67			others vs. leaves

*= Significant at 0.001 (99.9% confidence level)

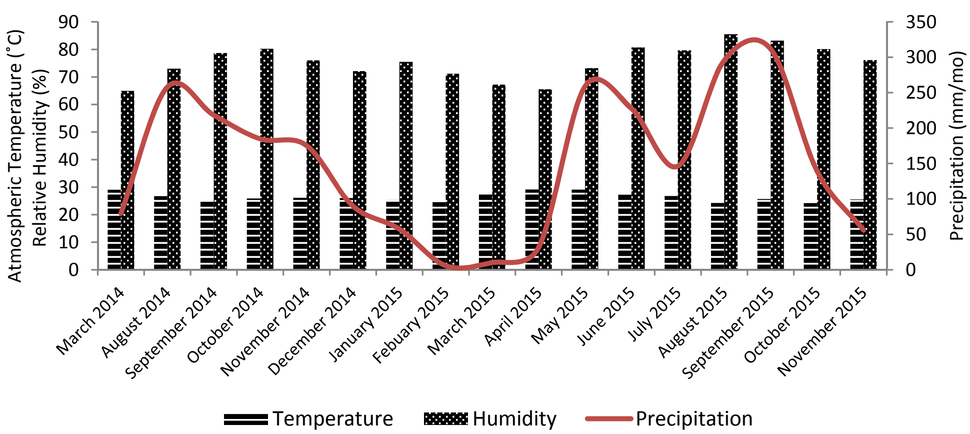

Fig. 5: Monthly climatic factors in the study site

partially burned giant bamboo clumps resulted to less litterfall, particularly leaf. But the amount of litterfall gradually increases by October to November 2015 with average temperatures reaching 24-25^{o}C.

In contrast, precipitation shows no correlation with litterfall. According to Delitti (2005), the relationship between litterfall production and rainfall actually depends on the type of ecosystem. For instance, the study of Lopes *et al.* (2015) revealed that the highest litterfall accumulation in the dryland vegetation of Brazil occur at the beginning of the dry season and the least during the rainy season. The less litterfall production during the rainy season is because plants optimize the use of water resources to produce new foliage to increase photosynthetic capacities (Suoto, 2006). However, Ndakara (2012) study on litterfall in the rainforest of Nigeria revealed that highest litterfall of *Terminalia catappa* stands occur during heavy rainfall, in contrast to the adjoining rainforests, which produced the highest litterfall during the dry season.

Dendrocalamus asper litterfall production and nutrient availability

One significant contribution of litterfall is on increasing organic matter (OM), which is essential to nutrient dynamics occurring in the soil. Results of the tissue analysis of fresh giant bamboo shown in Fig. 6 indicate that carbon is consistently the highest percentage while total phosphorus (P) is the least in all plant parts. Embaye *et al.* (2005) presented similar findings on Masha natural bamboo forest where phosphorus is lowest at 8 kg from a production of more than 8 t/ha/yr of plant litter. Nitrogen is highest with 15 kg while the K content is at 56 kg. On the other hand, Thomas *et al.* (2014) presented consistent findings on their study on the nutrient release dynamics of *Ochlandra setigera*, a rare endemic bamboo species of Nilgiri biosphere, where decomposing litter mass was in rank order N = Mg > K = Ca > P. Accordingly, nutrient release from litter was continuous and it was in synchrony with growth of new culms. Interestingly, Fig. 6 shows that the different bamboo components obtain a more or less the same values for carbon.

In the study of Patricio and Dumago (2014), *Dendrocalamus asper* obtained the highest average carbon stored at 173 Mg C/ha compared to *Bambusa vulgaris* and *Bambusa blumeana* at 57.29 MgC/ha and 53.59 MgC/ha, respectively. Comparing carbon sequestration potential of bamboo with other grass species, the study of Odiwe *et al.* (2016) comparing

Table 4: Pearson r correlation between climatic factors and litterfall components

Climate variables	Litterfall Components (g/m^2)						
	Leaves	Leaf sheath	Twig	Stalk	Branch	Others	Total
Temperature	-0.350	-0.611*	-0.486	-0.114	-0.904**	0.132	-0.629*
Precipitation	-0.146	0.271	0.157	-0.365	0.057	-0.314	-0.050
Wind Speed	0.543*	0.350	0.025	0.611*	0.382	0.186	0.525*
Humidity	-0.036	0.529*	0.404	-0.157	0.539*	-0.189	0.275

*= Significant at 0.05 (95% Confidence level)
**= Significant at 0.01 (99% Confidence level)
Unmarked values are not significant

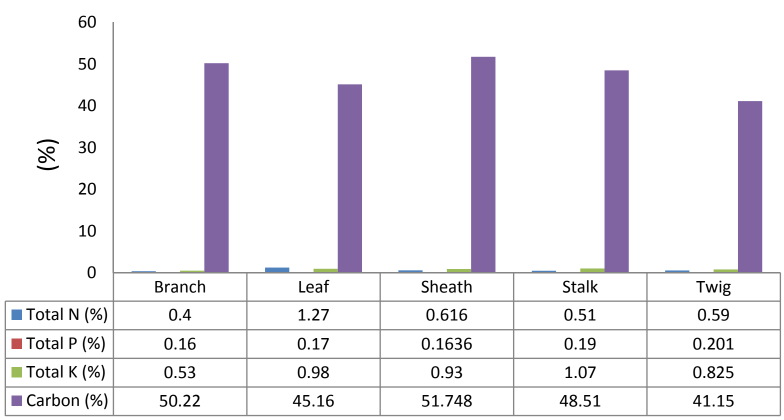

Fig. 6: Tissue analysis of giant bamboo for Total N, P,K and C

Table 5: Comparison of soil nutrients between a giant bamboo stand and an open area

Site	pH	OM (%)	Avail P (ppm)	Exch. K (ppm)	Classification
Bamboo stand	6.41	7.12	1.39	109.33	Clay
Open area	5.55	5.65	2.16	86.5	Clay

carbon stock of grass species revealed that *Panicum maximum* has the highest carbon stock of 26.6 Mg C/ha.

The data highlight the contribution of bamboo in reducing CO_2 emission. In fact, Yiping *et al.* (2010) declared that bamboo is a relatively important carbon store of the ecosystem.The study of Ge *et al.* (2014) also revealed that the average carbon content of litterfall in a moso bamboo is about 13%. For leaf litter, N range from 2.15% to 2.17%. Whilst, the amount of nutrient inputs through leaf litter is in this order: N > Ca > K > Mg > P . Given the data shown in Fig. 6 obtained the highest followed by K, N then P.

A comparison on the amount of nutrients found in the soil between a bamboo stand and the adjacent open clearing revealed that bamboo stand contains higher OM and exchangeable K (Table 5). Open clearing is also slightly acidic as compared to the bamboo stand. The high OM content of giant bamboo indicates its other contribution in the availability of nutrients in the soil due to the accumulation of litterfall. Zou *et al.* (2006) stressed that litterfall plays an important role in nutrient cycling and energy flow of forest ecosystems. In fact, Fukushima *et al.* (2015) reported that the rise in the C/N ratio of the broad-leaved secondary forest-floor organic matter in Kyoto, Western Japan was observed when moso-bamboo (*Phyllostachys pubescens*) invaded the area.

Bamboos are regarded as commodities that provide social and economic benefits both for the households and the society, in general. Bamboos are also planted in sloping, degraded areas and riverbanks to control erosion. However, findings of this study reveal the ecological contribution of bamboo litterfall in soil nutrients. The data generated from this study adds to the growing literature on the ecological role of litterfall, particularly bamboos. Thus, similar studies may be conducted to highlight the role of litterfall in the natural process of soil productivity and restoration of degraded areas.

CONCLUSION

This study generated findings that could add to the growing literatures on the ecological role of bamboos, particularly the giant bamboo. The biological characteristics of giant bamboo stand such as the number of culms, circumference, diameter and height is not correlated with the production of litterfall. The total litterfall generated in the giant bamboo stand from March 2014- December 2015 is 1,890.222 g or 201 g/m^2. Average litterfall is computed at 94.51 g/m^2/mo. From the total litterfall collected, leaf dominates which comprises 49.46% of the total litterfall. The correlation of litterfall with climate factors shows that only temperature, wind speed and humidity have moderate to high correlation. In terms of nutrient availability, giant bamboo fresh plant tissue contains highest C followed by K, N and P being the least amount. This implies the contribution of bamboo in carbon sequestration. Giant bamboo stand also contains higher OM as compared to the open clearing, which implies the contribution of giant bamboo litterfall in the availability of soil nutrients. The above data generated from this study reveal the ecological services of giant bamboo in terms of carbon sequestration and soil nutrient availability.

RECOMMENDATION

The methodology and application of the outputs of this study could be enhanced by extending the duration and sampling frequency to capture differences of litterfall production during dry and wet seasons over five years. A similar study may be conducted to compare the litterfall production and the amount of nutrients in tissues of different bamboo species. It would be interesting to compare the soil nutrients of bamboo and tree plantations. Given the ecological services of giant bamboo, it is also suggested to highlight the role of bamboo litterfall production in environmental protection and conservation initiatives, particularly on soil productivity restoration. Thus, planting of bamboo is recommended in sloping and degraded areas to restore soil productivity.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

1m x 1m	One meter by one meter
AWS	Automatic weather station
C	Carbon
C/N	Carbon nitrogen ratio
Ca	Calcium
cm	Centimeter
CMU	Central Mindanao University
CO_2	Carbon dioxide
DOST	Department of Science and Technology
ERDB	Ecosystems Research and Development Bureau
Exch. K	Exchangeable potassium
F-value	Statistical value for the F-test
g	Grams
g/m^2	Grams per square meter
ha	Hectare
K	Potassium
kg	Kilograms
kg/ha	Kilogram per hectare
kg/ha/yr	Kilogram per hectare per year
m	Meter
masl	Meters above sea level
MgC	Mega grams carbon
MgC/ha	Mega grams carbon per hectare
mo	Month
mm	Millimeter
N	Nitrogen
ns	Not significant
OM	Organic matter
p-value	Probability value
P	Phosphorus
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PCAARRD	Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development
Pearson r	Pearson producer moment coefficient of correlation
pH	Potential hydrogen
SPAL	Soil and plant analysis laboratory
t/ha/yr	Ton per hectare per year
vs	Versus

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