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Litterfall variation and soil nutrient dynamics in *Swietenia macrophylla*, *Samanea saman* and *Bambusa blumeana* woodstands: Implications for nutrient cycling and soil fertility

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Abstract

This study addresses the knowledge gap regarding litterfall dynamics in university wood stands, focusing on Tarlac Agricultural University and its diverse tree species. While extensive research exists on soil dynamics and litterfall in large-scale plantations and forested areas in the Philippines, university wood stands remain understudied. The research assesses and compares litterfall variation among *Swietenia macrophylla*, *Samanea saman* and *Bambusa blumeana*, exploring implications for nutrient cycling, soil fertility, and amelioration. Litterfall was collected using the catch net method, followed by soil nutrient analyses to establish correlations. Results indicate significant variations in litterfall quantity, organic matter, phosphorus, and nitrogen across *akasya, mahogan*y, and kawayang tinik woodstands. *S. macrophylla* (mahogany) shows the highest litterfall production (39.97 gday^{-1}), while *S. saman (akasya)* exhibits the highest organic matter content in both top and subsoil layers (2.23% and 1.69%). *B. blumeana* (kawayang tinik) woodstands demonstrate elevated nitrogen and phosphorus levels in the topsoil (0.09% and 27 ppm) while *S. saman* showing the highest levels in the subsoil (0.08% and 18 ppm). The study also highlights the influence of leaf senescence seasonality on litterfall production and species-specific nutrient composition in soil layers. Notably, kawayang tinik shows promise for soil amelioration due to its substantial litterfall production and positive soil quality impact. In conclusion, this research provides valuable insights into litterfall and soil nutrient dynamics in university wood stands, emphasizing the role of plant species and offering practical implications for soil management strategies. *B. blumeana* emerges as pivotal for enhancing soil fertility and amelioration, with broader implications for sustainable agriculture practices.

Keywords

Litterfall; nutrient cycling; Swietenia macrophylla; Samanea saman; Bambusa blumeana; SDG15 life on land

Introduction

Litterfalls are plant materials such as leaves, twigs and barks that have fallen to the ground due to natural processes or influences of various abiotic factors. During leaf senescence, portions of the plant's nutrients are reabsorbed into the leaves and through time, litterfall accumulation leads to the leaching of nutrients by rainfall, throughfall or by efforts of detritivores, leading to the release and breakdown of nutrients back into the soil. Once nutrients are resorbed into the soil, plants absorb them through their roots and aid in nourishment and growth.

Nutrients concentrated in leaf litter directly reflect soil fertility and served as the main pathway of nutrient recycling (1-3) especially for essential soil elements such as nitrogen and phosphorus (4, 5). Litter of leaves, needles, and herbaceous materials consequently provided more frequent inputs into the nutrient cycle in comparison to other sources and lack of leaf litter ultimately leads to soil degradation over time (6).

In the Philippines, while research on soil dynamics and litterfall variations has been extensive in large-scale plantations, mountainous, or forested areas, there is a noticeable gap in understanding these processes within local wood stand settings. Notably, Tarlac Agricultural University, recognized as a green university boasting diverse tree species within its wood stands, has yet to be a focal point for studies on litterfall variation and its consequential implications for soil fertility. As the university actively seeks to enhance its database in alignment with sustainable agriculture practices, comprehensive investigations are essential.

The objectives of this study were crafted to address the existing knowledge gap and contribute to the sustainable development goals of the university. These objectives are as follows:

- Determine the extent of variation in the amount of litterfall biomass produced by mahogany (*S. macrophylla*), akasya (*S. saman*) and kawayang tinik (*B. blumeana*).
- Identify differences in the amount of organic matter, nitrogen and phosphorus levels in the topsoil and subsoil layers of mahogany, akasya and bamboo woodstands.
- Determine the extent of relationship between the amount of litterfall produced by the selected plant species and the amount of organic matter, nitrogen and phosphorus found in topsoil and subsoil layers.
- Established the ecological significance of mahogany (*S. macrophylla*), akasya (*S. saman*) and kawayang tinik (*B. blumeana*) in terms of their potentials for soil amelioration.

Materials and Methods

Time and Locale of the Study

The study was conducted at the Tarlac Agricultural University located in Tarlac, Philippines. The area is an agricultural school compound, occupying 75 ha of land area and is known in the community as a cradle of various crops and trees. The area also houses various forested areas and woodstands including mahogany (*S. macrophylla*), akasya (*S. saman*) and kawayang tinik (*B. blumeana*). The study was conducted in the month of April 2020.

Establishment of Catch Net Sites and Litterfall Collection

Woven collection nets are used to gather litters of mahogany (*S. macrophylla*), akasya (*S. saman*) and kawayang tinik (*B. blumeana*). The traps were made of 1 mm nylon mesh with a dimension of 1×1 m^2 and 0.25 m depth and were elevated at about 0.5 m above the ground. The catch nets are suspended using ropes and are tied to bamboo poles. The catch nets were randomly placed in experimental sites which are chosen based on predominant vegetation occupying the area. Leaves, twigs and flowers that were fallen from the tree and collected in nets are gathered daily for four (4) weeks.

Obtaining Dry Matter Biomass

Air and oven drying were done daily to obtain the dry matter content of collected litters. Air drying was done in clean, open area for 24 hr followed by series of oven drying with temperature regulation at 65 °C for 16 hr. Daily oven drying is repeated until constant dry weight is obtained.

Soil Analysis

Soil analysis was also done to determine the levels of organic matter, nitrogen and phosphorus accumulated in top and subsoil layers in experimental sites. Visual soil structure assessment was utilized to determine soil sublayers. Topsoil samples were taken 25 to 30 cm from the soil surface while subsoil layers sample was taken 31 to 60 cm deep in the ground with characteristic lighter color and clay texture compared to the topsoil. Composite samples were also taken in each woodstands to ensure proper representativeness (7, 8). Collected composite soil samples were taken for analysis in the Benguet State University Soil Laboratory.

The amount of organic matter in the soil is measured using the Walkley-Black method. This process involves weighing and digesting soil samples with strong sulfuric acid. After adding potassium dichromate to oxidize the organic materials, a typical ferrous ammonium sulfate solution is used to titrate the excess dichromate. After calculating and converting the organic carbon content to organic matter, the findings are given as a percentage (9). As for the phosphorus content, the Olsen method was utilized. In this procedure, soil was extracted using sodium bicarbonate solution, then reduced with ascorbic acid after adding a molybdate-vanadate reagent. The sample was then calibrated using phosphorus standards and measured for absorbance (10).

The standard Kjeldahl method was also employed to calculate the total nitrogen content of soil. The procedure involves digesting the soil sample with concentrated sulfuric acid and a catalyst, followed by distillation of the produced ammonia. The ammonia was trapped in a boric acid solution, and the collected ammonia was titrated with a standard acid solution. The nitrogen content was then calculated, and results were reported as a percentage (11).

Statistical Analysis

The study utilized averages to describe the quantitative characteristics and differences of the amount of plant litters produced by different plant species, as well as the levels of organic matter, nitrogen and phosphorus in different soil layers. Pearson correlation and One-Way Analysis of variance (ANOVA) were used to determine relationships between the biomass, organic matter, nitrogen and phosphorus levels in the topsoil and subsoil layers. A T-test for independent samples was employed to assess the disparity in organic matter, nitrogen, and phosphorus content between the topsoil and subsoil across various plant species.

Results and Discussion

Results showed mahogany (39.97 gday^{-1}) produced higher litterfall biomass as compared to akasya (26.79 gday^{-1}) and bamboo (12.98 gday^{-1}). These results are largely associated with the seasonality of litter production among the plant species (Table 1). Numbers of studies have shown that litter production in mahogany plants is higher during periods of lower rainfall, and higher solar radiation and temperatures (12–14). This occurs to minimize water loss and control the transpiration process.

Table 1. Variation of Litterfall Biomass in Mahogany (*S. macrophylla*), Akasya (*S. saman*) and Kawayang tinik (*B. blumeana*).

Plant Species	Dry Matter Produced Per Day (Grams)
Mahogany	39.97 a
Akasya	26.79 b
Bamboo	12.98 c

F-computed = 24.51

F-critical value = 3.23

Probability = 1.28E-07 = .000

Means followed by different letters are significantly different at 5% level.

Since the majority of the plant litters collected was leaves, the biomass produced by the selected plant species is also largely related to their leaf area. Mahogany has the greatest leaf area compared to the akasya and kawayang tinik, thus obtaining the highest biomass. Leaves are generally the main constituents of litter and, as they decompose rapidly in forest ecosystems, they form the main route by which nutrients reach the soil (3, 14, 15).

As for akasya *(S. saman)*, peak litterfall production is from June to October (16, 17) while other studies suggest peaking in the months of July to December (18, 19). The peak litterfall for *B. blumeana* was studied to be during the winter seasons or from November to February, producing approximately 3640 kg/ha of litterfall, while some *Bambusa* species exhibited maximum litterfall by December to January (20, 21). Some studies suggest bamboo species lose 72–83% of the leaf litterfall during the winter season, 13–22% during the summer and 12–22% during the rainy seasons (22).

In terms of the organic matter, nitrogen and phosphorus contents in the soil layers, results revealed significantly higher levels of organic matter in the topsoil compared to the subsoil layer in all 3 plant species (Table 2). Specifically, in *S. macrophylla*, the topsoil recorded a measure of 1.23% organic matter, whereas the subsoils contained 0.6%. For *S. saman* woodstands, the topsoil exhibited a higher content with 2.23% organic matter, while the subsoils contained 1.69%. In the case of kawayang tinik woodstands, the topsoil revealed 1.78% organic matter, whereas the subsoils contained 0.95 units.

Table 2. Variation in Organic Matter, Nitrogen and Phosphorous Levels in Topsoil and Subsoil Layers of Selected Plant Species.

Plant Species	Soil Layer		Probability (2-Tail Test)	F-Computed Value	F-Critical Value
	Topsoil	Subsoil			
Organic Matter (%)					
Mahogany	1.23 a	0.6 b	.000	9.15E+15	2.055
Akasya	2.23 a	1.69 b	.000	8.77E+15	2.055
Bamboo	1.78 a	0.95 b	.000	6.54E+15	2.055
Nitrogen Levels (%)					
Mahogany	0.06 a	0.03 b	.000	8.77E+15	2.055
Akasya	0.01 a	0.08 b	.000	1.8E+16	2.055
Bamboo	0.09 a	0.05 b	.000	65535	2.055
Phosphorus Levels (ppm)					
Mahogany	18 a	13 b	.000	6.54E+15	2.055
Akasya	15 b	18 a	.000	65535	2.055
Bamboo	27 a	15 b	.000	65535	2.055

Row means followed by different letters are significantly different at 5% level.

Given that the accumulation, deposition and decomposition of litter and other organic matter mostly occur in the topsoil, it is expected that higher organic matter would be located in the topsoil layer in all plant species. Topsoil is the upper, outermost layer of soil, usually the top 2 inches (5.1 cm) to 8 inches (20 cm) and can account for as little as 40% or as much as 80% of the soil bulk. The topsoil contains the highest concentration of organic matter and microorganisms and is where most of the Earth's biological soil activity occurs (23, 24).

The observed variations in organic matter content among the plant species may be attributed to specific characteristics of their litterfall. For *S. saman,* the high amounts of organic matter may be associated with its litters lacking polyphenols coupled with the high amount of lignin. Polyphenols have an inhibitory effect on the decomposition of litter, while lignin makes plant parts resistant to the decomposition process (25, 26). Moreover, the linear or horizontal growth of branches typically present in *S. saman* trees may contribute to the decreased rate of decomposition and increased organic matter content in the soil. A study suggests that the growth pattern in branches of *S. saman* reduces light intensity under the canopy by 38% compared to open light pastures (27).

Significant differences between the amount of nitrogen in topsoil and subsoil layer in all 3 plant species is also evident from Table 2. Bamboo has the highest soil nitrogen content (0.9%) on the topsoil layer while *S. saman* showed the highest soil nitrogen levels in the subsoil (0.8%).

This outcome may be attributed to the naturally high nitrogen concentration found in bamboo litter. Various studies highlight that nitrogen is the most abundant nutrient in bamboo leaf litter, followed by phosphorus, calcium, and magnesium, contributing to an estimated annual return of nutrients through litterfall. Nitrogen levels have been reported to range from 28 to 49 kg/ha, phosphorus at 1.32 kg/ha, calcium at 33 to 85 kg/ha, and magnesium at 1.4 to 28 kg/ha (21). Another study proposes nitrogen levels to be approximately 120 kg/ha, phosphorus at 10 kg/ha, calcium at 60 kg/ha, and magnesium at 60 kg/ha (20). Furthermore, additional research indicates that roughly 2% of nitrogen, 0.2% of phosphorus, and 1% of potassium from bamboo leaves are reintroduced to the soil (28). Moreover, studies revealed nitrogen as the most efficient nutrient to be returned from the litter to the soil in bamboo plantations (29). Provided that most of the soil nutrients came from the litters, there has high possibility that the significant amount of nitrogen came from the litterfall of bamboo as well. *S. saman*, on the other hand, belongs to the family Fabaceae or Leguminosae; thus, it is considered to be a legume. Legumes have the ability to convert atmospheric nitrogen into available forms through the rhizobium bacteria in the roots, usually at the subsoil level.

Further analysis also revealed a significant difference between the amount of phosphorous in the topsoil and subsoil layer in all 3 plant species. The amounts of phosphorous in bamboo woodstands are highest among the three plant species in the topsoil layer (27 ppm), while phosphorous content of akasya litterfall is higher in the subsoil (18 ppm). The result of the study may still be related to the innate characteristics of the litters of the plants being studied. Studies suggest efficient phosphorus return via litterfall is noted in bamboo plantations, ranging between 13–29 kg per ha (21). Moreover, the innate immobility and prolonged residence time of phosphorus in bamboo soils may also contribute to the results obtained (20, 29). The high amount of phosphorus in the subsoil of *S. saman* plant could still be associated with the plant being identified as a legume.

Based on the data obtained, it can be concluded that soils of bamboo woodstands are the most fertile among the 3 plant species. Since soil fertility is largely correlated with litterfall nutrient return, it can further be concluded that litterfall from *B. blumeana* has the highest potential for soil amelioration. This result is supported by various studies recommending the use of bamboo litters, particularly kawayang tinik, in improving soil quality of badlands or soils that have high silt and clay contents, bulk density, and soil electric conductivity (30, 31). Another study also suggests incorporating bamboo litters to enrich soil and improve tree diversity in coastal ecosystems (32). Although *S. saman* also shows the highest amount of organic matter, this can be correlated with the inability of its litterfall to decompose efficiently due to the presence of polyphenols containing anti-decomposing properties (25).

Results further revealed that there is a highly significant relationship between the amount of litterfall and the amount of organic matter and phosphorus in the topsoil layer in all plant species (Table 3). The negative sign of the coefficient of correlation implies that the amount of organic matter and phosphorus in the topsoil layer tends to go high when the amount of litterfall is less and vice versa. The table also shows no relationship between the amount of litterfall and the amounts of nitrogen in the topsoil and subsoil layers, as well as the amount of organic matter and phosphorus in the subsoil layer.

Table 3. Relationship of the Amount of Litterfall of Plant Species with the Content of Organic Matter, Nitrogen and Phosphorus in Topsoil and Subsoil Layers.

Variables Correlated	Coefficient of Correlation	Probability (Significant value)
Amount of Litterfall × Amount of Organic Matter in Topsoil Layer	-.400	.009 **
Amount of Litterfall × Amount of Organic Matter in Subsoil layer	-.233	.155 ns
Amount of Litterfall × Amount of Nitrogen in Topsoil Layer	-.288	.064 ns
Amount of Litterfall × Amount of Nitrogen in Subsoil Layer	-.286	.067 ns
Amount of Litterfall × Amount of Phosphorous in Topsoil Layer	-.547	.000 **
Amount of Litterfall × Amount of Phosphorous in Subsoil Layer	-.286	.067 ns

not significant (**ns**); highly significant (******).

The above-mentioned trends are associated with the decomposition process, in that, as decomposition proceeds, the amount of litterfall decreases above ground, leading to the production of soil organic matter and release of nutrients such as nitrogen and phosphorus below ground. On the other hand, the faith of individual nutrients in the soil layers will largely be dependent on several factors, such as soil and plant type and nutrient mobility.

Conclusion

The study highlighted the variability of litter production in mahogany (*S. macrophylla*), akasya (*S. saman*) and bamboo (*B. blumeana*), its effect on soil fertility and its potential use for natural soil amelioration strategies. The results further show that litterfall production largely depends on the natural leaf senescent seasonality of each species, while elements in the different soil layers also depends on the natural mobilization process. Moreover, *B. blumeana* emerged as a promising candidate for soil amelioration due to its substantial litterfall production and soil quality. As such, the promotion of *B. blumeana* within local agroforestry and land management practices could serve as a strategic approach for enhancing soil quality and promoting sustainable agricultural ecosystems.

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Compliance with ethical standards

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