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WATER-RETENTION OF THE LITTER LAYER OF TREE-BASED SYSTEMS IN MT. PANGASUGAN, PHILIPPINES

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Tropical rainforests are frequently characterised by elevated temperatures and increased precipitation, which contribute to accelerated rates of soil erosion and leaching, hence, the key problems revolve around the loss of soil and water. The study evaluated the water-retention properties of the litter layer of five tree-based systems, natural forest, rainforestation site, narra plantation, mahogany plantation, and abandoned kaingin site in Mt. Pangasugan. Though the maximum water-holding capacity of the total litter layer and of the undecomposed litter layer did not vary across the five tree-based land covers, the maximum water retention capacity, which had the same trend with that of the effective water-retention capacity, were significantly higher in both the mahogany and narra plantations. Changes over time in the water-holding capacity were similar in the natural forest (7169 g kg^{-1}), the narra plantation (6891 g kg^{-1}), and the mahogany plantation (6427 g kg^{-1}). It is recommended to strengthen restoration and conservation efforts of natural forests to preserve the highly desirable hydrological properties of their litter layer. In addition, the use of mahogany and narra in tree plantation development show potential in forest restoration projects for soil and water conservation.

Keywords: nature-based solutions, climate change, forest restoration, soil and water conservation, water-holding capacity

INTRODUCTION

Forests are generally located in mountainous areas, supporting many ecosystem services such as source of wood products, atmospheric carbon (C) sequestration, local and regional climate regulation, and numerous cultural services linked with recreational activities and natural encounters (Bauhus et al. 2010, Gamfeldt et al. 2013, Miura et al. 2015, Mori 2017). One crucial function of forests in local climate regulation is their heavy involvement in the hydrologic processes. The process in which the canopy layer blocks rainfall, the litter layer interrupts the intercepted water, and the soil absorbs the remaining water to complete the hydrologic cycle (Zhou et al. 2018) significantly determines the water budget of a forest ecosystem (Llorens & Domingo 2007, Fan et al. 2015).

Serving as the border between the atmosphere and the soil, the litter layer is crucial in the hydrologic cycle. Generally, the litter layer comprises decaying plant matter in the form of undecomposed and semi-decomposed litters (Keith et al. 2010a, Keith et al. 2010b). The volume of rainwater that is readily accessible for permeation and overflow becomes altered when litter layer covers bare land and reallocates rainfall, which later impact the hydrological process of the forest (Guevara-Escobar et al. 2007, Keith et al. 2010a, Sato et al. 2004). In addition, the litter layer effectively conserves soil water (Deguchi 2006) and helps prevent excessive soil erosion (Staelens et al. 2008).

Most studies regarding how much water litter layers can hold are on with monoculture, distinct forest formation, or single plant species while some focused on the water-holding properties of litter layers across varying land cover types in a similar site in karst geography (Zhou et al. 2018). Exploring the water-holding properties of the litter layer of different land cover types within the same environmental condition is essential. This paper aimed to assess the capacity of the litter layer to absorb and retain (its water-holding characteristics) of five commonly found tree-based systems in Mt. Pangasugan, namely natural forest, narra plantation, mahogany plantation, rainforestation site, and abandoned kaingin site. Data gathered in this study is relevant in assessing the biological and hydrologic potential of forests in the tropical region, especially since rainfall events have become highly erosive in recent times. Furthermore, the study area has been susceptible to rainfall-induced landslides, flooding, and extreme weather events brought about by the changing climate. This will also guide the development of suitable soil and water management strategies and ecological rehabilitation approaches.

MATERIALS AND METHODS

Study site

The study sites are located in a natural forest (10°45'6.247N, 124°48'51.277E), mahogany plantation (10°44'57.09N, 124°48'30.817E), narra plantation (10°45'4.865N, 124°48'5.023E), rainforestation site (10°44'39.269N, 124°48'17.67E), and abandoned kaingin area (10°44'46.337N, 124°48'5.412E) which are situated at Mt. Pangasugan in Baybay City, Leyte (10°44' N, 124°48'E) (Figure 1). This mountain is located west of the Philippine fault line, which runs roughly through the middle of Leyte Island (Asio 1996), and at the western edge of a natural forest that is 150 km^2 or more in size (Heaney et al. 1989). Parallel ridges that form the mountain eventually descend to a small alluvial plain (Asio 1996). Andesitic and basaltic pyroclastic (Pangasugan formation) make up the majority of its geology (Asio 1996). The Modified Coronas Climatic Classification classifies the climate of the region as category IV, rainfall that is more or less uniformly distributed during the year, with an average annual rainfall of 2500 mm.

A natural forest contains indigenous trees that have naturally established themselves on the site (Convention on Biological Diversity [CBD] 2006, The National Forest and Nature Agency 1994). Mount Pangasugan, one of the remaining forests in the Philippines that is less disturbed, houses a vast area of natural forest. For this study

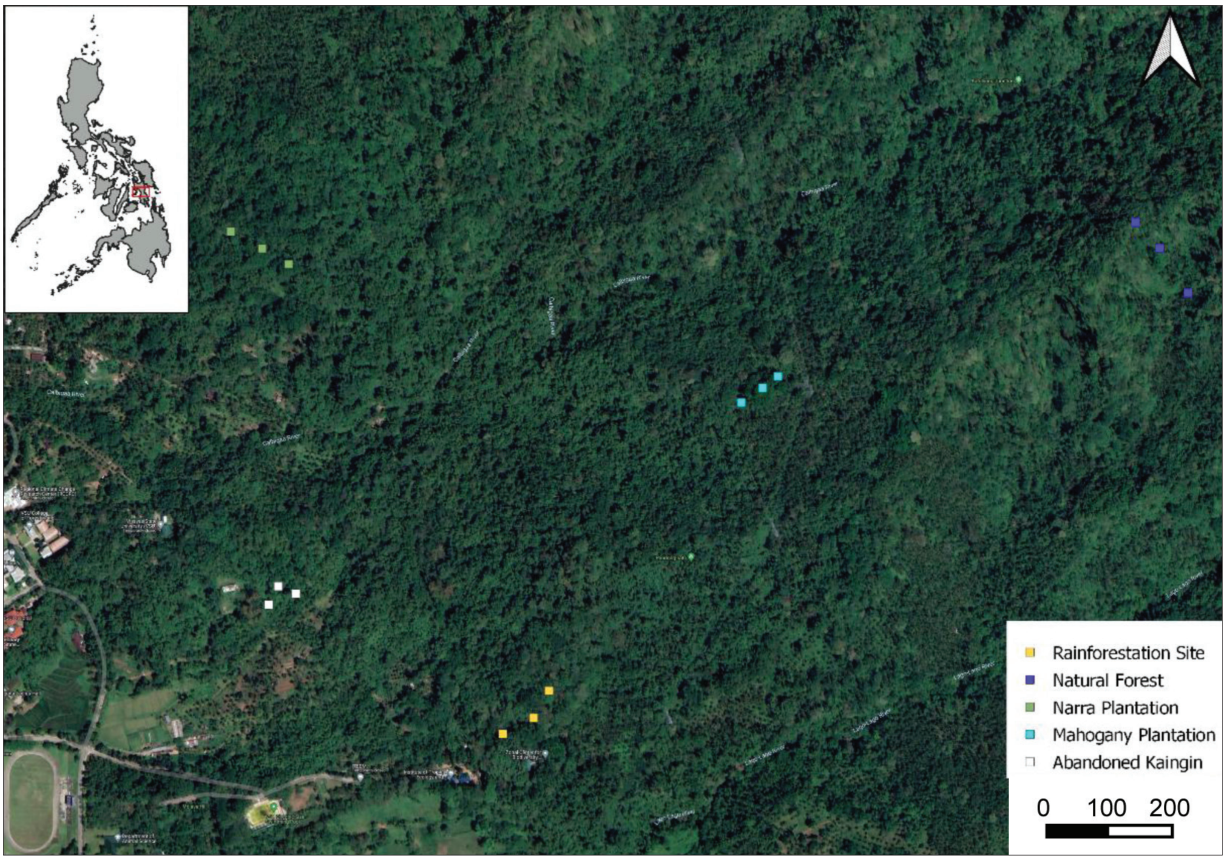

Figure 1 The Philippine archipelago, the Leyte Island, and the location of the sampling plots. ©QGIS v. 3.24.3-Tisler and Google Hybrid (2022)

the plots (10°45'6.247N, 124°48'51.277E), in the natural forest were dominated by *Anisoptera thurifera, Lithocarpus llanosii,* and *Strombosia philippinensis* with mean diameter at breast height (DBH) and height of 35.91 cm and 9.32, respectively (Table 1).

The narra plantation is a type of plantation forest dominated by *Pterocarpus indicus.* Currently, the narra plantation site (10°45'4.865N, 124°48'5.023E) has an understorey composed of various pioneering and other native tree species, (Appendix 3). The plots were dominated by *Coffea arabica, Ficus ulmifolia,* and *Pterocymbium tinctorium,* with trees having a DBH of ≥10 cm had an average DBH and height of 42.66 cm and 7.03 m, respectively.

The mahogany plantation is another type of plantation forest in an afforested land or secondary forest established through planting or direct seeding, mainly of *Swietenia macrophylla.* The mahogany plantation site in this study (10°44'57.09N, 124°48'30.817E) has a dense population of big-leafed mahogany with DBH averaging to 33.47 cm and average height of 6.33 m.

The Rainforestation site was established using the rainforestation farming technology whereby native tree species are gradually planted to restore and rehabilitate degraded lands. In 1992, a research plot with an area of 2.8 hectares of denuded forestland within the forested section of VSU along Mt. Pangasugan (10°44'39.269N, 124°48'17.67E) was established to observe the performance of a "closed canopy and high diversity farming system," now rainforestation (Baldos & Rallos 2019). Currently, the trees in the site with more than 10 cm in DBH has a mean DBH and height of 53.24 cm and 9.46 cm, respectively. The site is dominated by *Diplodiscus paniculatus, Parashorea malaanonan,* and *Dipterocarpus validus.*

The kaingin site is an area applied with a farming system that involves slashing and burning forests in lieu of planting agricultural crops. An abandoned kaingin site is an area applied with swidden farming (shifting cultivation) without subsequent rehabilitation or ecological restoration activities. The abandoned kaingin sites used in the study (10°44'46.337N, 124°48'5.412E) did not experience any management interventions. The plots were dominated by *Canarium luzonicum, Artocarpus blancoi,* and *Ficus ulmifolia,* with trees of more than 10 cm in DBH having a mean DBH and height of 24.94 cm and 5.45 cm, respectively.

Sampling procedure

Fifteen sample plots measuring 10 m × 10 m were set up, three in each tree-based system (natural forest, narra plantation, mahogany plantation, rainforestation, and abandoned kaingin site) in Mt. Pangasugan. Within each plot, tree height, canopy density, tree density, and tree diameter at breast height were measured. Dominant tree species were derived through the Importance

Table 1 Characteristics of the sample plots

TREE-BASED LAND COVER	MEAN DBH (cm)	MEAN HEIGHT (m)	TREE DENSITY (trees/ha)	CANOPY CLOSURE	DOMINANT SPECIES
Narra Plantation	42.66	7.03	1967	92.72	*Coffea arabica* *Ficus ulmifolia* *Pterocymbium tinctorium*
Mahogany Plantation	33.47	6.33	2467	94.11	*Swietenia macrophylla* *Artocarpus heterophyllus* *Ficus latsoni*
Rainforestation	53.24	9.46	1,233	91.68	*Diplodiscus paniculatus* *Parashorea malaanonan* *Dipterocarpus validus*
Natural Forest	35.91	9.32	1,950	97.57	*Lithocarpus llanosii* *Strombosia philippinensis* *Anisoptera thurifera*
Abandoned Kaingin	24.94	5.45	1,467	89.6	*Canarium luzonicum* *Artocarpus blancoi* *Ficus ulmifolia*

Value Index by adding the relative frequency, relative density, and relative dominance (Curtis & McIntosh 1950). Canopy density was measured using a spherical densiometer. Tree density was derived from the formula: (average number of trees per plot)/((100 m)^2/10000 ha)

Five 30 cm x 30 cm quadrats were chosen from each plot—four at each corner and one in the diagonal middle. The entire litter layer's thickness, including the semi-decomposed and undecomposed parts of it, were sampled. Litter layer whose shape and colour were still unchanged and the sources still identifiable was defined as undecomposed, while litter layer with altered shape and colours but which sources can still be identified was defined as semi-decomposed (Chen et al. 2018).

Quantification of the litter water-holding properties

Litter samples were first air-dried indoors in an area with good air circulation then placed in an oven at 75 °C to finish drying; the dry weights were used to determine the litter mass (Carnol & Bazgir 2013). A soaking experiment was conducted in the laboratory to ascertain the litter›s ability to contain water (Gong et al. 2007).

Fifty grams of dry litter were placed inside a gauze bag with a pore size of 0.2 mm and submerged in a plastic basin of clean water. The soaking times ranged from five minutes to a whole day. Specific soaking times were at five, 20, 30, 60, 90, 120, 240, 360, 480, 600, 840, and 1440 minutes. Each of the gauze bags were removed from the basin of clean water, and were hung on a line until water stopped dripping, after which their weights taken using an electronic balance. After 1440 minutes or 24 hours of soaking, maximum water-holding capacity is considered achieved (Gong et al. 2007). Estimation of the water-retention capacity of the litter was done using the formula by Li et al. (2015):

$$R_0 = \frac{M_1 - M_2}{M_2} \times 100 \qquad (1)$$

$$W_1 = M_{24} - M_0 \qquad (2)$$

$$R_1 = \frac{M_{24} - M_0}{M_0} \times 100 \qquad (3)$$

$$W_2 = R_2 \times M_2 \qquad (4)$$

$$R_2 = R_1 - R_0 \qquad (5)$$

$$W = 0.85R_1 \times R_0 \qquad (6)$$

where M_0 is the litter weight after air drying in a well-ventilated indoor environment, M_1 is the fresh weight of the litter sample, M_2 is the weight of the litter after oven drying, and M_{24} is the weight of the litter soaked for 24 hours (all measured in grams). R_0, R_1, and R_2 represent mean water content (Equation 1), maximum water-holding capacity (Equation 3), and maximum water-retention capacity (Equation 5), respectively (all measured as percentages) W_1 and W_2 are the maximum water-holding capacity (Equation 2) and water-retention capacity (Equation 4), respectively; W is the effective water-retention capacity (Equation 6), and M is the litter mass (the W and M values will be measured in t ha^{-1}).

Statistical analysis

Variables tested for significant differences among the five tree-based systems were litter mass, litter thickness, and the water-retention characteristics of the litter (maximum water-holding capacity, maximum water-interception capacity, and effective water-interception capacity). For variables with a normal distribution and homogenous variance (Haynes 2013), a one-way analysis of variance (ANOVA) followed by Tukey HSD ($p \leq 0.05$) were performed, otherwise, Kruskal-Wallis ANOVA with a multiple-comparison extension test was applied (Kruskal & Wallis 2008) were done. Data analyses were performed using the R Program (R Core Team 2022). The package "car" was used to perform one-way ANOVA and "agricolae" was employed to make multiple comparisons of treatments by means of Tukey using the default level of alpha 0.05 (HSD test; de Mendiburu & Yaseen 2020). The package "pgirmess" was used to make multiple comparison tests between treatments or treatments versus control after the Kruskal-Wallis test (Siegel & Castellan 1988). Figures were made using "ggplot2", "patchwork" and "gridExtra".

RESULTS AND DISCUSSION

Litter thickness and mass

Total litter and semi-decomposed litter was significantly thicker ($p \leq 0.05$) in the natural forest (8.33 cm and 4.41 cm) and rainforestation site (6.45 cm and 4.12 cm) while the undecomposed litter layer was significantly thicker in the natural forest (3.92 cm). The mahogany plantation had a substantially thicker semi-decomposed and total litter layer than the narra plantation and abandoned kaingin site (Figure 2). Semi-decomposed litter type comprised 70.83 % of the total litter mass in the narra plantation, 58.77 % in the mahogany plantation, 64.35 % in the rainforestation site, 64.54 % in the abandoned kaingin area, and 63.40 % in the natural forest (Figure 3). These findings may be attributed to the differences in the abscission period of the tree species across the study area, the size of the litter, and the degree of decomposition. As leaves have larger surface areas, they tend to consume more space on the forest floor, thereby resulting in higher litter thickness. This result supports the findings of Li et al. (2013) that aside from the abscission period, forest litter layer thickness in North China was also governed by the size of the leaf litter and the degree of decomposition. The intensity and frequency of rainfall events might also influence the degree of decomposition of litter (Liu et al. 2005). The significantly lower litter thickness of the abandoned kaingin site may be due to the sparser canopy closure of the vegetation.

Total litter layer thickness in the sampled sites in Mt. Pangasugan ranged from 2.52 cm to 8.33 cm (Figure 2). Comparing these values to those obtained by Zhou et al. (2018) which varied from 4.1 cm to 5.6 cm, some were lower and some were higher. With these values (Benkobi et al. 1992), the litter layer in Mt. Pangasugan may be able to absorb the energy of rainwater while inhibiting soil erosion, upholding high infiltration rates, and covering soil surface from the atmosphere hence reducing evaporation rate facilitating a lowered soil temperature (Walsh & Voight 1977).

The highest total and undecomposed litter mass were recorded in the abandoned kaingin area (52.47 Mg ha^{-1} and 48.73 Mg ha^{-1}) (Figure 3). This can be attributed to the leaf litter morphology, leaf size, and leaf shape of the tree species with the most number of stems in the area (e.g. *Artocarpus blancoi, Canarium luzonicum,*

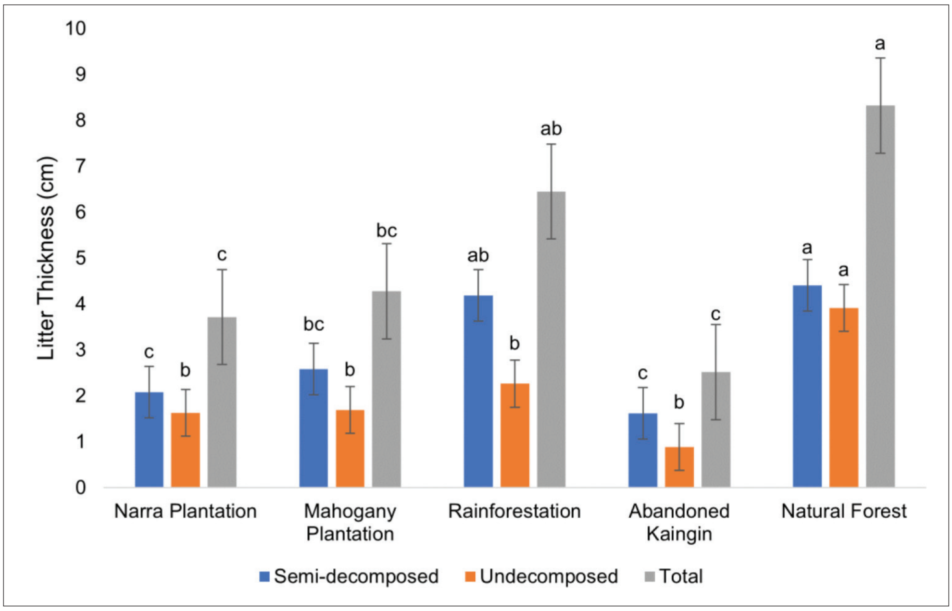

Figure 2 Litter thickness per litter type of each tree-based system. Comparison is for each litter type between tree-based systems. Different letters on bars with the same colour (same litter type) are significantly different from each other (p ≤ 0.05)

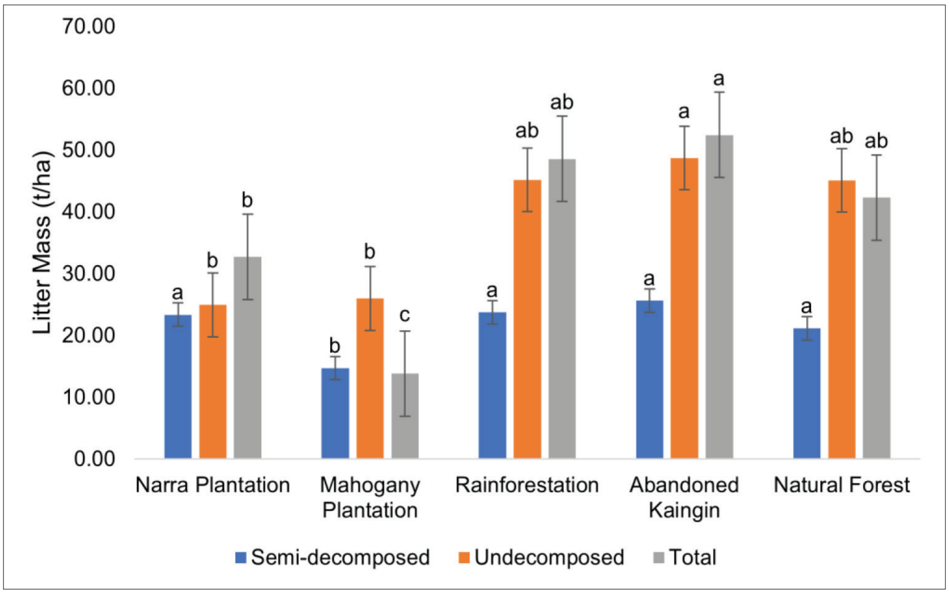

Figure 3 Litter mass per litter type of each tree-based system. Comparison is for each litter type between tree-based systems. Different letters on bars with the same colour (same litter type) are significantly different from each other ($p \leq 0.05$)

and *Ficus ulmifolia*). The natural forest and rainforestation site had significantly higher ($p \leq 0.05$) total (42.33 Mg ha^{-1} and 48.60 Mg ha^{-1}, respectively) and undecomposed litter mass (45.10 Mg ha^{-1} and 45.20 Mg ha^{-1}, respectively) than the narra and mahogany plantation (32.73 Mg ha^{-1} and 24.97 Mg ha^{-1}; 13.87 Mg ha^{-1} and 26.00 Mg ha^{-1}, respectively). For the semi-decomposed and total litter layer, the mahogany plantation (14.74 Mg ha^{-1} and 13.87 Mg ha^{-1}) had the lowest litter mass (Figure 3). These differences may be due to the differences in the degree of decomposition, size, and shape of the litter across the five tree-based land covers. Additionally, the differences in the abscission period of the tree species across the study area may have also caused the differences in the litter mass since the more litter accumulated on the forest floor, the greater the litter mass will be derived. The total litter mass in Mt. Pangasugan ranged from 13.87 Mg ha^{-1} to 52.47 Mg ha^{-1}.

Maximum water-holding capacity of the litter layer

The highest water-storing ability of the litter layer is the greatest volume of water that the litter layer can retain. The maximum water-storing ability of the total litter layer and undecomposed litter layer across the five tree-based systems in Mt. Pangasugan was uniform. No significant differences were found between the semi-decomposed and undecomposed litter layers in all five tree-based systems (Figure 4). The similarity in the undecomposed and semi-decomposed litter layers support the findings by Zhou et al. (2018). For the semi-decomposed litter, the maximal water holding capacity was slightly greater in the narra plantation (16.18 Mg ha^{-1}) versus the mahogany plantation and rainforestation site (12.09 Mg ha^{-1} and 10.82 Mg ha^{-1}, respectively). The trend in the maximal water-storing capacity of the semi-decomposed litter layer was narra plantation > mahogany plantation ≈ rainforestation site > natural forest ≈ abandoned kaingin site (Figure 4).

The maximum water storage ability of the total litter layer in Mt. Pangasugan, which ranged from 20.57 Mg ha^{-1} to 34.04 Mg ha^{-1}, was higher than that found in the findings by Cui et al. (2007) which ranged from 10.40 Mg ha^{-1} to 12.18 Mg ha^{-1}. Additionally, the investigation of Zhang et al. (2009) revealed that the maximal water-storing ability in their study area varied from 27.60 Mg ha^{-1} to 32.10 Mg ha^{-1}. These values were in the range of the maximal water-storing ability of the entire litter layer in Mt. Pangasugan. Environmental conditions, like higher precipitation and temperature that do not restrict the growth of trees facilitate litter

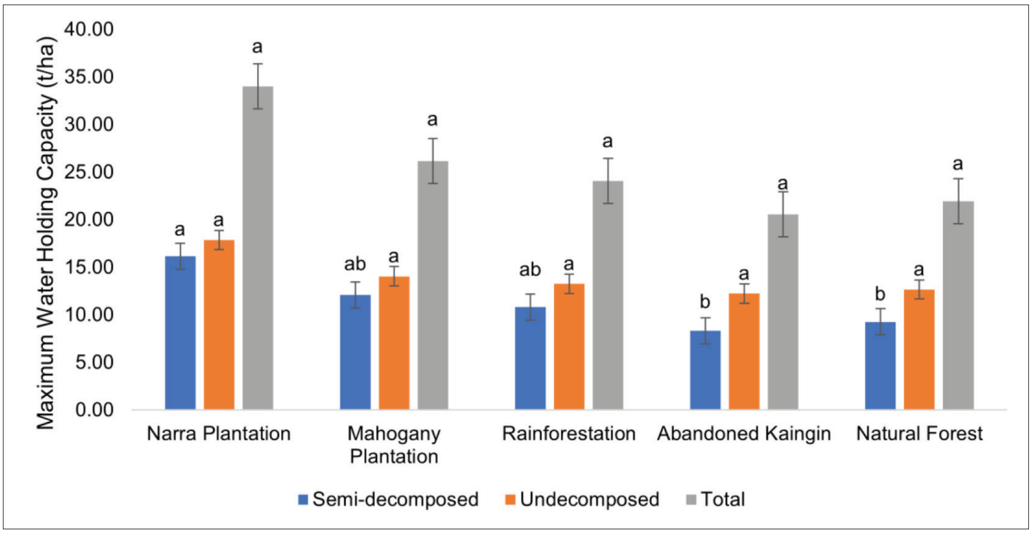

Figure 4 Maximum water holding capacity per litter type of each tree-based system. Comparison is for each litter type between tree-based systems. Different letters on bars with the same colour (same litter type) are significantly different from each other ($p \leq 0.05$)

accumulation, resulting in a greater volume of litter layer in the forest floor which further results in a greater capacity of the litter layer to hold more water (Zhou et al. 2018).

Maximal and effective water interception capacities of the litter layer

In order to quantify the litter layer's ability to arrest rainfall (note that 1 Mg ha^{-1} is equivalent to 1 mm of precipitation), the values of the maximal and effective rainfall interception abilities were utilized. These capacities differed across the five tree-based land covers and their litter types (Figure 5a and 5b). The maximum rainfall interception capacity of the semi-decomposed and total litter layer was considerably higher in the mahogany plantation (34.10 Mg ha^{-1} and 112.65 Mg ha^{-1}, respectively). On the other hand, the undecomposed litter's maximum rainfall interception ability was significantly higher in both mahogany (81.53 Mg ha^{-1}) and narra plantation (78.55 Mg ha^{-1}) (Figure 5a). The high total maximum water-retention capacity in mahogany plantation may be due to the combination of the high interception storage capacity of the semi-decomposed and undecomposed litter layer. Rainfall intensity plays a pivotal role in the interception storage capacity (Li et al. 2013). Since it was raining during the collection of litter samples in the mahogany and narra plantation, this might have resulted in a significantly higher ($p \leq 0.05$) maximum water retention capacity. On the other hand, the weather was clear during the collection of litter samples in the natural plantation, abandoned kaingin, and rainforestation site.

In Mt. Pangasugan, the trends for the effective rainfall interception ability were identical to the maximum effective rainfall interception capacity. The effective rainfall interception capacity of the semi-decomposed litter layer in the mahogany plantation (28.98 Mg ha^{-1}) was approximately six times higher than narra plantation (4.61 Mg ha^{-1}) and five times higher than the rainforestation site (5.59 Mg ha^{-1}). The undecomposed litter's effective rainfall interception capacity of the narra plantation (68.30 Mg ha^{-1}) and mahogany plantation (67.77 Mg ha^{-1}) was approximately twice higher than rainforestation site (31.86 Mg ha^{-1}) and natural forest (30.85 Mg ha^{-1}), and thrice higher than abandoned kaingin (21.49 Mg ha^{-1}). The effective water retention capacity for the total litter layer of the mahogany plantation (96.76 Mg ha^{-1}) was approximately twice higher that the rainforestation site (37.45 Mg ha^{-1}) and abandoned kaingin area (36.37 Mg ha^{-1}). For the maximum and effective water retention capacities, the trend for the semi-decomposed litter layer was mahogany plantation > natural forest ≈ abandoned kaingin > rainforestation site ≈ narra plantation, whereas, for the undecomposed litter layer, the trend was narra plantation ≈ mahogany plantation >

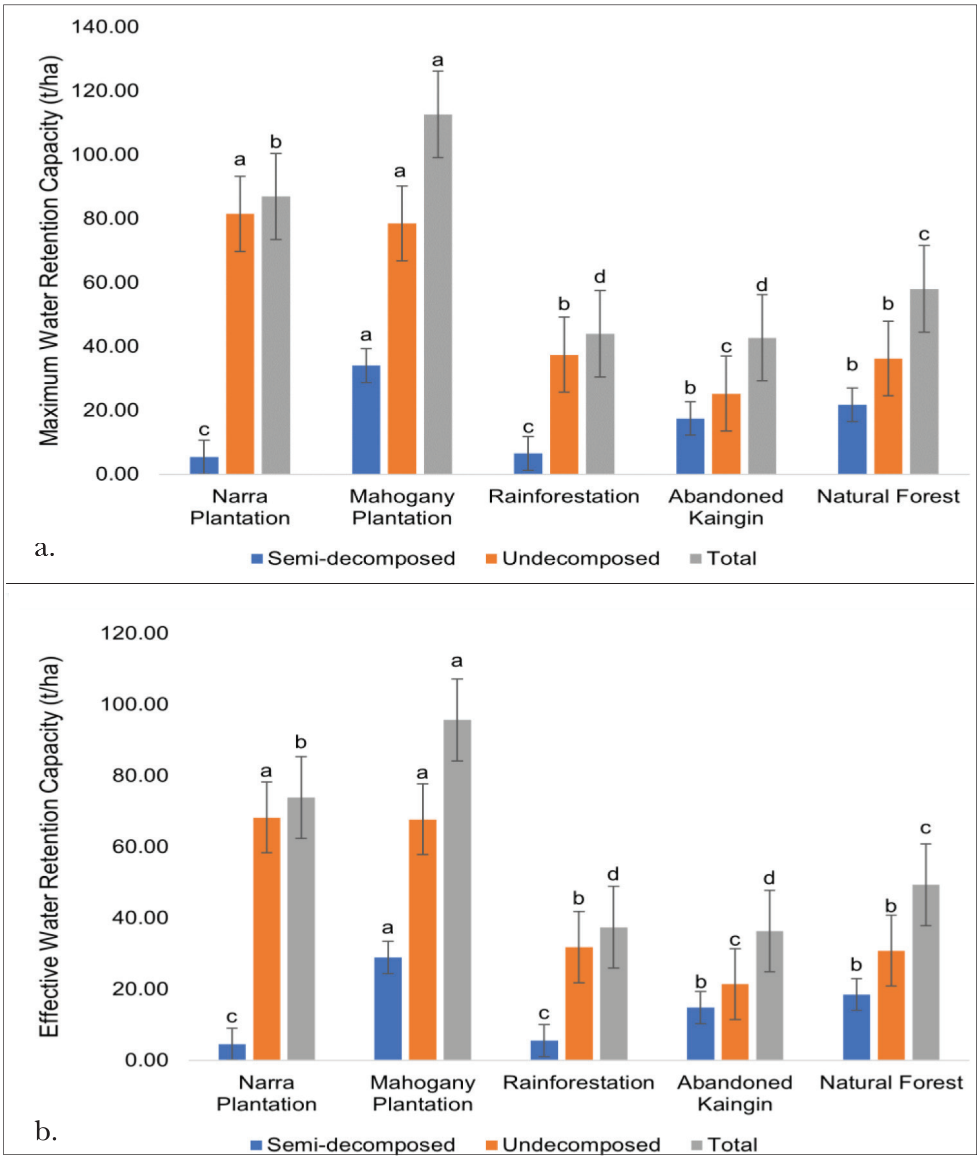

Figure 5 (a) Maximum and (b) effective water retention capacity per litter type of each tree-based system. Comparison is for each litter type between tree-based systems. Different letters on bars with the same colour (same litter type) are significantly different from each other ($p \leq 0.05$)

rainforestation site ≈ natural forest > abandoned kaingin site. For the total litter layer, the trend was mahogany plantation > narra plantation > natural forest > rainforestation site ≈ abandoned kaingin area (Figure 5b).

If we compare these results to the findings of this study by Zhou et al. (2018) which varied from 14.6 Mg ha^{-1} to 33.6 Mg ha^{-1}, the maximum water-retention capacities in Mt. Pangasugan were higher as they ranged from 42.79 Mg ha^{-1} to 112.65 Mg ha^{-1}. Litter type may dictate the litter layer's water-retention capacity (Li et al. 2013). Since all litter in Mt. Pangasugan originated from broadleaved tree species, this could be the reason why the derived values of the maximal rainfall interception abilities of the litter layer in this area are higher than those obtained by Zhou et al. (2018).

Temporal variation in water-storing capacity of the litter layer

The findings of the immersion test emphasize the disparities in how litter layers of every tree-based land cover absorb water (Figure 6). An asymptotic relationship across the five tree-based land covers was observed. Most of the water volume was absorbed within the initial 100-minute period.

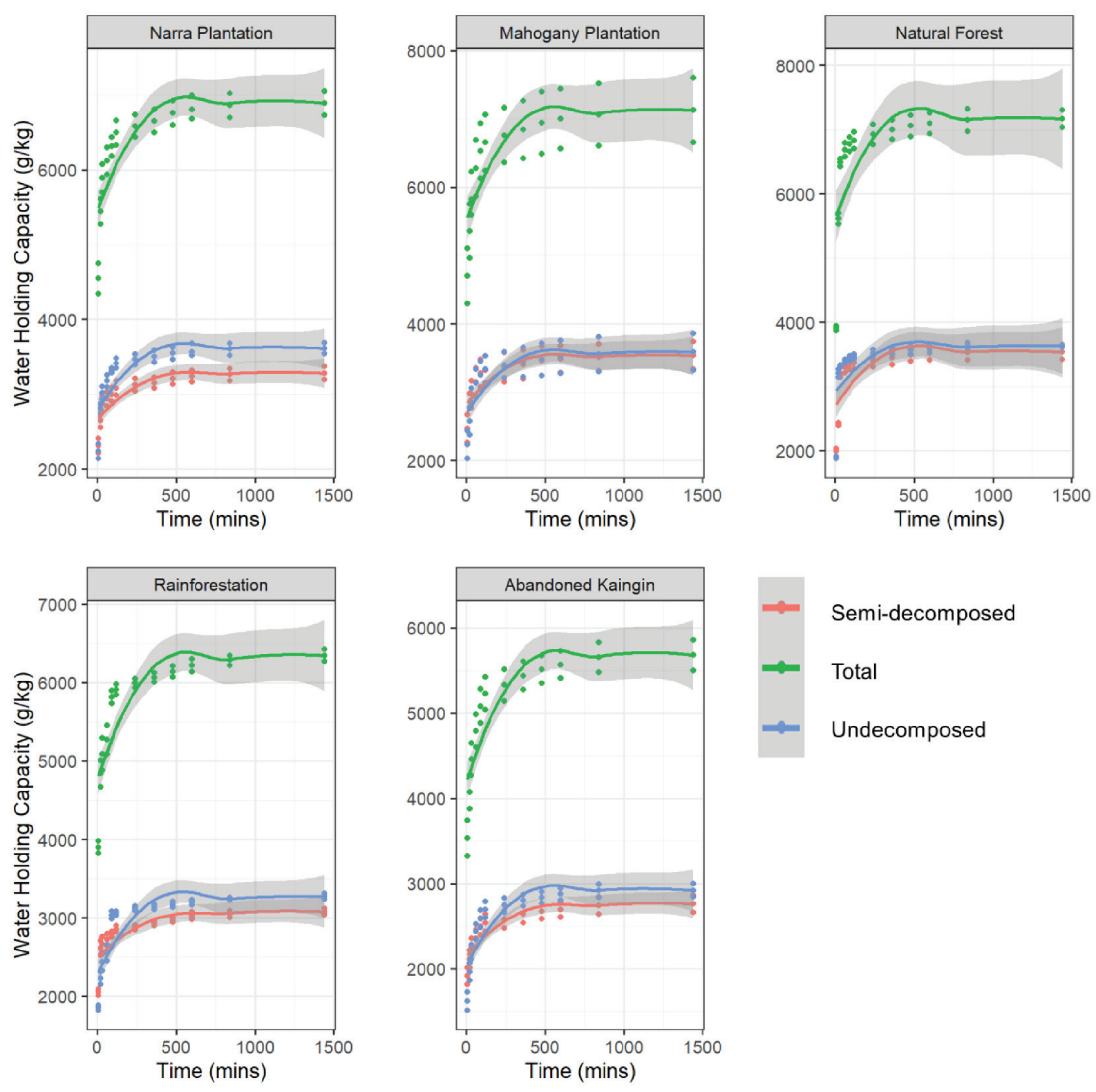

Figure 6 Water-storing ability per litter type of each tree-based system during the immersion test. The line denotes the total trend for every tree-based land cover and litter type, and the shaded region symbolizes the 95% confidence interval

At the end of the experiment, total water-storing capacity was highest in the natural forest (7169 g kg^{-1}), followed by narra plantation (6891 g kg^{-1}), and mahogany plantation (6427 g kg^{-1}). In the case of the narra plantation, the high total water-holding capacity may be attributed to a higher water-storing ability of the undecomposed litter. The high total water-storing capacity of the litter layer in the natural forest and mahogany plantation may have been driven by the combination of higher water-holding capacity of both the undecomposed and semi-decomposed litter layers. Moreover, the water-storing ability of the undecomposed and semi-decomposed litter at the culmination of the immersion test was highest in the natural forest (3631 g kg^{-1} and 3538 g kg^{-1}, respectively). The total water-storing ability of the rainforestation site (6437 g kg^{-1}) was marginally superior to the abandoned kaingin (5679 g kg^{-1}).

Results of this study revealed that the total water-storing ability at the culmination of the immersion test ranged from 5679 g kg^{-1} to 7169 g kg^{-1}, higher than the total water-holding capacity of the Karst region, which ranged from 2889 g kg^{-1} to 3825 g kg^{-1} (Zhou et al 2018). Although results from both studies presented an asymptotic relationship, the absorption rate of the majority of the volume of water was imbibed in the first 100 minutes in Mt. Pangasugan versus the 30-minute mark in the Karst region. This implies that the litter layer in the Karst region absorbed water faster than the litter layer in Mt. Pangasugan.

CONCLUSION

Several factors apparently influenced the litter layer's water-holding properties in Mt. Pangasugan. Generally, the whole litter layer sampled in natural forest exhibited a higher capacity to retain water compared to the other tree-based land cover. The maximum water-holding capacity of the total and undecomposed litter layer was similar in all the tree-based land covers of Mt. Pangasugan. Although the maximum water storage capacity of the entire litter layer did not vary across the five tree-based land covers, other water-holding properties differed from each other. The undecomposed layer exhibited a greater water-retention capacity in the narra plantation and mahogany plantation. There were apparent variations in the hydrological influence across the five tree-based land covers in Mount Pangasugan. The natural forest generally had the best desirable water-holding properties. Narra and mahogany plantations also showed promising water retention characteristics. Thus, in developing forest rehabilitation initiatives in tropical rainforests, the protection and conservation of natural forests must be reinforced to foster the preservation of soil and water and maximization of the ecosystem services that tropical rainforests can offer. In addition, utilising mahogany and narra in tree plantation development and decrease the pressure on natural forests may be a potential option, wherever this may be feasible.

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REFERENCES

Asio VB. 1996. Characteristics, weathering, formation, and degradation of soils from volcanic rocks in Leyte, Philippines. in *Hohenheimer Bodenkundliche Hefte* 33. Stuttgart, Germany.

Baldos AP & Rallos RV. 2019. Indications of enhanced soil ecosystem functions in polyculture reforested grassland. *Annals of Tropical Research* 41: 32–44. https://doi.org/10.32945/atr4114.2019 .

Bauhus J, Van Der Meer P & Kanninen M. 2010. *Ecosystem Goods and Services from Plantation Forests*. Earthscan, United Kingdom.

Benkobi L, Trlica MJ & Smith JL. 1993. Soil loss is affected by different combinations of surface litter and rock. *Journal of Environmental Quality* 4: 657–661. https://doi.org/10.2134/jeq1993.00472425002200040003x.

Carnol M & Bazgir M. 2013. Nutrient return to the forest floor through litter and throughfall under 7 forest species after conversion from Norway spruce. *Forest Ecology and Management* 309: 66–75. https://doi.org/10.1016/j.foreco.2013.04.008.

Chen S, Cao T, Tanaka N, Gao T, Zhu L & Zou CB. 2018. Hydrological properties of litter layers in mixed forests in Mt. Qinling, China. *iForest-Biogeosciences and Forestry* 11: 243. https://doi.org/10.3832/ifor2535-011.

Convention On Biological Diversity. 2006. Forest biodiversity definitions. https://www.cbd.int/forest/definitions.shtml.

Cui HX, Zhang ZW & Li ZF. 2007. Studies on the shrub, herbage and litter hydrological effect under different forest type in Badong Area. *Research of Soil and Water Conservation* 14: 203–205.

Curtis JT & Mcintosh RP. 1950. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* 31: 434–455. http://dx.doi.org/10.2307/1931497

Deguchi A, Hattori S & Park H. 2006. The influence of seasonal changes in canopy structure on interception loss: Application of the revised Gash model. *Journal of Hydrology* 318: 80–102. https://doi.org/10.1016/j.jhydrol.2005.06.005 .

De Mendiburu F & Muhammad Y. 2020. agricolae: Statistical Procedures for Agricultural Research. R package version 1.4.0, https://cran.r-project.org/package=agricolae.

Fan J, Oestergaard KT, Guyot A, Jensen DG & Lockington DA. 2015. Spatial variability of throughfall and stemflow in an exotic pine plantation of subtropical coastal Australia. *Hydrological Processes* 29: 793–804. https://doi.org/10.1002/hyp.10193.

Gamfeldt L, Snäll T, Bagchi R et al. 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications* 4: 1340. https://doi.org/10.1038/ncomms2328 .

Gong YB, Chen LW, Luo CD, Wu XX & Cheng YZ. 2007. Hydrological benefit of litter of five forest types in severe degraded areas of upper reaches of Jialing River. *Scientia Silvae Sinicae* 43: 12–16.

Guevara-Escobar A, Gonzalez-Sosa E, Ramos-Salinas M & Hernandez-Delgado GD. 2007. Experimental analysis of drainage and water storage of litter layers. *Hydrology and Earth System Sciences* 11: 1703–1716. https://doi.org/10.5194/hess-11-1703-2007 .

Haynes, W. 2013. Tukey's Test. In Dubitzky W, Wolkenhauer O, Cho KH & Yokota H. (eds) *Encyclopedia of Systems Biology*. Springer, New York. https://doi.org/10.1007/978-1-4419-9863-7_1212.

Heaney LR, Heideman PD, Rickart EA, Utzurrum RB & Klompen JSH. 1989. Elevational zonation of mammals in the central Philippines. *Journal of Tropical Ecology* 5: 259-80. https://doi.org/10.1017/S0266467400003643 .

Keith DM, Johnson EA & Valeo C. 2010a. A hillslope forest floor (duff) water budget and the transition to local control. *Hydrological Processes* 24: 2738–2751. https://doi.org/10.1002/hyp.7697 .

Keith DM, Johnson EA & Valeo C. 2010b. Moisture cycles of the forest floor organic layer (F and H layers) during drying. *Water Resources Research* 46: 1–14. https://doi.org/10.1029/2009WR007984 .

Kruskal WH & Wallis WA. 2008. Use of ranks in one-criterion variance analysis. *Journal of American Statistical Association* 47, 583–621 and errata, ibid. 4: 907–911 (1952).

Li Y, Li B, Zhang X, Chen JJ et al. 2015. Differential water and soil conservation capacity and associated processes in four forest ecosystems in Dianchi Watershed, Yunnan Province, China. *Journal of Soil and Water Conservation* 70: 198–206. https://doi.org/10.2489/jswc.70.3.198 .

Liu Q, Peng SL, Bi H et al. 2005. Decomposition of leaf litter in tropical and subtropical forests of southern China. Litter and its hydrological characteristics of typical forest types in Xishuangbanna. *Journal of Tropical Forest Science* 17: 543–556. https://jtfs.frim.gov.my/jtfs/article/view/1065

Llorens P & Domingo F. 2007. Rainfall partitioning by vegetation under Mediterranean conditions. A review of studies in Europe. *Journal of Hydrology* 335: 37–54. https://doi.org/10.1016/j.jhydrol.2006.10.032 .

Miura S, Amacher, Hofer T, San-Miguel-Ayanz J, Ernawati & Thackway R. 2015. Protective functions and ecosystem services of global forests in the past quarter-century. *Forest Ecology Management* 352: 35–46. https://doi.org/10.1016/j.foreco.2015.03.039.

Mori AS. 2017. Biodiversity and ecosystem services in forests: management and restoration founded on ecological theory. *Journal of Applied Ecology* 54: 7–11. https://doi.org/10.1111/1365-2664.12854 .

R Core Team. 2022. R: *A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Sato Y, Kumagai TO, Kume A, Otsuki K & Ogawa S. 2004. Experimental analysis of moisture dynamics of litter layers—The effects of rainfall conditions and leaf shapes. *Hydrological Processes* 18: 3007–3018. https://doi.org/10.1002/hyp.5746 .

Siegel S & Castellan NJ. 1988. *Nonparametric Statistics for The Behavioural Sciences*. MacGraw Hill International, New York.

Staelens J, Schrijver Ad, Verheyen K & Verhoest N. 2008. Rainfall partitioning into throughfall, stemflow, and interception within a single beech (*Fagus sylvatica* L.) canopy: Influence of foliation, rain event characteristics, and meteorology. *Hydrological Processes* 22: 33–45. https://doi.org/10.1002/hyp.6610 .

The National Forest And Nature Agency (Skov- Og Naturstyrelsen). 1994. *Strategy for Natural Forests and Other Forest Types of High Conservation Value in Denmark*. Ministry of the Environment. Copenhagen.

Walsh RPD & Voight PJ. 1977. Vegetation litter: an underestimated variable in hydrology and geomorphology. *Journal of Biogeography* 4: 253–274. https://doi.org/10.2307/3038060 .

Zhang Z, Lei Y, Su K, Wang G, Wang D & Ma H. 2009. Hydrological characteristics of litter in different forest succession stages at Liuxihe Watershed, southern China. *Frontiers of Forestry in China* 4: 317–322. https://doi.org/10.1007/s11461-009-0053-z .

Zhou Q, Keith DM, Zhou X, Cai M & Cui X. 2018. Comparing the water-holding characteristics of broadleaved, coniferous, and mixed forest litter layers in a karst region. *Mountain Research and Development* 38: 220–229. https://doi.org/10.1659/MRD-JOURNAL-D-17-00002.1 .