# Statistical Evaluation of Litter Interception Models Across Forest Sites Using Regression, ANOVA, and Cluster Analysis

ASHA GUPTA[1], BINITA KANGJAM[2]
[1]Department of Life Sciences,
Manipur University,
INDIA

[2]Oriental College, Imphal West,
Manipur,
INDIA

*Abstract:* - Forest litter interception is a key hydrological process influencing water balance and ecological resilience. Litter Interception refers to precipitation that does not reach the soil, but instead intercepted by the leaves, branches of plants and the forest floor. This study evaluates precipitation–litter interception relationships across four forest sites located in Nongmaiching Hill using linear regression, ANOVA, and hierarchical clustering. The interception magnitude showed the order Broad Leaved Forest>Logged Forest>Pine Plantation>Secondary Growth Forest.Regression diagnostics revealed varying model strengths,Site II i.e. Pine plantation showed the strongest model fit ($R^2 \approx 31\%$, $p = 0.0012$) showing the highest explanatory power , followed by Secondary regrowth forest following shifting cultivation Site IV ($R^2 \approx 22\%$, $p = 0.0073$) demonstrating efficient predictive accuracy .Sites I and III Broadleaved Natural and Logged forest sites exhibited comparativelyweaker but significant fits. Heterogeneous litter structure and complex broadleaved canopymight be responsible for such results. Cluster analysis groupedtogether Broadleaved Natural and Logged forest sitesat the lowest linkage distance showingthemost similar sites merge at a low distance exhibiting the close connection indicating strong similarity in their interception dynamics whereas Pine plantation and Secondary regrowth forest Sites formed a distinct cluster reflecting differences in hydrological resilience. Cluster analysis validated regression-based site differences. The study suggests that structurally diverse or mature canopies may involve more complex interception processes and dynamics. Site-specific variability in litter interception provides a comparative framework for forest management and policy applications.

*Key-words:* - litter interception, precipitation, regression diagnostics, ANOVA, cluster analysis, Nongmaiching Hill

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## 1 Introduction

Rainfall interception is recognized as one of the most underestimated processes in forest hydrology. Forest litter interception is an important element of the water balance of the forest and can be an important parameter of the rainfall runoff models in a forested area. Through processes like soil infiltration, litter and canopy interception, forest ecosystems exercise control over hydrological cycle. Litter interception is essential for improving ecological resilience as it reduces surface runoff, enhances infiltration and buffers precipitation inputs.

Rainfall that falls on forest cover is intercepted by the litter layer and subsequently evaporates back into the atmosphere [1,2]. Interception, retention and redistribution of precipitation are significant for assessing water budgets of forest ecosystems altering the amount of water available to percolate into the uppermost layer of forest soils[3]. Many workers [2,4,5] pronounce that less attention has been paid to interception and retention processes in the forest-floor litter layer.

Litter layer is an important component of forest ecosystems and its importance is often underestimated in water resource management [6]. Litter production dynamics, litter layer structure and hydrological properties of secondary forests, plantationsandhumid forest eco-systems, as well as their relevance in water conservation management have not been widely studied. Li et al. [7] highlighted that the roles of the litter layer were disregarded in hydrological models despite the importance of its hydrological functions.The forest litter interception in a southern Appalachian hardwood stand was investigated by Helvey and Patrick [8] who found that litter interception depends mainly on the annual quantity of forest litter. In a study Putuhena and Cordery [9] determined interception using all the organic materials which was present a maximum 50 cm above the soil surface. Zagyvainé Kiss et al [10] employed a hydrologic model for estimation of forest litter interception of a middle-aged sessile oak stand. From different results, the litter interception was obtained usually 2–12% in proportion to the gross precipitation due to the different climate (rainfall and evaporation conditions), measurement methodology, litter weight and tree species.

Forest floors comprise organic litter at various stages of decay and short sub-canopy vegetation overlying the soil surface[2]. Water intercepted by the forest floor may be retained for longer periods and evaporates more slowly as per Baird & Wilby[11], unlike precipitation that is intercepted by forest canopies, exposed to conditions that can drive rapid evaporation. According to Klamerus et al.[4], forest-floor litter layers are mostly root-free, and thus, water fluxes are primarily controlled by gravitational forces, direct evaporation and the overall physical storage properties of the litter, rather than plant water uptake. Besides Li et al.[7] highlighted that the roles of the litter layer were disregarded in hydrological models despite the importance of its hydrological functions. Although the canopy interception processes were often taken into account in hydrological models (such as the Gash, Rutter and Merriam models), few models were developed to represent litter interception processes for forested land. For sustainable forest management, understanding of site-specific variability in litter interception is significant particularly in areas where precipitation patterns are changing as a result of climate change.

The present study aims to integrate regression diagnostics, ANOVA, and clustering to identify site-level differences by investigating how the variation in litter interception in a land use is related to types and structural variation of litter under the same precipitation regime. Distinguishing in the magnitude of interception processes is important for understanding the role of litter variability in various forest types with different landuse history and disturbance. Such differences in interception patterns might affect the hydrological processes in forest sites of retention and redistribution of precipitation on the forest floor and help in the assessment of water budgets. The previous studies focussed on precipitation–interception relationships. However, a gap existed about the comparative statistical evaluation across multiple sites. This study addresses this gap by applying regression, ANOVA, and cluster analysis to precipitation–litter interception data from four forest sites, aiming to identify statistical patterns and ecological implications.

## 2 Objectives

In this paper, we aim to assess the trends in litter interception in different land uses along a hilly terrain by evaluating precipitation–litter interception relationships across four sites integrating regression diagnostics, ANOVA, and hierarchical clustering andidentify site-level differences with the following objectives:

i) To get the site specific regression models ii) to evaluate the impact of litter structure on interception response iii) to compare the Statistical diagnostics revealing the predictability of litter interception models iv) to apply Cluster analysison basis of similarity in their interception dynamics v) to integrate regression diagnostics with hierarchical clustering and identify site-level differences.

# 3 Material and Methods

## 3.1 Study Site

For the study Nongmaiching Hill ($24^0$43'55"N - $24^0$59'17"N Latitude and 93 $^0$59'17"E - $94^0$2'21"E Longitude) having rising to the altitude of 1565 m above mean sea level was chosen.Two locations viz. Awaching and Ngariyalching with two sites eachat an altitude of approximately about 1150 m above MSL were selected. Nongmaiching Hill is located in a biodiversity hotspot of Indo-Myanmar in the North Eastern State of India at Manipur. The site has a Subtropical Climate. Awaching and Ngariyalching had different land uses and separated by about 3 kms distance. Awaching included Sites I and II viz. natural forest and pine plantation and Ngariyalching had Sites III and IV viz.logged forest and secondary growth forest(Fig1).

At Nongmaiching Hill forest, the dominant trees included *Bombax ceiba, Rhus insignis, Artocarpus integra* and *Quercus dealbata (Site* I), *Pinus kesiya* (Site II), *Rhus insignis, Celtis australis, Melia ajadirachta, and Gmelina arborea* (Site III) *Eleocarpus floribundus, Melia azadirachta, Cinamomum glaucensens* and *Erythrina indica* (Site IV ).

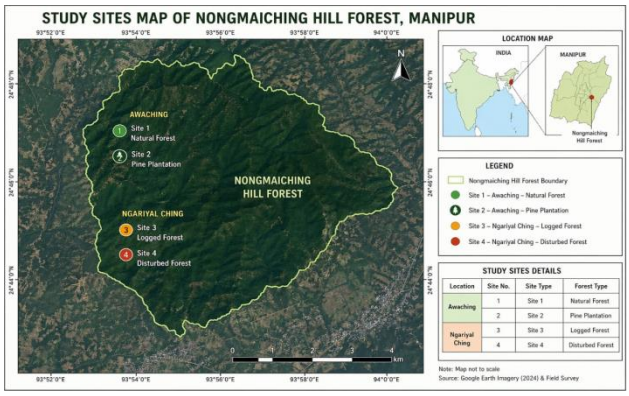



Figure 1- Location of Four Study Sites on Nongmaiching Hill

Soil are classified as sandy clay loam and sandy loam (Sites I and Il) and clay loam and sandy clay respectively (Sites III and IV).

Litter estimation at all sites was done by the litter trap method. The annual litter production was quantified as 6.434 Mg $ha^{-1}$ (Site I), 2.029 Mg $ha^{-1}$ (Site II), 6.263 Mg $ha^{-1}$ (Site III), and 2.135 Mg $ha^{-1}$ (Site IV). Leaf litterfall was estimated as 4.127 Mg $ha^{-1}$ (Site I), 1.664 Mg $ha^{-1}$ (Site II), 4.057 Mg $ha^{-1}$ (Site III) and 1.756 Mg $ha^{-1}$(Site IV).

## 3.2 Litter Interception Study

At each Site, five 50 × 50 cm sampling units were established using wire mesh supported by a 20 cm deep tray [12]. The wire mesh was placed 2.5 cm below the rim of the trays, which were positioned in open areas well away from the influence of the tree canopy at each site. Rainwater collected in the trays was measured and considered as litter interception. 31 rainfall events were monitored, and the interception of gross rainfall on those dates was recorded by using a rain gauge.Litter interception for each site represents the mean value from five 50 × 50 cm litter interception collectors installed at each site.

## 3.3 Statistical Analysis

Regression analysis and ANOVA were done using precipitation and litter interception data for evaluating precipitation–litter interception relationships across four sites regression diagnostics, ANOVA, and hierarchical clustering were integrated and site-level differences were identified. The regression models quantify how litter interception responds to precipitation across Sites.

Cluster analysis by Ward's method, using squared Euclidean distance, was performed on hill forests viz. Site1 Broad-leaved, Site2 Pine Plantation, Site3 Logged forest, and Site 4 Secondary growth forest on litter interception data on basis of similarity in their interception dynamics. An agglomeration schedule was obtained and a dendrogram was plotted. Statgraphics was used for the purpose.

# 4 Results

## 4.1 Gross Precipitation and Litter Interception

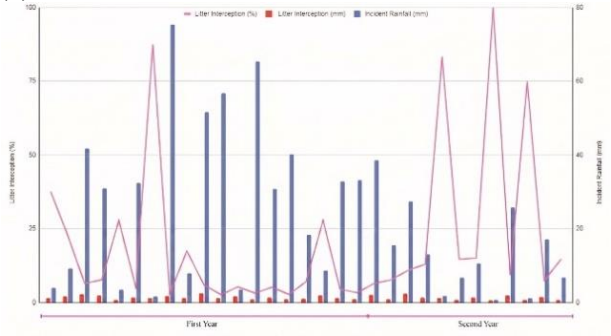
Details of rainfall distribution under various shower classes reveal that during the hydrological year,1682.4 mm of precipitation was recorded of which 68.24% was obtained during Julyto October. The total numbers of rainfall events for the hydrological year (March 2015-Feruary 2016) were 217. The maximum number of rainfalls constitutes 38.22% in

shower size of 1-10 mm. 35.02% events were recorded as trace, 10.5% ,9.6%,3.2%,0.9% and 2.3% of shower events were recorded under shower classes of 11-20 mm, 21-30mm, 31-40mm, 41-50mm and >50 mm respectively.

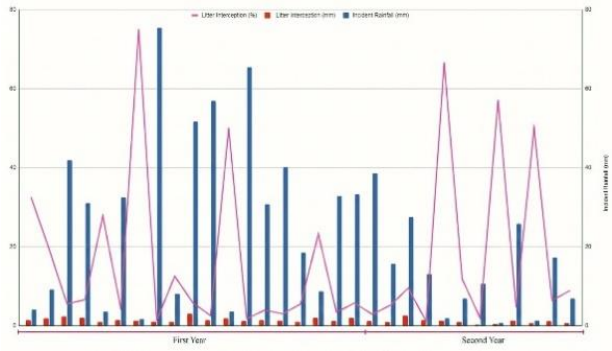
### 4.2 Hydrological Responses in Different Land uses

Rainfall - Litter Interception graphs (Fig 2 a,b,c,d) demonstrate the Gross precipitation (mm) and Litter interception (mm) recorded across four Sitesviz. a-Broad Leaved forest (Site I), b-Pine Plantation (Site II), c-Logged Forest (Site III) and d-Secondary Forest (Site IV for the studied hydrological year 2015-2016.

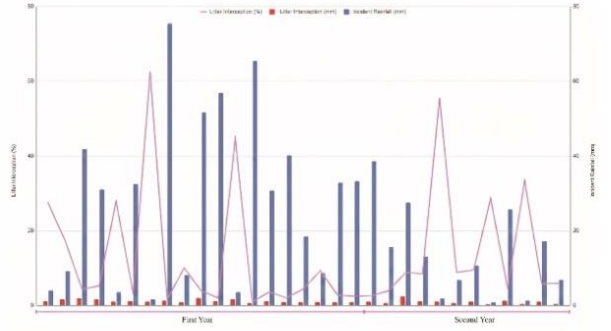
(a)




(b)




(c)




(d)

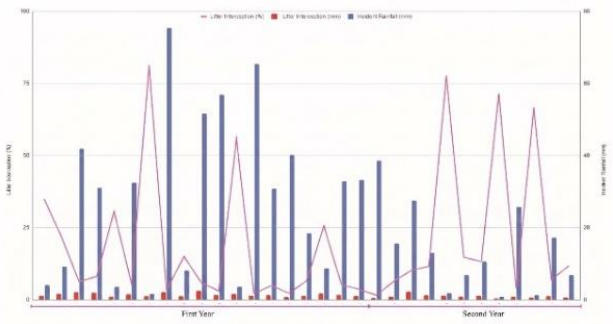



Figure 2 Rainfall-Litter Interception graphs for Hydrological Year 2015-2016 for a-Broad Leaved forest (Site I), b-Pine Plantation (Site II), c-Logged Forest (Site III) and d-Secondary Forest (Site IV)

Figure 2 reflects event-based temporal dynamics of gross precipitation (mm), litter interception depth (mm), and relative litter interception efficiency (%) across hydrological year (2015–2016) in four forest ecosystems of Nongmaiching Hill. Blue bars denote incident gross precipitation (mm), red bars indicate absolute litter interception (mm), and pink lines trace relative litter interception efficiency (%).

The graphs suggest that litter interception is strongly linked to forest cover quality and canopy/litter-layer condition: the natural broadleaved forest shows the strongest and most stable interception, logged forest follows next, followed by the pine plantation and the disturbed/secondary forest generally shows the weakest and most erratic pattern. Studies also show that interception rises quickly at the start of rainfall, then slows and levels off as the litter layer approaches saturation. Interception increased more in high-intensity showers than in low-intensity showers, but only up to the litter storage limit. In low-intensity rain, interception remained modest because rainfall arrived slowly; in high-intensity rain, interception rose faster before reaching a plateau. The litter interception at Nongmaiching Hill forest reflected better litter interception at Site-I (22.39%), Site-Ill (19.92%) in the natural broadleaved forest and logged forest, by pine plantation in Site-III (16.93%) and the disturbed forest Site-IV (13.24%) of Gross precipitation respectively. The average interception was found to be 13.24%.

### 4.3 Litter Interception

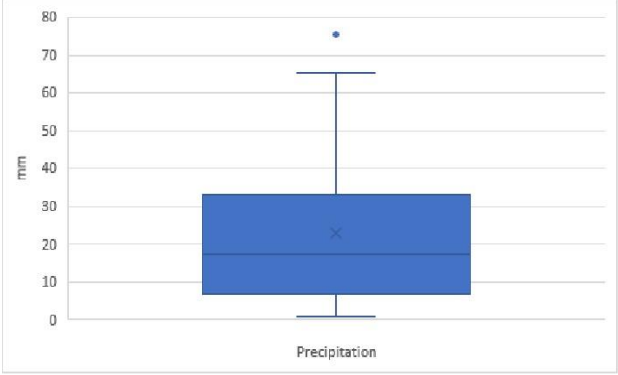
| | Precipitation (mm) | Site 1- Litter Interception (mm) | Site 2- Litter Interception (mm) | Site 3- Litter Interception (mm) | Site 4- Litter Interception (mm) |
|---|---|---|---|---|---|
| Sample Size(n) | 31 | 31 | 31 | 31 | 31 |
| Mean | 23.03 | 1.7 | 1.38 | 1.53 | 1.04 |
| Median | 17.2 | 1.5 | 1.2 | 1.4 | 1.0 |
| Standard deviation(SD) | 20.28 | 0.64 | 0.69 | 0.66 | 0.52 |
| Standard error(SE) | 3.64 | 0.115 | 0.124 | 0.118 | 0.09 |
| Coeff. of variation(CV)% | 88.07% | 37.67% | 50.18% | 43.14% | 50.37% |
| Range(Min-Max) | 0.70-75.40 | 0.70-3.10 | 0.20-3.00 | 0.50-3.00 | 00-2.10 |
| Std. skewness | 2.11 | 1.37 | 1.45 | 1.61 | 0.73 |
| Std. kurtosis | 0.223 | -0.59 | -0.29 | -0.30 | -0.24 |

**Note:** Values are based on 31 rainfall events. Litter interception for each site represents the mean value from five 50 × 50 cm litter interception collectors installed at each site.

**Table 1.** Summary Statistics of Precipitation and Litter Interception Across Four Study Sites

Table 1 provides across four forest Sites located in the in the Nongmaiching Hill values reflecting mean, median, standard deviation, standard error, Coefficient of Variation, range, skewness and kurtosis for recorded field values (mm) of Gross precipitation and Litter Interception. Forest floor litter interception varied somewhat across the 31 recorded rainfall events (mean gross precipitation=23.03 ± 20.28 mm). Site 1 exhibited the highest mean interception capacity as 1.70 ± 0.64 mm (range: 0.70–3.10 mm), followed by Site 3 (1.53 ± 0.66 mm) and Site 2 (1.38 ± 0.69 mm). Site 4 had the lowest amount at 1.04 ± 0.52 mm (range: 0.00–2.10 mm). Litter interception showed lower, more consistent relative dispersion across all sites (CV = 37.67% to 50.37%), whereas, gross precipitation showed high variability (CV = 88.07%) and positive skewness (2.11).

(a)




(b)

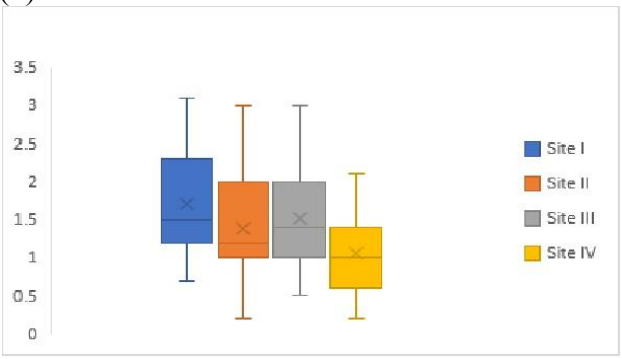



Fig 3 (a) Box Plot Diagram of Precipitation (mm) at Nongmaiching Hill
(b) Box Plot Diagram of Litter Interception at four Sites viz. Broad Leaved Forest (Site I), Pine Plantation (Site II), Logged Forest (Site III) and Secondary Forest (Site IV).

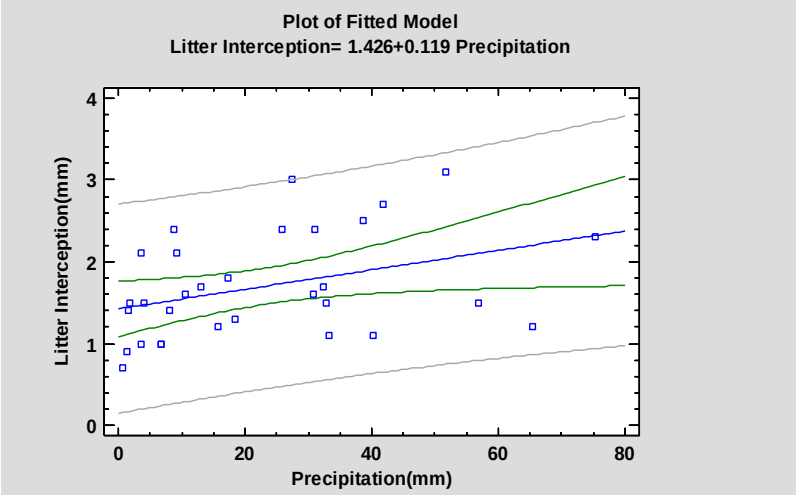
Fig 3 (a) provides the Box Plot Diagram of Gross Precipitation (mm) at Nongmaiching Hill illustrating mean value as 23.03±20.28 mm, the range being 0.7-75.4 mm. Fig 3(b) gives the Box Plot Diagram of Litter Interception at four Sites viz. -Broad Leaved forest (Site I), -Pine Plantation (Site II), -Logged Forest (Site III) and Secondary Forest (Site IV) at Nongmaiching Hill illustrating mean values as 1.7±0.64mm, 1.38 ±0.69 mm, 1.53±0.66mm and 1.04±0.52mm respectively. The range for litter interception being 0.7-3.1 mm, 0.2 -3.0 mm, 0.5-3.0 mm and 0.2.1 mm respectively. The values for median, standard error, Coefficient of Variation, skewness and kurtosis for recorded field values of Gross precipitation and Litter interception are found in the table1.The box plot diagrams exhibit the average, Interquartile Range (IQR) i.e. the box itself holding the middle 50% of data, from the 25th percentile (Q1) to the 75th percentile (Q3) and Overall spread,thus exhibiting the distribution and overall spread of dataset.

| **Site** | **Forest Type** | **Pearson r** | **$R^2$ (%)** | **Slope (β)** | **F(1,29)** | **p-value** | **Interpretation** |
|---|---|---|---|---|---|---|---|
| **1** | Broadleaved forest | 0.38 | 14.18 | 0.012 | 4.79 | 0.036 | Weak positive but significant relationship—litter interception mildly increases with precipitation |
| **2** | Pine plantation | 0.57 | 30.96 | 0.019 | 13.00 | 0.001 | Strongest most predictive model —pine litter responds more linearly to rainfall; notable outliers |
| **3** | Logged mixed forest | 0.43 | 18.52 | 0.014 | 6.59 | 0.015 | Moderate predictive strength—logged litter layers vary |
| **4** | Disturbed secondary forest | 0.47 | 22.33 | 0.011 | 8.34 | 0.007 | Surprisingly decent fit for disturbed land—may reflect structural recovery of litter layer, less variability in residuals |

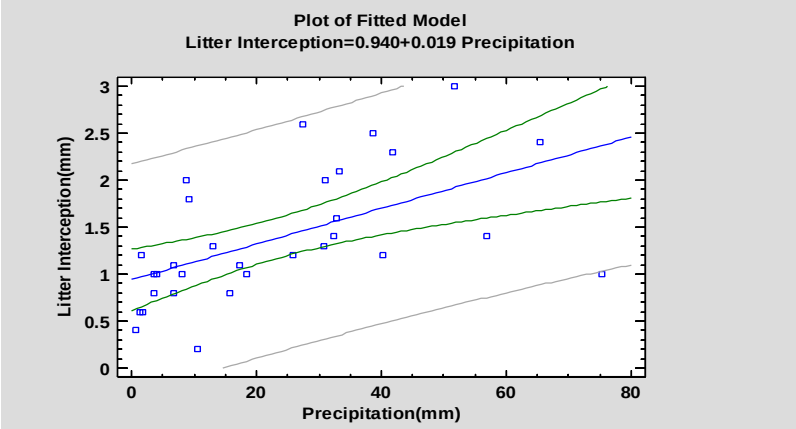
Litter interception in four land-use types showed distinct hydrological responses to precipitation, influenced by structural complexity, disturbance history, and vegetation composition (Table 2). The Pearson correlation coefficient values obtained between Gross Precipitation and Litter Interception were obtained as 0.38, 0.57, 0.48 and 0.43 for broadleaved stand, pine plantation, logged mixed forest and disturbed secondary forest. Gross precipitation was a significant predictor of litter interception in all four forest types as revealed by simple linear regression ($p < 0.05$; Table 2). The pine plantation (Site 2) showed the highest sensitivity to rainfall intensity and strongest linear relationship ($R^2 = 30.96\%$, $\beta = 0.019$, $F(1,29) = 13.00$, $p = 0.001$). Disturbed secondary forest (Site 4; $R^2 = 22.33\%$, $\beta = 0.011$) and logged mixed forest (Site 3; $R^2 = 18.52\%$, $\beta = 0.014$) pointed out moderate predictive capacity, whereas the broadleaved stand (Site 1) showed the weakest, yet significant, association ($R^2 = 14.18\%$, $\beta = 0.012$, $p = 0.036$). Litter interception capacity increases steadily with gross precipitation volume, across all sites, as confirmed by positive slopes ($\beta = 0.011 – 0.019$).

Pine plantation had the strongest linear relationship between interception and precipitation i. e pine litter responds more linearly to rainfall, reflecting a homogeneous canopy and consistent litter structure conducive to predictable rainfall capture. Scatter plots confirmed model fidelity, with most predicted values aligning tightly with observations, exhibits notable outliers, while protected broadleaf forest at Site 1 had a weaker but significant correlation i.e. litter interception mildly increases with precipitation, characterized by vertical scatter and prediction variability due to complex canopy stratification and diverse leaf litter morphology.

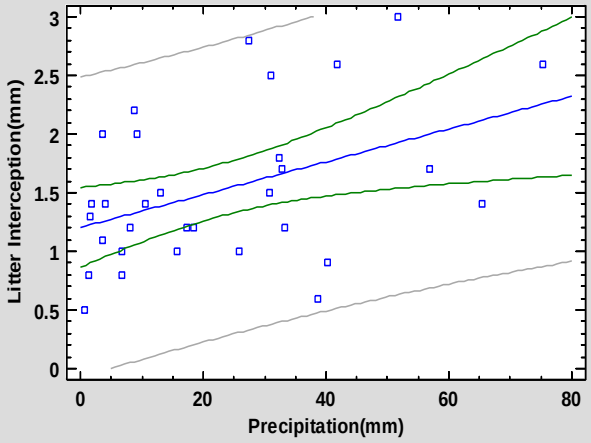
Site 1:




Site 2:



Site 3:




Site 4:

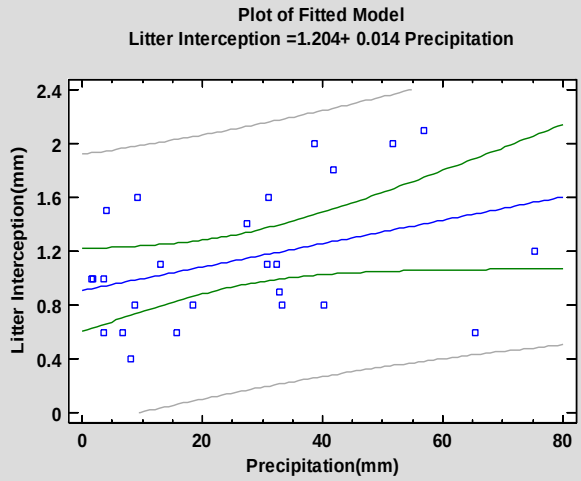
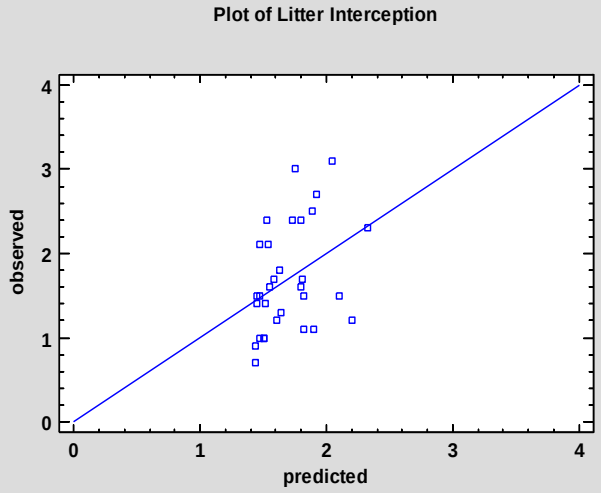



Figure 4: Litter Interception Models Across Four Forest Sites

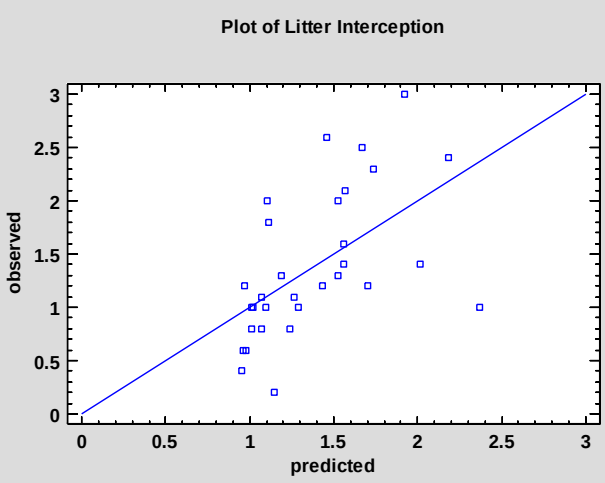
Figure 4 provides the fitted linear regression models relating gross precipitation (mm) to litter interception (mm) across the four study sites in Nongmaiching Hill: (a) Broadleaved forest, (b) Pine plantation, (c) Logged mixed forest, and (d) Secondary forest ($n = 31$, $p < 0.05$). Shaded bands represent the 95% confidence intervals.

Linear regression modelling reflected different hydrological responses of forest floor litter in the studied four land-use types in Nongmaiching Hill. With the steepest response rate ($\beta = 0.019$) and an explanation of 30.96% of the variance in interception storage ($R^2$=0.31,p=0.001),pine plantation litter demonstrated the highest sensitivity to incident rainfall . On the other hand, response rates were relatively moderate in, broadleaved forest (Site 1), logged mixed forest (Site 3), and disturbed secondary forest (Site 4) ($\beta = 0.011–0.014$, $R^2 = 0.14–0.22$, $p < 0.05$).With needle-litter packing structure producing a more predictable rainfall-interception relationship than heterogeneous broadleaved and disturbed litter beds, the tighter confidence intervals observed across all four models confirm that gross precipitation serves as a significant, positive linear driver of litter interception, with needle-litter packing structure yielding a more predictable rainfall-interception relationship than heterogeneous broadleaved and disturbed litter beds.

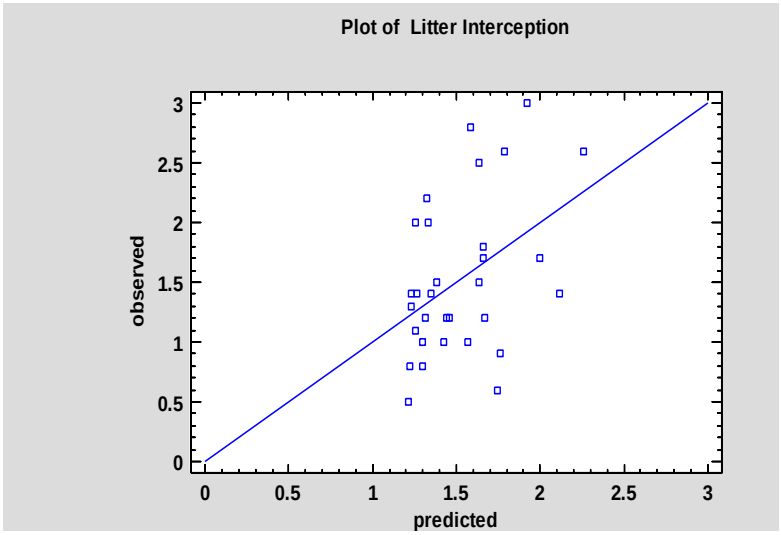
Site 1:




Site 2:




Site 3:




Site 4:

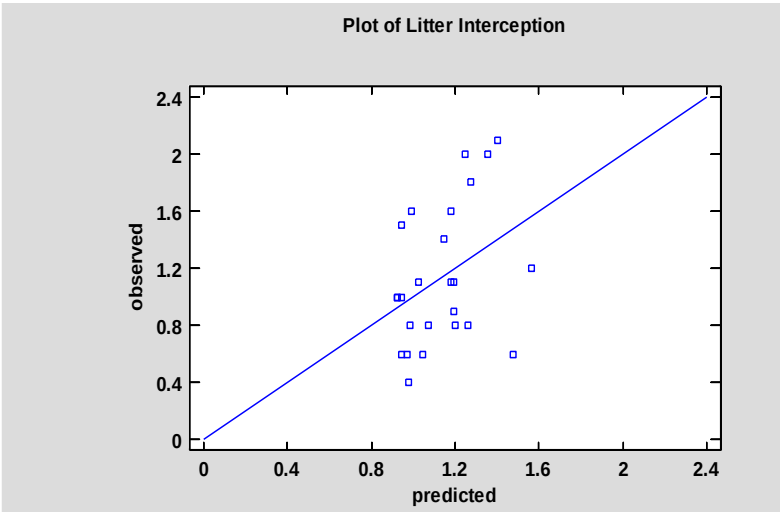



Figure 5: Observed versus Predicted Litter Interception Across Four Forest Sites

Figure 5 gives the Comparison of observed versus model-predicted litter interception (mm) across four forest sites in the Nongmaiching Hill catchment. Dashed diagonal line indicates the 1:1 line of perfect agreement.

All four forest types showed unbiased residual scatter and good model fidelity when the fitted regression models were validated through observed versus predicted litter interception plots. Predicted values aligned closely along the 1:1 reference line, especially for Site 4 (SEE = 0.449 mm,MAE} = 0.365 mm) and Site 2 (SEE = 0.584 mm, MAE = 0.440 mm). Saturation thresholds during higher-magnitude rainfall events (>60 mm), where litter layer storage capacity approached maximum retention are reflected. Additionally, the scatter patterns were supported by non-significant Durbin-Watson diagnostics ($p>0.05$), confirming the absence of systematic under- or over-prediction across the sampled rainfall spectrum.

The study found at Site 3 (Logged forest),the moderate relationships and intermediate fit ($R^2$ = 18.5%, F = 6.59, p = 0.0157)with scatter plots revealing patchy prediction performance—indicative of disturbance-induced variability in canopy cover and litter accumulation(Figure 5). Site 4, a secondary regrowth site following shifting cultivation yielded an $R^2$ of 22.3% (F = 8.34, p = 0.0073), with visual plots showing a tighter fit and lower residual spread than Site 1 or 3, suggesting early ecological recovery and re-establishment of litter interception functionality. Inspite of being a disturbed site,it showsdecent litter-precipitation coupling—possibly a sign of regeneration or consistent ground cover.

### 4.4 Analysis of Variance

Table 3 shows the results for Analysis of Variance for a–Broadleaved forest (Site I),b-Pine Plantation (Site II), c-Logged Forest (Site III) and d-Secondary Forest (Site IV) whereas Table 4 provides the Summary Statistics for Precipitation and Litter Interception across four forest Sites.

| Site / Forest Type | Source of Variation | Sum of Squares (SS) | Degrees of Freedom (df) | Mean Square (MS) | F-ratio | p-value |
|---|---|---|---|---|---|---|
| **Site 1** *(Broadleaved forest)* | Model (Regression) | 1.74 | 1 | 1.74 | | |
| | Residual | 10.56 | 29 | 0.36 | 4.79 | 0.036 |
| | Total (Regression) | 12.30 | 30 | — | | |
| Site 2 *(Pine plantation)* | Model (Regression) | 4.44 | 1 | 4.44 | | |
| | Residual | 9.90 | 29 | 0.34 | 13.00 | 0.001 |
| | Total (Corrected) | 14.33 | 30 | — | | |
| Site 3 *(Logged mixed forest)* | Model (Regression) | 2.41 | 1 | 2.41 | | |
| | Residual | 10.59 | 29 | 0.37 | 6.59 | 0.015 |
| | Total (Corrected) | 12.99 | 30 | — | | |
| Site 4 *(Disturbed secondary forest)* | Model (Regression) | 1.68 | 1 | 1.68 | | |
| | Residual | 5.85 | 29 | 0.20 | 8.34 | 0.007 |
| | Total (Corrected) | 7.54 | 30 | — | | |

*Note:* Dependent variable: Litter Interception (mm); Independent variable: Gross Precipitation (mm). Significance evaluated at alpha = 0.05. Site 4 values rounded from raw software output to two decimal places for consistency.

Table 3.One-way Analysis of Variance (ANOVA) for Linear Regression Models of Litter Interception Across Four Forest Sites (n = 31)

Analysis of variance (ANOVA) demonstrated that the simple linear models relating gross precipitation to litter interception were statistically significant across all four forest stands ($p < 0.05$) as illustrated in Table 3.The regression models explained 1.74 units of variation in litter interception out of a total sum of squares of 12.30 (Site 1), 4.44 units of variation out of a total of 14.33 (Site 2), 2.41 units of the total variation of 12.99 (Site 3) and 1.68 units of variation from a total of 7.54 (Site 4). ANOVA of the regression models showed that precipitation significantly affected litter interception at all four study sites. The strongest relationship was observed in the Pine Plantation ($F = 13.00$, $p = 0.001$), followed by the Disturbed Secondary Forest ($F = 8.34$, $p = 0.007$), Logged Mixed Forest ($F = 6.59$, $p = 0.015$), and Broadleaved Forest ($F = 4.79$, $p = 0.036$). Although the magnitude of the relationship varies, the results prove that rainfall is an important determinant of litter interception across four sites.

| Diagnostic Metric | Site 1 (Broad-leaved) | Site 2 (Pine) | Site 3 (Log-ged) | Site 4 (Secon-dary) |
|---|---|---|---|---|
| Correlation Coefficient (r) | 0.38 | 0.56 | 0.43 | 0.47 |
| Coefficient of Determi-nation ($R^2$ %) | 14.18% | 30.96% | 18.52% | 22.33% |
| Adjusted $R^2$ (%) | 11.22% | 28.58% | 15.71% | 19.65% |
| Standard Error of Estimate (SEE) | 0.603 | 0.584 | 0.604 | 0.449 |
| Mean Absolute Error (MAE) | 0.481 | 0.440 | 0.472 | 0.365 |
| Durbin–Watson (DW) Statistic | 2.54 | 1.89 | 1.67 | 1.58 |
| DW p-value | 0.944 | 0.385 | 0.174 | 0.119 |
| Lag-1 Residual Autocor-relation | -0.281 | 0.055 | 0.154 | 0.152 |

**Note:** DW values near 2.0 and non-significant DW p-values ($p > 0.05$) indicate that regression residuals satisfy the assumption of independence without significant first-order serial correlation.

**Table 4.** Model Performance and Residual Diagnostic Statistics for Litter Interception Regressions

Site 2 (Pine plantation) exhibited the greatest model sum of squares (SS= 4.44, $F(1, 29) = 13.00$, $p = 0.001$), accounting for 30.96% of the variance ($R^2$adj) = 28.58 %). Residual dispersion was obtained as lowest in Site 4 (SEE = 0.449, MAE = 0.365), reflecting tighter clustering around the regression trend line even with disturbed canopy conditions. Model diagnostics proved the validity of ordinary least squares assumptions as Durbin–Watson test statistics ranged from 1.58 to 2.54 with non-significant p-values ($p > 0.05$), thus,confirming that regression residuals were free of problematic first-order serial autocorrelation across all rainfall events(Table 4).

### 4.5 Residuals & Model Diagnostics

Table 4 provides the Summary of statistical diagnostics for litter interception models across four forest sites.Site 2 shows notable standardized residuals, with one exceeding 3—indicating possible outliers. Durbin-Watson stats across sites are near 2, indicating low autocorrelation—thus the regressions are statistically robust and residuals behave well. Error terms are lowest at Site 4 (SEE≈ 0.45), suggesting a tighter spread in predictions which seems to be interesting for a disturbed site. Residual variability of site 4 suggests spatial inconsistencies in hydrological processes affecting infiltration, runoff regulation, and soil moisture retention.Visual diagnostics of Site 4 suggest that partial canopy recovery and mixed litter inputs lead to moderate interception efficiency.Across all sites, regression diagnostics, including Durbin-Watson statistics near 2.0, affirmed minimal autocorrelation, supporting the use of linear models despite ecological complexity.

### 4.6 Cluster Analysis

The dendrogram is based on the hierarchical clustering of four forest types based on litter interception patterns, using Ward's method and squared Euclidean distance. At Stage 1, Site 1 (Broad-leaved) and Site 3 (Logged Mixed Species) merge at distance 6.75 (lowest distance) forming the first cluster. Thus, the most similar sites merge at low linkage distance showing the close connection. This indicates strong similarity in interception dynamics of Sites 1 and3. At Stage 2, Site 2 (Pine Plantation) and Site 4 (Secondary Growth) merge at distance 19.27 showing that these 2 sites form a second cluster with the moderate connection.

At Stage 3, the two resulting clusters merge at distance 33.06 revealing that the most

dissimilar two clusters finally join (the highest distance). This is the final merge at the highest linkage distance, representing the least similar grouping. Thus, dendrogram ensures that the final merge is at the highest point where the two branches join, preserving the correct hierarchy of dissimilarity reflecting distinct ecological regimes. The diagram preserves the correct sequence and scale of clustering, emphasizing how canopy structure and species composition influence interception across forest types.

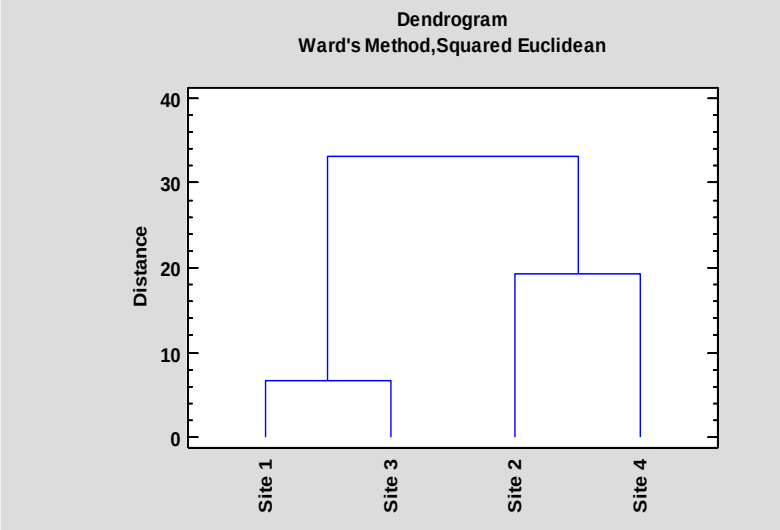



**Figure 6:** Dendrogram revealing Litter Interception Use in a at four sites in Nongmaiching Hill.

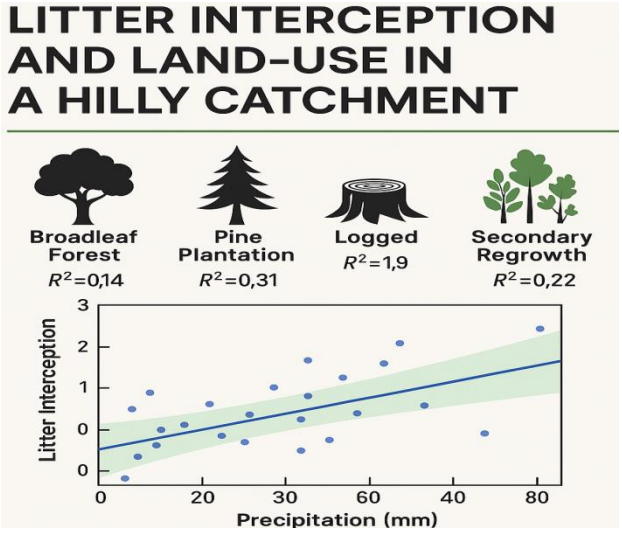



**Figure 7:** Litter Interception and Land- Hilly Catchment

Site 1 - Broad Leaved forest, Site 2 - Pine Plantation, Site 3 - Logged Forest and Site 4 - Secondary Forest

The four forest sites were grouped using hierarchical cluster analysis based on the similarity of their litter hydrological characteristics and interception dynamics to group the four forest sites. Due to similar interception averages (1.70 mm and 1.53 mm) and residual dispersion profiles, the dendrogram identified two primary clusters: one joining Site 1 (Broadleaved forest) and Site 3 (Logged mixed forest) and a second cluster separating the monoculture Pine plantation (Site 2) and the Disturbed secondary forest (Site 4). Site 4 got separated due to its lower interception capacity (1.04 mm) brought on by canopy degradation and shallower litter accumulation, isolated branching of Site 2 reflects the unique packing density and water-holding properties of coniferous needles(Fig 6).

In Nongmaiching hilly forests a conceptual synthesis of the catchment signifies the influence of forest canopy structure and land management on forest floor ecohydrology (Fig 7). Litter interception serves as a crucial primary buffer regulating effective throughfall across contrasting stands—ranging from intact broadleaved and pine plantations to logged and regenerating secondary forests. The comparative model fits ($R^2$ = 0.14–0.31) highlight the significance of litter layer conservation in reducing surface runoff and soil erosion in sloping tropical catchment ecosystems by showing that undisturbed and monoculture stands exhibit distinct hydrological buffering relative to disturbed sites.

## 5 Discussion

### 5.1 Gross Precipitation and Litter Interception

Litter interception is a vital aspect of the forest floor water balance from a hydrological standpoint. The interception storage theory, perceives the litter layer as a temporary reservoir that holds rainfall until its storage capacity is reached [1,13], our finding is consistent with such theoretical standpoint.

Interception has an important ecological function even though occasionally considered

as a loss in the hydrological cycle because of subsequent evaporation. Litter interception modifies soil moisture dynamics, improves infiltration, and decreases surface runoff according to Calder [14].

Floor litter can reduce the amount of water reaching the soil layer through rainfall interception. The rainfall interception capacity of floor litter varies with the physical features of the litter and rainfall characteristics.

The precipitation -litter interception graphs suggest that litter interception is strongly linked to forest cover quality and canopy/litter-layer condition. The natural broadleaved forest shows the strongest and most stable interception, the logged forest is next, the pine plantation is lower, and the disturbed/secondary forest shows the weakest and most erratic pattern. It was noted that the higher litter interception means less kinetic impact of raindrops on soil, so erosion risk is lower. Lower interception in logged and disturbed forests means more rainfall reaches the soil quickly, increasing runoff, splash erosion, and nutrient loss on hill slopes. On hilly terrain, these differences matter even more because steep slopes amplify runoff once the protective litter layer is reduced. Interception increases with rainfall intensity, with high-intensity showers producing greater intercepted amounts than low-intensity showers. However, the increase was not linear; interception rose rapidly at the start of rainfall and then approached a saturation threshold, after which additional rainfall contributed mainly to runoff.

## 5.2 Litter Characteristics and Interception

This study assessed the maximum and minimum interception storages of litter layers and assessed the effects of litter type and rainfall characteristics on litter interception. The rainfall interception capacity of floor litter varies with the physical features of the litter and rainfall characteristics. Our results indicate a wide variation in interception values of litter, types regardless of the rainfall intensity and duration. The broadleaf litter retained more water than the needle leaf litter. The over-all fraction of total annual precipitation that is temporarily retained in the forest-floor litter layer, or potentially evaporated from this layer back to the atmosphere, can be significant, although the absolute volumes that can be stored in this layer are small (a few millimetres) according to [2,5]. As almost all precipitation that falls on the forest floor must travel through the litter layer, processes like storage, transport and evaporation taking place there can alter water dynamics, total evapotranspiration fluxes, along with the rates and chemical composition of soil water recharge.

## 5.3 Factors affecting the litter interception

There are three main factors that affect the interception of litter layer: rainfall conditions, litter characteristics (leaf type, litter accumulation and thickness [2] and the potential evaporation. The water holding capacity of litter differs per litter type (or forest floor type) and thickness (or mass) [14], and the frequency of precipitation have a large influence on the interception process[15]. Broad-leaved litter can intercept more water than needle-leaved litter [16,7]. Laminar structure of broad-leaved litter had been found to form a transverse moving passage for rainwater under a certain slope, resulting in less rainwater held by broad-leaved litter than by needle-leaved litter [17]. Overlooking Forest-floor interception losses can lead to substantial overestimates of forest transpiration rates[18]. The litter layer shields the underlying soil from evaporation (2.8 times less evaporation at the plot with litter) and potentially also insulates against ground heat fluxes from the sub-surface[19]. The role of mixed forests, on hydrological processes and soil carbon dynamics have been worked out specifically with reference to the interaction between pine and broadleaved trees, in litter interception.

To quantify their water storage properties, earlier studies were conducted on forest litter samples [6,20,3]. However, only a few studies have measured the litter interception. The interception process (I) can be defined as the sum of the change in interception storage (Si)

and the evaporation (Ei): I=dSi/dt+Ei. Litter interception (IL),is the process described as the difference between the net precipitation (PL) and the infiltration (FL): IL=PL−FL [2]. Three main factors, viz. rainfall conditions, litter characteristics (leaf type, litter accumulation and thickness influence the interception of litter layer [2] and the potential evaporation. The water holding capacity of litter differs as per litter type and thickness [14]. To simulate raindrop–foliage interactions, a simplified hydrological model was used for dripping effects in rainy scenes[21]. Interception loss averaged 7.2% of rainfall, with strong variability, while the interception ratio remained a stable long-term water balance indicator[22]. However, Zhao et al. [17] recorded that the laminar structure of broad-leaved litter had been found to form a transverse moving passage for rainwater under a certain slope, resulting in less rainwater held by broad-leaved litter than by needle-leaved litter. A study by Levia et al.[23] from the eastern forests of the United States found that interception by the empty fruiting heads is considerable, ranging from 2.6 to 218.5% of the incident gross precipitation, with a mean of 42.7%. The pattern of natural rainfall, like raindrop size and intensity, varies in space and time.

Previous studies reported that broadleaf litter possess a larger storage capacity when compared with the needle litter. The storage capacity per unit dry weight of broadleaf litter was higher than that of needle litter by factors of up to 1.6, 1.8, 2.65 and 1.4, respectively[3,6]. Structural differences between the litter types is related to the larger storage capacity in broadleaf litter as compared to needle litter [4,7] that occurs due to sink effects(water drops retained in depressions on the leaf surfaces) occurring on individual leaves. According to Walsh & Voigt, [3] the broadleaf litter also has a higher surface area to weight ratio compared to the needle litter. Gerrits and Savenije[2] reviewed the storage capacity of different litter types from several studies. However, in a few studies,no large differences between broadleaf and needle litter storage capacity were found, and needle storage capacity even exceeded broadleaf storage capacity in some studies. Pathak et al [24] concluded that a major portion (14.3 to 28.0%) of the gross rainfall is intercepted by the forest canopy.. Litter interception was greater in broad leaf of forest as compared to pine plantation and disturbed forest. The greater interception causes the increased messiness in the litter layer of broadleaf forest, favouring the activity of the microbes and litter fauna, so critical for nutrient cycling [24]. The litter layer also maintains the humidity of the soil and regulates the water cycling as evaporating back the intercepted water to the atmosphere.

Thus, the variation in the type of litter and the mixing trend of different species impact the rainfall partitioning process, affecting the processes of interception, infiltration, and runoff. Broadleaved litter generally has a higher interception capacity.

Slope and rainfall intensity influence the Water absorption and storage capacity of the litter layer. There is a substantial contribution to overall interception by the understory in pine plantations, through litter interception, mixed forests play an important role in soil carbon dynamics and regulating water cycles. The intercepting properties of the litter layer can be affected by the composition of various types of litter. Litter interception is impacted by factors like interaction of forest structure, slope, and rainfall intensity. In some forest types, such as pine forests, understory vegetation can play a major role in overall interception

A study by Han et al [25]aimed to investigate the patterns of rainfall interception and distribution associated with various leaf litter morphologies, specifically *Pinus massoniana, Cinnamomum camphora*, and *Magnolia grandiflora*. The findings indicated that the capacity for precipitation interception varied according to slope gradients, rainfall intensities, and type of leaflitter on a flat slope, *Pinus massoniana* exhibited the highest interception capacity, followed by *Cinnamomum camphora* and *Magnolia grandiflora*.

### 5.4 Regression Diagnostics and Clustering

Various interactions related to precipitation–interception closely match the hierarchical clustering structure as well as reflect the site-specific regression models. The structural complexity of canopy and species diversity in Sites 1 (Broad-leaved) and 3 (Logged Mixed Species) forests probably introduces interacting effects, though precipitation affects interception. Sites 1 and 3 got clustered at the lowest linkage distance and reveal statistical significance but relatively modest slopes and lower $R^2$ values. It suggests that structurally diverse or mature canopies may involve more complex interception processes and dynamics.Sites 2 (Pine Plantation) and 4 (Secondary Growth), on the other hand, formed a distinct cluster at a moderate distance exhibiting stronger linear relationships reflected by higher slopes, greater model fit (higher R) and lower mean absolute errors, suggesting more predictable interception behaviour. This is because of homogeneous litter characteristics and simplified canopy structure. These findings suggest that a more consistent litter characteristics or simplified canopy design in these forests results in more predictable precipitation-related interception responses. The idea that canopy complexity and species composition drive both the statistical and ecological variability in litter interception is supported by the model diagnostics, and final cluster merge at a higher distance confirming ecological divergence between the two groups of structurally complex and simplified forest types.

Considering the effect of precipitation, the residual component accounted for the unexplained variation in litter interception. Residual sum of squares values were 10.56, 9.90, 10.59, and 5.85 for Sites 1, 2, 3, and 4, respectively, suggesting that variables other than precipitation also significantly influenced the variation in litter interception among the study sites. Litter interception dynamics cannot be fully explained by precipitation alone, because of the persistence of substantial residual variation across all forest types. The amount of water retained in the litter layer is probably influenced by a number of other factors, including litter accumulation, species composition, canopy cover, decomposition stage, and antecedent litter moisture conditions. The prediction of litter interception in forest ecosystems may be improved by when these variables into future models are incorporated.

Dendrogram demonstrates that Sites 1 (Broad-leaved forest) and 3 (Logged forest ) group together in a cluster due to similar interception dynamics whereas structural characteristics and distinct ecological regimes, under Sites 2 (Pine plantation) and 4 (Secondary growth), form a second cluster. Thus, it is concluded that linear models are inadequate for structurally varied forests but offer a considerable amount of explanatory power in simplified or recovering systems. According to cluster analysis, statistical diagnostics and litter interception are influenced by ecological divergence and differences in species composition. Ecological function and statistical predictability are both greatly impacted by canopy variability.

## 6. Conclusion

The litter layer constitutes an important component in forest hydrology. However, not much is known about the litter characteristics and its hydrological responses in various types of forests in the subtropical zones. This study serves as a benchmark for forests on a hilly landscape Nongmaiching Hill at Manipur, NE India.

Considering the interaction of rainwater with litter in Pine plantation and Secondary growth forest, there is a potential reduction in interception. Extensive areas occupied by forest plantations are able to modify the hydrological balance [26]. However, the prediction at these sites is more accurate, as seen by the coefficient of determination ($R^2$) explaining homogeneity and litter consistency Mixed forests show higher litter interception rates and soil carbon storage than the monoculture stands indicating that mixed forest ecosystems play an important role in the climate change mitigation and controlling water cycles. Pine and broadleaved trees present in the mixed forest will intercept more rainfall than plantations, reducing runoff

and thus influencing soil moisture. Climate change has caused great variation in the rainfall regime, so these results point the way to greater economic and environmental sustainability. Forest resource managers should consider those differences along with the other components of the water budget when making management decisions.

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